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Comparison of fatty acid profiles and volatile compounds among quality grades and their association with carcass characteristics in *longissimus dorsi* and *semimembranosus muscles* of Korean cattle steer

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ABSTRACT

This study was performed to compare the content and composition of fatty acids (FA) and volatile compounds among four quality grades (QG1++, 1+, 1, and 2), and to understand their association with carcass characteristics in longissimus dorsi (loin) and semimembranosus (rump) cuts of Korean cattle steers. QG1++ and QG2 loins showed the highest ($P < 0.05$) and lowest percentages of oleic acid (C18:1n9) and monounsaturated FA, respectively. QG1++ loins had greater ($P < 0.05$) percentages of volatile hydrocarbons, including n-pentane, n-hexane, and 2-butene, and these compounds were positively correlated ($0.56 \leq r \leq 0.81$; $P < 0.001$) with QG and crude fat content (g/100 g meat). Percentages of loin acetonitrile ($r = 0.74$, $P < 0.01$) and butanal ($r = 0.71$, $P < 0.01$) were positively correlated with flavor, whereas those of loin 2-methyl-2-propanol ($r = -0.62$, $P < 0.05$) and 3-methyl-2-butanone ($r = -0.60$, $P < 0.05$) were negatively correlated with flavor. In conclusion, loin FA percentages, especially C18:1n9 and monounsaturated FA, tended to be higher with increasing QG. Loin volatile compounds, including n-pentane, n-hexane, and 2-butene, were also higher with increasing QG.

1. Introduction

In Korea, Korean cattle beef is generally more expensive, because consumers believe it is fresher and has better quality than imported beefs (Jo et al., 2014). The quality grade (QG) of Korean cattle beef is primarily determined by the marbling score (MS), as well as other carcass traits, including meat color, fat color, texture, and maturity on the basis of Korean carcass grading system established in 1992 (Cho et al., 2010). A higher QG is achieved with a higher MS, more red meat color, and more white fat color (Moon et al., 2003). It is generally agreed that intramuscular fat (IMF) and QG in beef are positive factors that affect meat sensory characteristics, such as tenderness, juiciness, flavor, and overall palatability (Emerson et al., 2013).

Several studies reported that fatty acid (FA) content, and not only IMF, is an important factor affecting beef palatability (Ba et al., 2013). For example, an increase in fat content up to 36% enhanced the umami and beef flavor intensity in the longissimus thoracis muscle of Japanese Black steers (Iida et al., 2015). Studies reported that oleic acid might positively relate to beef flavor, whereas polyunsaturated fatty acids (PUFA) and saturated fatty acid (SFA) might be negatively associated with beef flavor (Melton et al., 1982). Since most studies have reported FA composition (%) from total FA, limited information is available regarding the correlation between FA content or amount with QG, flavor and palatability in Korean cattle beef. Content or amount (g FA/100 g meat) of FA per meat type, rather than the percentage of individual FA, may be more directly associated with QG, sensory quality and volatile compounds.

Several volatile compounds, including aldehydes, hydrocarbons, alcohols, ketones, furans, pyrazines, thiophenes, and thiazoles, are formed when meat is cooked, and these compounds affect palatability, as well as flavor (Watkins et al., 2012). There are several ways in which volatile compounds are formed, including thermal lipid degradation, the Maillard reaction of amino acids or peptides with reducing sugars (e.g., glucose or ribose), vitamin (e.g., thiamin) degradation during cooking, and the interaction between Maillard reaction products and lipid oxidation products (Ba et al., 2012a). The major volatile com-

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pounds are produced by thermal degradation of beef fat, and FA oxidation is primarily responsible for the development of flavor (Neethling et al., 2016). Therefore, the amount of fat and FA composition in beef can affect development of special characteristics of aroma and flavor upon thermal processing. For example, increased flavor desirability was associated with increased IMF (O'Quinn et al., 2012). Levels of 2-butanone, 2-pentanone, and 3-hydroxy-2-butanone increased with increasing IMF content in beef (El-Magoli et al., 1996). Some volatile compounds, such as n-aldehydes (heptanal, octanal, nonanal), were negatively correlated with fat content (Legako et al., 2015). However, other studies reported that increased IMF content did not affect the generation of volatile flavor compounds (Mottram and Edwards, 1983). Therefore, clarification is needed regarding the association of fat content and volatile compounds.

Different types of FA may affect the generation of volatile compound types, and thus, flavor (Neethling et al., 2016). In grilled beef from Aberdeen Angus and Holstein-Friesian steers, linoleic acid levels were higher in the muscle of concentrate-fed animals than that of silage-fed steers, and a greater amount of volatile compounds were derived from linoleic acid decomposition (Elmore et al., 2004). Currently, limited information is available regarding the association of FA content and volatile compound generation, which affects palatability of Korean cattle beef. This study was performed to compare FA and volatile compounds among QGs for the loin and rump of Korean cattle steers and to identify any correlation between QG and these parameters.

2. Materials and methods

2.1. Loin and rump samples

Previously, we reported comparison of carcass and sensory traits and free amino acid contents among QGs in loin (longissimus dorsi muscle) and rump (semimembranosus muscle) of Korean cattle steer (Piao et al., 2015). In this study, we used same sets of loin and rump samples. Details regarding animal rearing, diets (ingredient, composition, fat content), slaughter, and carcass grading methods have been previously described (Piao et al., 2015). Briefly, carcass of Korean cattle steers was evaluated by a meat grader using the Korean carcass-grading system of Korea Institute for Animal Products Quality Evaluation (KAPE, 2013) at 24 h post mortem. Carcass weight, longissimus muscle area, fat thickness, MS, meat color, fat color, texture, and maturity were examined and reported by an official meat grader. Among these parameters, MS was mainly used for determining QG. Five quality grades (QG 1++, 1+, 1, 2, and 3) are assigned by meat graders. The marbling score of the Beef Marbling Standard (BMS) ranges from 1 (devoid) to 9 (abundant); 8 or 9 was the MS for QG1++, 6 or 7 was the MS or QG1+, 4 or 5 was the MS for QG1, 2 or 3 was the MS for QG2, and 1 was the MS for QG3. Additionally, meat color, fat color, texture, and maturity of the exposed longissimus muscle at the 13th rib interface were used for QG determination (NLCF, 1998). Forty-eight loin and rump muscles with 12 steers from each four QGs (QG 1++, 1+, 1 and 2) had been collected. Loin from the 14th to 18th vertebrae was obtained, and rump (*semimembranosus muscle*) was obtained at P8 site from the posterior of the cattle's body where the thighs join the hips. Beef samples were transported on ice (4 °C) to a laboratory within 30 h postmortem, and were subsequently kept at −80 °C for one week. The samples were thawed at 4 °C for one day before analysis. External fat was trimmed away from the meat samples. The beef samples were minced using a mini chopper (CH180, Kenwood, Shanghai, China) for 30 s. Minced beef samples from various locations were pooled for the analysis of fatty acid and volatile compounds.

2.2. Carcass traits, chemical compositions, and sensory characteristics

Carcass traits, chemical compositions, and sensory characteristics were previously determined (Piao et al., 2015) and used for analyses of correlation coefficients in this study.

2.3. Fatty acid composition

Lipids in beef samples (20g) were extracted with 200 mL of chloroform/methanol (2:1, v/v) according to the procedure of Folch et al. (1957). Extracted lipids were evaporated using N_2 gas (99.99%) and 1g mixed with 2 mL of BF_3-methanol (14%, w/w) before being heated in a water bath (60 °C) for 1 h. After cooling, hexane (2 mL) and deionized distilled water (5 mL) were added and centrifuged at 3100 rpm for 10 min (HM-150IV, Hanil Co. Ltd., Korea). Next, the top hexane layer containing fatty acid methyl esters (FAME) was transferred to a vial, then the 1 μL of FAME in hexane was injected into a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA). A split inlet (split ratio, 50:1) was used to inject the samples into a capillary column (SP™ 2560 Capillary column; 100 m×0.25 mm ×0.20 μm film thickness), and a ramped oven temperature was used (100 °C for 5 min, increased to 240 °C at 4 °C/min and maintained for 20 min). The inlet temperature was 210 °C. N_2 served as the carrier gas at a constant flow rate of 1 mL/min. Individual FAME were identified by comparison of the relative retention times of peaks from samples, with those of the standard mixture 37 component FAME Mix (Supelco, Bellefonte, PA). The FA composition of fat was calculated based on the peak area. Relative quantities were expressed as weight percent of total FA.

Fatty acid contents (values per 100 g of beef) are also useful. When fatty acid contents are being calculated, the fact that the total fat in a food includes triglycerides (of which a proportion is glycerol, i.e. not fatty acid), phospholipids, and unsaponifiable components such as sterols should be considered. Thus, a conversion factor (0.953; 0.953 g total FA/g fat) was applied to obtain the individual FA content/100 g meat from FA percentage values and crude fat content, based on a previous report (Anderson et al., 1975). The conversion factor was also used for calculating FA content from FA percentage in other studies (Brugiapaglia et al., 2014; Horcada et al., 2016). Individual FA g/100 g meat was calculated as follows:

Individual FA content (g FA/100 g meat) = crude fat content (g fat/100 g meat) × individual FA percentage (%) × 0.953 (g FA/g fat).

2.4. Volatile compounds

To analyze the volatile compounds, samples were prepared according to the method described by Garcia-Esteban et al. (2004). Samples were thawed at 4 ℃, and 4 g of each sample was homogenized (IKA Works T10 basic homogenizer, Wilmington, NC, USA) with saturated 12 mL of NaCl solution at speed no. 6 for 1 min. In order to reduce the loss of flavor compounds during cooking, the 10 mL of homogenate was transferred to individually labeled 20 mL clear glass vial (PerkinElmer® N9306078) and closed with a polytetrafluoroethylene septa and screw cap. Then, the samples were heated using a water bath (Thermo-minder Sm-05, Taitec, Tokyo, Japan) at 80 °C for 30 min and then cooled in cold water. The vials were placed in the oven of the head-space sampler, and the extraction of the volatile compounds of the samples was performed using a headspace auto sampler. The transfer line from the headspace sampler was directly connected to the injector of the gas chromatograph (GC).

A PerkinElmer 680 GC (Perkin Elmer, Boston, Massachusetts, USA) equipped with a 600 T MS detector was used. Volatiles were separated using a HP-PLOT Q column (30 m×0.53 mm ×0.25 μm film

thickness, Agilent, Wilmington, DE, USA). GC conditions were: initial oven temperature 35 °C, held for 5 min, then programmed to 180 °C at 7 °C/min, then held for 0.0 min at 180 °C, then increased 5 °C/min to 250 °C and held for 21.0 min. The transfer line temperature was maintained at 250 °C. A mass spectrometer scanned from *m/z* 30 to *m/z* 250 at 0.2 s cycle time. The ion source was set at 250 °C. Headspace was maintained at 85 °C for 30 min and a ramped oven temperature was used (50 °C for 3 min, increased to 240 °C at 5 °C/min and maintained for 9 min). The inlet temperature was 210 °C. He served as the carrier gas at a constant flow rate of 20 mL/min. The resolved MS spectra obtained from the custom scripts were matched against reference mass spectra by using the National Institute of Standards and Technology (NIST) mass spectral search program for the NIST/EPA/NIH mass spectral library (version 2.0). In the present study, internal standard for the volatile compounds was not used. GC chromatogram was used to quantify the volatile compounds, and the mass spectrometry was used to identify the volatile compounds. Results of volatile analyses were expressed as percentage of total chromatographic area.

2.5. Statistical analysis

Data were analyzed by two-way analysis of variance to test the fixed effects of QG, cut type and their interaction by a generalized linear mixed model, using the Proc GLM procedure of SAS software (SAS Institute, Cary, NC, USA). Experimental unit was an individual animal for FA composition and volatile compound. Animal within QG or cut type was considered the random variable. The LSMEANS PDIFF option was used to compare differences among mean values at $P < 0.05$. The CORR procedure of SAS was used to calculate Pearson's correlation coefficients within an individual muscle.

3. Results and discussion

3.1. Fatty acid compositions in loin and rump fat

In the current study, thirteen FA were detected and quantified in loin and rump fat muscles of Korean cattle steers (Table 1). Of these, the percentage of oleic acid (C18:1n9) was the highest in both loin and rump, ranging from 42% to 47%, followed by palmitic (C16:0) (25–27.4%) and stearic acid (C18:0) (9.3–10.4%). Our results are consistent with those of previous studies that reported C18:1n9 content was the highest among FA in beef from Korean cattle (Lee et al., 2010; Kim et al., 2009), American Angus (St. John et al., 1987), and Japanese Wagyu (Oka et al., 2002).

QG x cut type interactions were observed (P=0.01) for the percentage of C18:1n9 and monounsaturated fatty acid (MUFA). This indicates that C18:1n9 and MUFA percentages were differently associated with QG depending on cut type. The percentages of C18:1n9 and MUFA from loin fat were the highest ($P < 0.05$) in the QG1++ group and lowest ($P < 0.05$) in the QG2 group, although there were no statistical differences among the QG1++, QG1+, and QG1 groups. C18:1n9 and MUFA percentages from rump fat were not different between QG1++ and QG2, resulting in significant interaction between QG and cut type. Our results are in accordance with those of Hunt et al. (2016), who reported that QG differentially affects C18:1n9 percentage, depending on the muscle type. Lee et al. (2010) showed that numerical values of C18:1n9 were highest in QG1++ group among QGs for loin of Korean cattle beef. Studies showed that C18:1n9 and MUFA percentages increased with increased fat or QG in the longissimus thoracis (Aldai et al., 2006). Similarly, heavy and medium carcass weight group had both higher IMF and C18:1n9 content (Jayasena et al., 2015). In our previous study using the same meat samples, we reported that the loin showed higher fat content and wider differences in fat contents among QGs than those observed in rump (Table 2; Piao et al., 2015). Thus, the significant interaction between QG and cut type for C18:1n9 and MUFA percentages observed in this study is most likely attributable to the differences in fat contents among QGs and between cut type.

A QG x cut type interaction was also observed ($P \leq 0.01$) for the percentages of pentadecanoic acid (C15:0), heptadecanoic acid (C17:0), linoleic acid (C18:2n6), cis-8,11,14-eicosatrienoic acid (C20:3n6), cis-5,8,11,14-eicosatetraenoic acid (C20:5), MUFA, PUFA, and PUFA/SFA, indicating that these FA percentages were also

Table 1
Fatty acid composition (% of fat, fresh basis) of loin and rump with different quality grades (QG) for Korean cattle steers.

	Loin					Rump					*P*-value		
Item	1++	1+	1	2	SEM	1++	1+	1	2	SEM	QG	Cut	QG*Cut
C14:0	3.53	3.57	3.83	3.39	0.10	2.71^{b}	2.54^{b}	3.66^{a}	2.60^{b}	0.14	0.01	0.001	0.29
C15:0	0.76^{c}	1.18^{b}	1.26^{b}	1.81^{a}	0.08	2.30^{a}	2.49^{a}	1.50^{b}	2.31^{a}	0.13	0.003	0.001	0.002
C16:0	27.41	27.03	26.88	25.79	0.28	24.59	25.41	26.57	25.76	0.35	0.48	0.01	0.11
C16:1	5.11	4.85	5.38	4.66	0.13	4.98	4.61	5.27	4.40	0.19	0.08	0.42	0.99
C17:0	0.76^{b}	0.66^{b}	0.98^{b}	1.37^{a}	0.07	1.62^{a}	1.76^{a}	1.01^{b}	1.45^{a}	0.08	0.03	0.001	0.001
C17:1	0.61	0.57	0.62	0.61	0.01	0.61	0.57	0.61	0.61	0.01	0.04	0.85	0.99
C18:0	10.44	10.26	9.74	10.34	0.18	9.39	9.26	9.69	9.97	0.17	0.59	0.02	0.41
C18:1n9t	0.84	0.76	0.80	0.88	0.03	0.64	0.60	0.75	0.79	0.03	0.051	0.002	0.57
C18:1n9	46.56^{a}	45.60^{a}	44.45^{ab}	43.14^{b}	0.38	42.41	41.50	44.06	42.16	0.36	0.04	0.001	0.01
C18:2n6	2.77^{c}	3.74^{b}	4.10^{b}	5.25^{a}	0.20	6.91^{a}	7.09^{a}	4.63^{b}	6.22^{ab}	0.30	0.02	0.001	0.001
C18:3n6	0.28^{a}	0.23^{ab}	0.20^{b}	0.22^{b}	0.01	0.23	0.19	0.19	0.24	0.01	0.02	0.11	0.22
C20:3n6	0.29^{c}	0.50^{b}	0.51^{b}	0.70^{a}	0.03	1.00^{a}	1.07^{a}	0.60^{b}	0.90^{a}	0.05	0.01	0.001	0.002
C20:5	0.63^{c}	1.05^{b}	1.23^{b}	1.84^{a}	0.09	2.61^{a}	2.92^{a}	1.46^{b}	2.60^{a}	0.14	0.001	0.001	0.001
SFA[1]	42.9	42.7	42.7	42.7	0.33	40.6	41.5	42.4	42.1	0.30	0.60	0.02	0.41
USFA[2]	57.1	57.3	57.3	57.3	0.33	59.4	58.5	57.6	57.9	0.30	0.60	0.02	0.41
MUFA[3]	53.1^{a}	51.8^{a}	51.3^{ab}	49.3^{b}	0.41	48.6^{ab}	47.3^{b}	50.7^{a}	47.9^{b}	0.41	0.01	0.001	0.01
PUFA[4]	3.97^{c}	5.52^{b}	6.04^{b}	8.02^{a}	0.30	10.8^{a}	11.3^{a}	6.88^{b}	9.97^{a}	0.49	0.002	0.001	0.001
MUFA/SFA	1.24	1.22	1.20	1.16	0.02	1.20	1.14	1.20	1.14	0.01	0.18	0.11	0.70
PUFA/SFA	0.09^{c}	0.13^{b}	0.14^{b}	0.19^{a}	0.01	0.27^{a}	0.27^{a}	0.16^{b}	0.24^{a}	0.01	0.01	0.001	0.001

n=12.
$^{a–c}$ Means with different letters within the same row differ ($P < 0.05$).
[1] SFA (saturated fatty acids) = C14:0+ C15:0+ C16:0+ C17:0+ C18:0.
[2] USFA (unsaturated fatty acids) = C16:1+ C17:1+ C18:1n9t + C18:1n9+ C18:2n6+ C18:3n6+ C20:3n6+ C20:5.
[3] MUFA (monounsaturated fatty acids) = C16:1+ C17:1+ C18:1n9t + C18:1n9.
[4] PUFA (polyunsaturated fatty acids) = C18:2n6+ C18:3n6+ C20:3n6+ C20:5.

Table 2
Total fatty acid content (g/100 g meat, fresh basis) of loin and rump with different quality grades (QG) for Korean cattle steers.[1]

	Loin					Rump					*P*-value		
Item	1++	1+	1	2	SEM	1++	1+	1	2	SEM	QG	Cut	QG*Cut
Crude fat,[2] %	23.8^{a}	17.3^{b}	14.1^{bc}	9.90^{c}	1.00	6.20^{a}	4.09^{ab}	2.78^{b}	3.60^{b}	0.41	0.001	0.001	0.001
C14:0	0.82^{a}	0.59^{b}	0.52^{bc}	0.32^{c}	0.04	0.19	0.10	0.09	0.10	0.02	0.001	0.001	0.002
C15:0	0.16	0.19	0.16	0.16	0.01	0.10^{a}	0.09^{a}	0.04^{b}	0.08^{a}	0.01	0.03	0.001	0.29
C16:0	6.24^{a}	4.44^{b}	3.64^{b}	2.44^{c}	0.27	1.53	1.00	0.71	0.90	0.11	0.001	0.001	0.001
C16:1	1.18^{a}	0.80^{b}	0.74^{b}	0.46^{c}	0.06	0.33^{a}	0.18^{b}	0.14^{b}	0.16^{b}	0.03	0.001	0.001	0.004
C17:0	0.16	0.10	0.12	0.12	0.01	0.08^{a}	0.07^{ab}	0.03^{c}	0.05^{b}	0.00	0.01	0.001	0.10
C17:1	0.14^{a}	0.09^{b}	0.08^{bc}	0.06^{c}	0.01	0.04^{a}	0.02^{ab}	0.02^{b}	0.02^{b}	0.00	0.001	0.001	0.001
C18:0	2.38^{a}	1.70^{b}	1.29^{bc}	0.94^{c}	0.11	0.52^{a}	0.35^{b}	0.26^{b}	0.33^{b}	0.03	0.001	0.001	0.001
C18:1n9t	0.19^{a}	0.12^{b}	0.11^{b}	0.08^{b}	0.01	0.04	0.02	0.02	0.03	0.00	0.001	0.001	0.001
C18:1n9	10.57^{a}	7.54^{b}	5.98^{bc}	4.13^{c}	0.46	2.57^{a}	1.62^{ab}	1.18^{b}	1.43^{b}	0.18	0.001	0.001	0.001
C18:2n6	0.60	0.61	0.53	0.49	0.03	0.32^{a}	0.27^{ab}	0.12^{c}	0.21^{b}	0.02	0.002	0.001	0.26
C18:3n6	0.06^{a}	0.04^{b}	0.03^{bc}	0.02^{c}	0.00	0.01^{a}	0.01^{ab}	0.00^{b}	0.01^{a}	0.00	0.001	0.001	0.001
C20:3n6	0.06	0.08	0.07	0.06	0.00	0.05^{a}	0.04^{ab}	0.02^{c}	0.03^{b}	0.00	0.01	0.001	0.04
C20:5	0.14	0.17	0.16	0.17	0.01	0.12^{a}	0.11^{a}	0.04^{b}	0.09^{a}	0.01	0.02	0.001	0.01
SFA[3]	9.77^{a}	7.03^{b}	5.73^{b}	3.98^{c}	0.42	2.42^{a}	1.62^{ab}	1.13^{b}	1.45^{b}	0.16	0.001	0.001	0.001
USFA[4]	12.95^{a}	9.47^{b}	7.70^{bc}	5.48^{c}	0.54	3.48^{a}	2.28^{ab}	1.53^{b}	1.98^{b}	0.23	0.001	0.001	0.001
MUFA[5]	12.08^{a}	8.56^{b}	6.91^{b}	4.73^{c}	0.53	2.98^{a}	1.85^{ab}	1.35^{b}	1.64^{b}	0.21	0.001	0.001	0.001
PUFA[6]	0.86	0.91	0.78	0.75	0.04	0.50^{a}	0.43^{ab}	0.18^{c}	0.34^{b}	0.03	0.002	0.001	0.19
MUFA/SFA	1.24	1.22	1.20	1.16	0.02	1.20	1.14	1.20	1.14	0.01	0.18	0.11	0.70
PUFA/SFA	0.09^{c}	0.13^{b}	0.14^{b}	0.19^{a}	0.01	0.27^{a}	0.27^{a}	0.16^{b}	0.24^{a}	0.01	0.01	0.001	0.001

n=12.
$^{a–c}$ Means with different letters within the same row differ ($P < 0.05$).
[1] Individual fatty acid content per meat (g/100 g meat) was calculated as described in Materials and Methods.
[2] Crude fat (%) was published previously (Piao et al., 2015).
[3] SFA (saturated fatty acids) = C14:0+ C15:0+ C16:0+ C17:0+ C18:0.
[4] USFA (unsaturated fatty acids) = C16:1+ C17:1+ C18:1n9t + C18:1n9+ C18:2n6+ C18:3n6+ C20:3n6+ C20:5.
[5] MUFA (monounsaturated fatty acids) = C16:1+ C17:1+ C18:1n9t + C18:1n9.
[6] PUFA (polyunsaturated fatty acids) = C18:2n6+ C18:3n6+ C20:3n6+ C20:5.

differently associated with QG, depending on the cut type. The percentages of fatty acids, 15:0, C17:0, C18:2n6, C20:3n6, C20:5, and sum of PUFA in loin fat were lowest ($P < 0.05$) in the QG1++ group and highest in the QG2, whereas the percentages of these FA in rump fat were lowest ($P < 0.05$) in the QG1 group. Our results were in accordance with a previous study that reported an increase in the percentage of MUFA, but a decrease in the percentage of PUFA, with increasing QG in loin (Legako et al., 2015). In addition, the accumulation of MUFA was higher than that of PUFA as the crude fat increased, and thus, the percentage of MUFA increased (Raes et al., 2004a).

In this study, percentages of C16:0, C18:0, SFA, and USFA did not differ among QGs in either loin or rump fat. Lee et al. (2010) also reported no differences in these FA among the four QGs in the loin and rump. We observed that the C18:1n9 percentage in loin increased with increasing QG with no change in C18:0 percentage. Stearoyl-CoA desaturase (SCD) is the rate-limiting enzyme for MUFA (C16:1, C18:1n9) synthesis from SFA (C16:0, C18:0) (Ntambi, 1999), and it is important for oleic acid accumulation in both muscle and adipose tissues of ruminants (Wood et al., 2008). For example, the increase in oleic acid and MUFA was associated with higher SCD activity (Wang et al., 2005). Increased SCD1 expression in obese humans compared with lean subjects was also correlated with increased C18:1n9, and lower C16:0 and C18:0 (Hulver et al., 2005). However, FA uptake from dietary sources may also contribute to oleic acid accumulation, in addition to endogenous MUFA production by SCD from SFA, although the extent of MUFA accumulation from each of these two sources is not known. Our gene expression study also indicates that combined effects of *de novo* FA synthesis, FA uptake, and FA esterification contribute to IMF deposition in steers (Jeong et al., 2012, 2013). Archibeque et al. (2005) reported that differences in SFA seemed to be independent of SCD enzyme activity in both subcutaneous fat and the IMF tissues of beef steers. They suggested that duodenal concentrations of fatty acids were more important in determining tissue fatty acid concentrations than endogenous desaturation by SCD. Thus, the increase in C18:1n9 percentage with increasing QG, with no change in C18:0 content in the loin, may be either because SCD activity was not enough for a change in C18:0 content or because the dietary origin of C18:1n9 contributed to increased C18:1n9 percentage.

In the comparison by cut type, the percentages C16:0, C18:0, C18:1n9, and MUFA were higher ($P < 0.05$), but those of C15:0, C17:0 and PUFA were lower ($P < 0.05$) in the loin fat than in the rump fat. Similar results regarding the content of these FA between cuts were reported by Schönfeldt et al. (2010). A recent study suggested that the differences in SFA and PUFA contents between cuts are correlated with the amounts of phospholipids and triacylglycerol in different locations (de Oliveira et al., 2015).

3.2. Fatty acid content of meat

Using the FA composition, the individual FA content (g FA/100 g loin or rump) was calculated based on a conversion factor (0.953, Anderson et al., 1975), as shown in Table 2. Among all FA contents, C18:1n9 content in loin meat was the highest, ranging from 4.13 to 10.6 g/100 g meat, followed by C16:0 (2.44–6.24 g/100 g meat) and C18:0 (0.94–2.38 g/100 g meat). Our results were in accordance with a previous study using sirloins of Angus beef (Prieto et al., 2010).

Interactions between QG and cut type were observed ($P < 0.01$) for contents of most FAs (Table 2). Contents (g/100 g meat) of palmitoleic acid (C16:1), C17:1, C18:0, C18:1n9, SFA, USFA, and MUFA were significantly influenced by QGs, but to different extents depending on the cut type, revealing a QG × cut type interaction. In loin meat, contents of C16:1, C17:1, C18:0, C18:1n9, SFA, USFA, and MUFA were highest ($P < 0.05$) in the QG1++ group and lowest in the QG2 group (Table 2). However, in rump meat, contents of these FAs were highest ($P < 0.01$) in the QG1++, but did not differ among other QGs (QG1+, QG1, QG2). In this study, C18:1n9 contents in loin muscles ranged widely between 10.57 and 4.13 g/100 g meat among the four QGs, whereas those in the rump muscles showed a narrower range (between 2.57 and 1.43 g/100 g meat). The differential degree of changes in FA contents among QGs depending on the cut type indicated significant

interactions of these FAs between QGs and cut types.

Interactions between QGs and cut types were also observed (P=0.001) for myristic acid (C14:0), C16:0, and C18:1 n9t contents (Table 2). Contents of C14:0, C16:0, and C18:1n9t in loin meat were highest ($P < 0.05$) in the QG1++ group and lowest in the QG2 group (Table 2), whereas contents of these FAs in rump meat did not differ among QGs.

In this study, we found significant interactions between QGs and cut types for many FAs. Loin fat contents decreased as the QG decreased from QG1++ to QG2, whereas rump fat contents were highest in QG1++, but similar among other QGs (QG1+, QG1, and QG2) (Table 2; Piao et al., 2015). Loin meat (16.3%: average of four QGs) had significantly higher fat content than did rump meat (4.2%: average of four QGs). Furthermore, loin meat (between 23.8% and 9.9%) had wider range of fat contents than did rump meat (between 6.2% and 2.78%) (Table 2; Piao et al., 2015). Thus, these differential extents of fat contents among QGs depending on cut type may cause significant interactions of FAs between QGs and cut types.

In this study, we found higher SFA and MUFA contents, but not PUFA contents, in QG1++ than in QG2 in both loin and rump meats. Total fat in a food includes triglycerides, phospholipids and other minor proportion of unsaponifiable components such as steroids. Triglycerides are mainly composed of SFA and MUFA, while phospholipids contain high amounts of PUFA (Raes et al., 2004b). Generally, the amount of triglycerides increased with an increase in total lipid content, while the amount of phospholipids was fairly constant (Wood et al., 2008). Thus, higher SFA and MUFA, but not PUFA, found in the QG1++ meats are likely due to higher fat contents in this study.

In the comparison by cut type, all FA contents were higher ($P < 0.001$) in loin meat than in rump meat. These differences also might be caused by the higher fat content in the loin than in the rump (Piao et al., 2015). A previous study demonstrated that higher content of total C14:0, C16:0, C18:0, C18:1n9, SFA, MUFA, and PUFA in top sirloin than in top round (Pavan and Duckett, 2013).

3.3. Volatile compounds

Through GC/MS analysis, a total of 24 volatile compounds, including aldehydes (acetaldehydes, butanal, pentanal, hexanal, heptanal, benzaldehyde, octanal, and nonanal), hydrocarbons (methanethiol, carbon disulfide, n-pentane, n-hexane, and 2-butene), ketones (2-propanone, 2-butanone, 2,3-butanedione, and 3-methyl-2-butanone), alcohols (ethanol, 2-methyl-2-butanol, and 2-methyl-2-propanol), and others [acetonitrile, chloroform (data not shown), 2-ethoxy- 2-methylpropane (data not shown), and acetic acid (data not shown)] were detected in the loin and rump of Korean cattle steers (Table 3). The abundant volatile compounds, accounting for 17–29% of total volatile compounds, included acetaldehydes, 2-methyl-2-propanol, and 2-propanone. The moderate compounds, accounting for 1.0–6.5%, included butanal, hexanal, benzaldehyde, methanethiol, carbon disulfide, n-pentane, ethanol, chloroform, and 2-ethoxy-2-methylpropane. The minor compounds, accounting for less than 1%, included pentanal, heptanal, octanal, nonanal, n-hexane, n-butene, 2-butanone, 2,3-butanedione, 3-methyl-2-butanone, 2-methyl-2-butanol, acetonitrile, and acetic acid. The amount or variety of volatile compounds from cooked meat is affected by various factors, including diet, breed, post-slaughtering ageing, cooking temperature and pH, irradiation, and techniques used for extraction and detection of volatile components (Ba et al., 2012b). Therefore, the major or minor component of volatile compounds detected from meat could vary with several factors, as described in this study.

In this study, most of the volatile compounds detected were aldehydes. Vasta and Priolo (2006) also reported that aldehydes were the major contributors to the volatile fraction in ruminant meat. Interaction between QG and cut type was observed ($P \leq 0.04$) for most of aldehyde percentages (butanal, pentanal, hexanal, heptanal, octanal, and nonanal), indicating that these were differently associated with QGs depending on the cut type (Table 3). In loin, pentanal, hexanal, and heptanal percentages were highest ($P < 0.05$) in QG1, and butanal and benzaldehyde percentages were highest ($P < 0.05$) in QG1+ and QG1, respectively. However, pentanal, hexanal, butanal, and benzaldehyde percentages in rump did not differ ($P > 0.05$) among the QGs. In loin, acetaldehyde, octanal, and nonanal percentages did not differ ($P > 0.05$) among the QGs. However, in rump, octanal and nonanal percentages were highest ($P < 0.05$) in QG2, and heptanal percentages were highest ($P < 0.05$) in QG1++ and QG2. Aldehydes arise from the thermal oxidation of USFAs such as C18:1n9, C18:2 n6, and C18:3 n6 (Cerny, 2007). Thus, interactions in these aldehydes might be related with significant interactions in the USFA contents (C18:1n9, C20:3n6) between QGs and cut types observed in this study.

Interactions between QGs and cut types were observed (P=0.001) for contents of two hydrocarbons (n-pentane and 2-butene) (Table 3). In the loin, n-pentane and 2-butene percentages were highest ($P < 0.05$) in the QG1++ group and lowest in QG1 and QG2 groups. However, n-pentane and 2-butene percentages in rump meat did not differ ($P > 0.05$) among the four QGs. The predominant hydrocarbon, n-pentane is mainly formed via the oxidation of linoleic acid (C18:2n6) (Seo, 1976). In this study, C18:2n6 was the major PUFA in loin and rump, and it was influenced by QGs and cut types (Table 1). Thus, significant interactions between QGs and cut types for n-pentane percentage may be due to differential C18:2n6 percentages among QGs and between cut types. In both loin and rump, n-hexane percentages were highest ($P < 0.05$) in the QG1++ group and lowest in QG1 and QG2 groups.

Hydrocarbons arise from the thermal oxidative decomposition of lipids, a reaction catalyzed by heme compounds, such as hemoglobin and myoglobin (Shahidi et al., 1986). Min et al. (1979) reported that n-hexane and 2-butene were not significantly related to flavor because they possess relatively weak and non-beef-like odors. Our correlation data obtained from loin and rump muscle likewise indicated that these compounds did not have a significant relationship with flavor. A previous study found that straight chain hydrocarbons with less than 10 carbon atoms, such as hexane, do not contribute to the flavor of dry cured meat products because of their high threshold value (Ramirez and Cava, 2007). Contents of other hydrocarbons in the loin, including methanethiol and carbon disulfide, did not differ ($P > 0.05$) among the four QGs.

The ketone percentages varied among the QGs. Interaction between QG and cut type was observed (P=0.001) for 2-butanone percentage (Table 3). The 2-butanone percentage in the loin was highest ($P < 0.05$) in the QG1+ group, whereas it in rump was highest ($P < 0.05$) in the QG2 group. The autoxidation of C18 USFA (via hydroperoxides pathway) was proposed as the main mechanism for methyl-ketones formation (Larick and Turner, 1990). In our study, C18 contents (C18:1n-9, C18:2n-6, C18:3 n-6) were significantly affected by QG and cut type (Table 2). Thus, the interaction observed in 2-butanone percentage is probably related to differential C18 contents among QGs and between cut type. The 2-propanone percentage in the loin was lowest in the QG2 group, but it was similar among the other QG groups (QG1++, 1+, 1).

3.4. Correlations

Generally, loin is tenderer and contains higher fat with high marbling than rump, and thus it is preferably used for cooking a steak or grilling. In this study, correlations among QG, MS, fat contents, sensory traits, FA contents, and volatile compounds were analyzed in both loin and rump. Loin is a preferred beef meat for grilling. In this study, we paid more attention to loin data, since correlation data of loin may give more valuable information than those of rump.

QG, MS, and fat content were positively correlated ($0.47 \leq r \leq 0.54$; $P < 0.01$) with the percentages of C18:1n9 and MUFA in loin fat

Table 3
Volatile compounds (%) of loin and rump with different quality grades (QG) in Korean cattle steers.

	Loin					Rump					*P*-value		
Item	1++	1+	1	2	SEM	1++	1+	1	2	SEM	QG	Cut	QG*Cut
Aldehydes													
Acetaldehyde	27.1	30.8	30.2	27.8	0.77	25.4	24.1	24.1	24.2	0.74	0.74	0.001	0.34
Butanal	1.12^{b}	1.40^{a}	1.54^{a}	1.08^{b}	0.05	1.08	1.08	1.31	1.28	0.05	0.01	0.14	0.04
Pentanal	0.36^{b}	0.51^{b}	1.07^{a}	0.56^{b}	0.06	0.27	0.31	0.28	0.29	0.03	0.001	0.001	0.001
Hexanal	2.73^{b}	4.23^{b}	10.29^{a}	4.90^{b}	0.61	1.91	2.95	2.37	2.38	0.32	0.001	0.001	0.001
Heptanal	0.13^{b}	0.14^{b}	0.28^{a}	0.16^{b}	0.02	0.16^{ab}	0.11^{b}	0.10^{b}	0.21^{a}	0.01	0.07	0.17	0.001
Benzaldehyde	0.99^{b}	1.24^{ab}	1.42^{a}	1.15^{b}	0.05	1.08	1.19	1.37	1.30	0.05	0.004	0.62	0.65
Octanal	0.25	0.20	0.29	0.24	0.02	0.23^{b}	0.20^{b}	0.17^{b}	0.43^{a}	0.02	0.003	0.61	0.001
Nonanal	0.21	0.19	0.20	0.33	0.03	0.32^{b}	0.31^{b}	0.30^{b}	1.^{a}	0.08	0.001	0.001	0.01
Hydrocarbons													
Methanethiol	6.02	6.46	6.16	5.69	0.28	5.73^{b}	5.70^{b}	7.77^{a}	6.56^{ab}	0.29	0.22	0.36	0.14
Carbon disulfide	2.37	1.55	1.87	1.36	0.15	1.95	1.75	1.29	1.48	0.19	0.17	0.48	0.59
n-Pentane	3.35^{a}	1.81^{b}	1.04^{b}	1.12^{b}	0.20	0.94	1.04	0.65	1.26	0.08	0.001	0.001	0.001
n-Hexane	0.55^{a}	0.28^{b}	0.16^{c}	0.07^{c}	0.03	0.64^{a}	0.24^{b}	0.05^{b}	0.06^{b}	0.06	0.001	0.78	0.69
2-Butene	0.42^{a}	0.33^{a}	0.18^{b}	0.23^{b}	0.02	0.23	0.23	0.25	0.26	0.01	0.003	0.03	0.001
Ketones													
2-Propanone	17.1^{ab}	18.8^{a}	17.1^{ab}	15.8^{b}	0.34	15.9	16.5	18.4	17.5	0.62	0.44	0.91	0.14
2-Butanone	0.83^{c}	1.00^{a}	0.92^{b}	0.82^{c}	0.02	0.74^{b}	0.81^{b}	0.82^{b}	0.94^{a}	0.02	0.001	0.004	0.001
2,3-Butanedione	0.32	0.31	0.24	0.31	0.02	0.13^{b}	0.14^{b}	0.13^{b}	0.30^{a}	0.02	0.07	0.001	0.17
3-Methyl-2-Butanone	0.07	0.07	0.06	0.08	0.00	0.07^{b}	0.09^{b}	0.09^{b}	0.12^{a}	0.00	0.001	0.001	0.13
Alcohols													
Ethanol	7.10	2.72	3.34	6.43	0.77	6.57	6.25	5.12	4.53	0.66	0.24	0.47	0.23
2-Methyl-2-butanol	0.63	0.63	0.57	0.73	0.03	0.92	0.90	0.89	0.95	0.03	0.36	0.001	0.91
2-Methyl-2-propanol	22.1	23.7	20.0	27.7	1.21	29.1	28.9	28.1	29.6	1.14	0.28	0.001	0.57
Others													
Acetonitrile	0.72^{b}	0.85^{b}	1.09^{a}	0.70^{b}	0.04	0.88^{a}	0.58^{b}	0.42^{b}	0.45^{b}	0.04	0.01	0.001	0.001

n=12.$^{a-c}$ Means with different letters within a same row differ ($P < 0.05$).

(Supplementary Table 1). Indurain et al. (2006) also reported positive correlations between fat content and MUFA and between the percentage of C18:1n9 and IMF. In contrast, QG, MS, and fat content were negatively correlated (−0.76≤ r ≤−0.63; $P < 0.001$) with the percentage of C18:2n6, C20:5, and PUFA in loin fat. A previous study found that high crude fat was related to high triacylglycerol that was rich in SFA and MUFA. However, PUFA content was relatively constant, and this may lead to the negative correlation between PUFA and fat content (Scollan et al., 2006). Conversely, meat texture score assigned by a meat grader was positively correlated with the percentage of PUFA (r =0.60, $P < 0.001$) in loin fat, whereas it showed a negative correlation with the percentages of C18:1n9 and MUFA (Supplementary Table 1). Beef texture mainly consists of several properties, including initial (first bite with incisors) and overall tenderness (after multiple chews), and more complex sensory attributes of chewing and mouthfeel with multiple descriptors (Juarez et al., 2011). According to the Korean beef grading system, texture scores ranged between 1 (very fine) and 3 (very coarse), where lower values indicate better texture. Our previous study, using the same set of samples, showed that the texture grade decreased with increasing QG and IMF (Piao et al., 2015), revealing that the beef texture improved with increasing QG and fat content. In this study, both QG and MS were positively correlated with the percentages of C18:1n9 and MUFA in loin fat, while they were negatively correlated with the percentage of PUFA (Supplementary Table 1). Therefore, the positive or negative correlations between texture and FA percentages in this study are likely due to strong associations between texture and QG and MS, as reported in our previous study (Piao et al., 2015). Wood et al. (2003) also reported that texture is more likely to be affected by the total amount of FAs than by individual FA.

Correlation data between carcass traits and chemical and fatty acid composition in rump are presented in Supplementary Table 2. Briefly, crude fat content was negatively correlated (−0.45≤ r ≤−0.31; $P < 0.05$) with percentages of C15:0, C18:0, and C18:2n6, whereas it was positively correlated (0.32≤ r ≤0.34; $P < 0.05$) with percentages of C16:0, C16:1, and MUFA in rump fat. Correlations between carcass traits and chemical compositions and fatty acid contents (g/100 g of meat) were also analyzed in both loin and rump. Briefly, QG, MS, and fat content had strong positive correlations (0.63≤ r ≤0.99; $P < 0.001$) with the contents of C16:0, C16:1, C18:0, C18:1n9, SFA, USFA, and MUFA in loin (Supplementary Table 3). QG and MS had positive correlations (0.44≤ r ≤0.48; $P < 0.01$) with C17:0 and C18:2n6 and PUFA contents in rump (Supplementary Table 4). Crude fat contents in rump had strong positive correlations (0.61≤ r ≤0.99; $P < 0.01$) with C14:0, C15:0, C16:0, C16:1, C17:0, C18:0, C18:1n9, C18:2n6, SFA, USFA, MUFA and PUFA.

Levels of hydrocarbons in loin, including n-pentane, n-hexane, and 2-butene, showed strong positive correlations (0.56≤ r ≤0.81; $P < 0.001$) with the content of QG, MS, and crude fat (Table 4). We found the highest content of these compounds in the QG1++ group. These hydrocarbons are the main volatile compounds formed via lipid oxidation in beef (Hierro et al., 2004). Therefore, higher fat content in higher QG might contribute to the strong relationships between QG and volatile hydrocarbons. During lipid oxidation process, a labile hydrogen atom comes from a fatty acyl chain and a reactive free lipid radical is produced which further react with oxygen to produce a peroxyradical. Then, the peroxyradical abstracts a hydrogen from another hydrocarbon chain, resulting in generation of a hydroperoxide and a new free radical that can continue the chain reaction (Ladikos and Lougovois, 1990). These hydroperoxides decomposed to smaller volatile compounds such as aldehydes, ketones, alcohols, and hydrocarbons. Thermal oxidative decomposition of lipid also produces different saturated or unsaturated hydrocarbons. However, flavor did not show any significant correlations with the hydrocarbons (n-

Table 4
Pearson correlation coefficients between carcass traits, chemical composition, and sensory characteristics and volatile compound composition in loin of Korean cattle steers.

Item	Methanethiol	2-Butene	Acetonitrile	n-Pentane	Butanal	2-Methyl-2-propanol	Chloroform	n-Hexane	3-Methyl-2-butanone-	Benzaldehyde
Slaughtering age	−0.07	0.01	0.28	0.09	0.15	−0.15	−0.11	0.09	−0.05	0.10
Carcass weight	0.11	0.02	0.05	0.06	0.09	−0.30*	0.06	0.16	−0.19	0.12
LM area	−0.13	0.29*	0.08	0.40**	0.04	−0.23	0.29*	0.41**	0.003	−0.08
Fat thickness	0.36*	−0.04	0.33*	−0.07	0.43**	0.37**	0.07	0.19	−0.24	0.44**
Marbling	0.03	0.56***	−0.07	0.63***	−0.05	−0.16	0.53***	0.79***	−0.13	−0.28
Quality grade	0.08	0.56***	−0.08	0.61***	−0.01	−0.18	0.54***	0.81***	−0.10	−0.22
Yield grade	−0.40**	0.12	−0.23	0.16	−0.29*	0.29*	0.04	−0.08	0.25	−0.31*
Yield index	−0.40**	0.13	−0.30*	0.18	−0.40**	0.35*	0.02	−0.08	0.27	−0.47**
Meat color	−0.27	0.07	−0.10	0.04	−0.15	0.21	0.21	−0.03	0.13	−0.20
Texture	−0.12	−0.25	−0.29*	−0.30*	−0.34*	0.30*	−0.21	−0.51***	0.27	−0.09
Maturity	−0.11	0.04	0.14	−0.02	0.03	−0.04	−0.11	−0.09	−0.08	0.03
Moisture	0.03	−0.59***	−0.08	−0.70***	0.01	0.16	−0.35*	−0.66***	0.20	0.16
Crude protein	0.09	−0.69***	0.001	−0.75***	0.13	0.04	−0.39**	−0.70***	0.01	0.32*
Crude fat	−0.05	0.63***	0.09	0.73***	−0.01	−0.14	0.40**	0.69***	−0.15	−0.18
Cooking loss	−0.20	−0.23	−0.08	−0.28	−0.23	0.23	−0.11	−0.29*	0.23	−0.06
Tenderness[1]	0.63*	0.12	0.33	0.36	0.46	−0.64*	−0.28	0.21	−0.69*	0.32
Juiciness[1]	0.65*	0.31	0.21	0.50	0.42	−0.58*	−0.11	0.46	−0.61*	0.22
Flavor[1]	0.16	−0.03	0.74**	0.13	0.71**	−0.62*	−0.25	0.09	−0.60*	0.68*
Overall acceptability[1]	0.50	0.32	0.34	0.47	0.52	−0.57	−0.05	0.49	−0.58*	0.33

n =48 for all parameters except sensory characteristics. [1]n=12 for sensory characteristics (tenderness, juiciness, flavor, and overall acceptability).
Correlation coefficients between carcass traits, chemical compositions, and sensory characteristics and content of volatile compound acetaldehyde, ethanol, carbon disulfide, 2-propanone, 2-butanone, 2,3-butanedione, propane-2-ethoxy-2-methyl, acetic acid, 2-butanol-2-methyl, pentanal, hexanal, heptanal, octanal, and nonanal were r < 0.50, and these values are not shown in this table. Correlation data of shear force, pH, and meat colors were also not shown in this table.
* P < 0.05.
** P < 0.01.
*** P < 0.001.

pentane, n-hexane, and 2-butene) in the present study. Therefore, our study convinced that these compounds might play a minor role in the generation of loin flavor due to high odor threshold value (Min et al., 1979), although these compounds proportionally increased with increases in QG because of the higher IMF.

The percentage of loin acetonitrile exhibited a strong positive correlation with flavor (r =0.74, $P < 0.01$). Acetonitrile is known as a volatile compound with a sweet-burnt taste and ether odor (Gasparetto et al., 2012). Little information is available regarding the role of acetonitrile in beef flavor. The percentage (range between 0.7% and 1.09%) of acetonitrile was relatively low in our study. Butanal and benzaldehyde also showed positive correlations with loin flavor, whereas 2-methyl-2-propanol and 3-methyl-2-butanone had negative correlations with loin flavor. Little information is available for the characteristics of butanal, benzaldehyde, 2-methyl-2-propanol, and 3-methyl-2-butanone.

MS and QG had positive correlations (0.50≤ r ≤0.65; $P < 0.01$) with percentages of acetonitrile and n-hexane, whereas these had negative correlations (−0.49≤ r ≤−0.45; $P < 0.01$) with percentages of 2-butanone, 3-methyl-2-butanone, and nonanal in rump (Table 5). Juiciness and overall acceptability had positive correlations (0.63≤ r ≤0.85; $P < 0.05$) with the percentages of acetonitrile in rump, whereas these had negative correlations (−0.64≤ r ≤0.59; $P < 0.05$) with the percentage of 2-butanone (Table 5). However, no correlation was observed between flavor and all volatile compounds in rump.

Percentages of both n-pentane and n-hexane in loin meat showed significant negative correlations (−0.55≤ r ≤−0.45; $P < 0.01$) with percentages of C18:2n6 and PUFA in loin fat (Table 6). These did not exhibit significant correlations with the percentages of other major FA, including C16:0, C16:1, C18:0, and C18:1n9 in loin fat.

Percentage of methanethiol in rump showed negative correlations (−0.37≤ r ≤−0.32; $P < 0.05$) with percentages of several FAs including C15:0, C17:0, C18:2n6, C20:3n6, C20:5, and PUFA in rump fat (Supplementary Table 5).

Percentages of hydrocarbon compounds, including 2-butene, n-pentane, and n-hexane exhibited strong positive correlations (0.52≤ r ≤0.79; $P < 0.001$) with contents (g/100 g of meat) of several FA, including C16:0, C16:1, C18:0, C18:1n9, SFA, MUFA, and USFA in loin (Table 7). We observed the highest percentage of hydrocarbons (n-pentane, n-hexane, and 2-butene) in the loin in the QG1++ group. This

Table 5
Pearson correlation coefficients between carcass traits, chemical composition, and sensory characteristics and volatile compound composition in rump of Korean cattle steers.

Item	Acetonitrile	2-Butanone	2,3-Butanedione	n-Hexane	2-Ethoxy-2-methylpropane	3-Methyl-2-Butanone	Octanal	Nonanal
Marbling	0.58**	−0.45**	−0.34*	0.54**	−0.30*	−0.49**	−0.40**	−0.49**
Quality grade	0.56**	−0.48**	−0.39**	0.50**	−0.34*	−0.48**	−0.39**	−0.45**
Texture	−0.26	0.45**	0.49**	−0.25	0.54**	0.50**	0.60**	0.59**
Crude protein	−0.45**	0.31*	0.20	−0.37**	0.07	0.21	0.14	0.20
Crude fat	0.39**	−0.17	0.03	0.18	0.002	−0.09	−0.12	−0.15
Tenderness[1]	0.55	−0.52	0.15	0.04	−0.46	−0.40	−0.17	−0.29
Juiciness[1]	0.63*	−0.64*	−0.09	0.29	−0.45	−0.50	−0.36	−0.47
Flavor[1]	0.43	−0.26	0.02	0.01	−0.51	−0.38	−0.43	−0.51
Overall acceptability[1]	0.63*	−0.59*	−0.21	0.36	−0.47	−0.54	−0.52	−0.61*

n =48 for all parameters except sensory characteristics. [1]n=12 for sensory characteristics (tenderness, juiciness, flavor, and overall acceptability).
* P < 0.05.
** P < 0.01.

Table 6
Pearson correlation coefficients between fatty acid composition (% of fat, fresh basis) and volatile compound composition in loin of Korean cattle steers.

Item	n-Pentane	n-Hexane
C14:0	0.002	−0.05
C15:0	−0.34*	−0.50***
C16:0	0.20	0.29*
C16:1	0.03	−0.04
C17:0	−0.31*	−0.39**
C17:1	−0.23	−0.15
C18:0	0.25	0.14
C18:1n9t	−0.03	−0.10
C18:1n9	0.23	0.38**
C18:2n6	−0.46**	−0.52***
C18:3n6	0.30*	0.28
C20:3n6	−0.43**	−0.54***
C20:5	−0.42**	−0.58***
SFA	0.15	0.09
USFA	−0.15	−0.09
MUFA	0.21	0.33*
PUFA	−0.45**	−0.55***
MUFA/SFA	0.03	0.11
PUFA/SFA	−0.45**	−0.54***

n =48.
Correlation coefficients between fatty acid content (% of fat) and content of volatile compound acetaldehyde, methanethiol, 2-butene, acetonitrile, ethanol, carbon disulfide, 2-propanone, butanal, 2-propanol-2-methyl, chloroform, 2-butanone, 2,3-butanedione, propane-2-ethoxy-2-methyl, acetic acid, 2-butanol-2-methyl, 2-butanone-3-methyl, pentanal, hexanal, heptanal, benzaldehyde, octanal, and nonanal were r < 0.50, and these values are not shown in this table.
* P < 0.05.
** P < 0.01.
*** P < 0.001.

might have been caused by the highest fat content and total FA content. As indicated earlier, hydrocarbons are produced from thermal oxidative degradation of lipid molecules. These three compounds had strong positive correlations with QG and fat content in loin. Taken together, the results of our study demonstrated that these hydrocarbon compounds are linked with beef QG even though they are not directly linked with beef flavor.

Percentage of acetonitrile showed positive correlations (0.38≤ r ≤0.44; $P < 0.01$) with contents of several FA, including C17:0, C18:0, C18:1n9, C18:2n6, C18:3n6, C20:3n6, C20:5, SFA, USFA, MUFA, and PUFA in rump (Supplementary Table 6). However, percentages of both methanethiol and benzaldehyde showed negative correlations (−0.36≤ r ≤−0.29; $P < 0.05$) with contents of C17:0, C20:3n6, C20:5, and PUFA.

In this study, we presented both the percentage of individual FA (based on total FA) and the content (g/100 g of meat) of individual FA in loin and rump. From the results, content of FA per meat type, rather than the percentage of individual FA, is likely more directly associated with volatile compounds.

Overall, abundant volatile compounds (acetaldehyde, 2-propanone) and most of the moderate compounds (hexanal, methanethiol, carbon disulfide, n-pentane, and ethanol) in loin were not correlated with sensory characteristics, including flavor and overall acceptability. Minor compounds, including acetonitrile, butanal, and benzaldehyde in loin were positively correlated with flavor, whereas 2-methyl-2-propanol and 3-methyl-2-butanone were negatively correlated with flavor. A recent study reported that acceptability and flavor were greater for longissimus lumborum steaks of USDA Prime and Choice than those of Standard grade, which is lower QG in the US (Legako et al., 2016). The authors also demonstrated that volatile compounds of grilled beef steaks varied with QG.

4. Conclusions

Beef QGs affected the compositions and contents of FAs and volatile compounds in loin and rump of Korean cattle steers. Loin FA percentages, especially those of C18:1n9 and MUFA, generally increased with increasing QGs. Some volatile compounds in loin and rump varied with QGs and were positively or negatively correlated with flavor.

Conflicts of interest statement

We declare that we have no relevant financial or personal relationships with other people or organizations that would create a conflict of interest.

Table 7
Pearson correlation coefficients between fatty acid contents (g/100 g meat) and volatile compound composition in loin of Korean cattle steers.

Item	2-Butene	n-Pentane	Chloroform	2-Butanone	n-Hexane	2-Ethoxy-2-methylpropane
C14:0	0.55***	0.66***	0.30*	−0.02	0.53***	0.28
C15:0	0.19	0.16	−0.02	0.19	0.11	0.24
C16:0	0.63***	0.74***	0.41**	0.04	0.70***	0.35*
C16:1	0.52***	0.62***	0.33*	−0.04	0.52***	0.28
C17:0	0.10	0.15	0.18	−0.06	0.18	0.12
C17:1	0.52***	0.62***	0.34*	0.03	0.59***	0.23
C18:0	0.68***	0.79***	0.40**	0.06	0.70***	0.41**
C18:1n9t	0.52***	0.64***	0.33*	0.01	0.56***	0.28
C18:1n9	0.61***	0.71***	0.42**	0.07	0.69***	0.33*
C18:2n6	0.27	0.21	0.07	0.30*	0.30*	0.19
C18:3n6	0.57***	0.66***	0.28	0.03	0.60***	0.30*
C20:3n6	0.17	0.10	−0.09	0.40**	0.12	0.19
C20:5	0.05	−0.01	−0.09	0.22	−0.06	0.14
SFA	0.65***	0.76***	0.40**	0.04	0.69***	0.37**
USFA	0.61***	0.70***	0.40**	0.08	0.67***	0.33*
MUFA	0.61***	0.71***	0.41**	0.06	0.68***	0.32*
PUFA	0.27	0.22	0.04	0.30*	0.26	0.22
MUFA/SFA	0.02	0.03	0.1	0.15	0.11	−0.13
PUFA/SFA	−0.33*	−0.45**	−0.38**	−0.01	−0.54***	−0.06

n =48.
Correlation coefficients between fatty acid content (g/100 g meat) and content of volatile compound acetaldehyde, methanethiol, acetonitrile, ethanol, carbon disulfide, 2-propanone, butanal, 2-propanol-2-methyl, 2,3-butanedione, acetic acid, 2-butanol-2-methyl, 2-butanone-3-methyl, pentanal, hexanal, heptanal, benzaldehyde, octanal, and nonanal were r < 0.50, and these values are not shown in this table.
* P < 0.05.
** P < 0.01.
*** P < 0.001.

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Appendix A. Supplementary material

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.livsci.2017.02.021.

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