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Association of carcass weight with quality and functional properties of beef from Hanwoo steers

Dinesh D. Jayasena[A,B], *Ki Chang Nam*[C], *Jong Ju Kim*[D], *Hyeonju Ahn*[E] and *Cheorun Jo*[E,F]

[A]Department of Animal Science and Biotechnology, Chungnam National University, Daejeon 305-764, Republic of Korea.
[B]Department of Animal Science, Uva Wellassa University, Badulla 90000, Sri Lanka.
[C]Department of Animal Science and Technology, Suncheon National University, Suncheon, 540-742, Republic of Korea.
[D]School of Biotechnology, Yeungnam University, Kyungsan, 712-749, Republic of Korea.
[E]Department of Agricultural Biotechnology, Centre for Food and Bioconvergence, and Research Institute of Agriculture and Life Science, Seoul National University, Seoul 151-921, Republic of Korea.
[F]Corresponding author. Email: cheorun@snu.ac.kr

Abstract. The association of carcass weight with quality and functional properties of Hanwoo (Korean native cattle) beef was investigated. The carcasses of 250 Hanwoo steers were categorised into light (<375 kg; n = 74), medium (375–425 kg; n = 76) and heavy (>425 kg; n = 100) groups and were evaluated for back fat thickness, rib eye area, and beef marbling score 24 h postmortem using the Korean carcass grading system. Rib eye area, back fat thickness, and marbling score significantly increased ($P < 0.05$) with increasing carcass weight. However, marbling score and intramuscular fat content showed only a little increase ($P < 0.05$) beyond a limit of 375 kg. Inosine-5′-monophosphate concentration was significantly higher ($P < 0.05$) in medium and heavy carcasses. Carnosine concentration was significantly higher in medium carcasses. Total saturated fatty acid content and n-6 : n-3 ratio decreased as carcass weight increased ($P < 0.05$). Medium and heavy carcasses had significantly higher ($P < 0.05$) scores for sensory quality parameters. Overall, medium carcasses of Hanwoo displayed optimal sensory and health benefits while minimising the economic disadvantages of growing cattle to heavier weights.

Additional keywords: creatine, histidyl dipeptides.

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Introduction

Hanwoo cattle, a type of Korean native cattle, have been raised in Korea since 2000 BC. However, the commercialised production of Hanwoo as meat cattle began in the 1960s, accompanying rapid economic growth in the country (Jo *et al*. 2012). Hanwoo beef is characterised by its high percentage of intramuscular fat (IMF), hypotrophy of muscle fibres, and lower connective tissue content compared with imported beef (Jo *et al*. 2012). Compared with Australian Angus slaughtered at 24 months of age (carcass weight of 342–423 kg), Hanwoo steers (carcass weight of 313–409 kg) showed less subcutaneous fat depth with higher ossification and marbling scores measured by the United States Department of Agriculture (USDA) scoring systems at similar age (Cho *et al*. 2005).

As Korea has developed economically, the demand for meats, in particular for more palatable meats, has increased compared with that before the 1980s, during which consumers preferred carcass yield to meat quality owing to insufficient beef supply within the country (Jo *et al*. 2012). Furthermore, a rapid increase in per capita meat consumption was observed in Korea – from 14 kg in 1985 to 40 kg in 2010 – with a parallel rise in beef consumption from 3 to 12 kg (Jo *et al*. 2012). Because the country is not yet self-sufficient in beef production, more than half of consumer demand is met by imports from Australia, USA, New Zealand, Mexico, and Canada. Nevertheless, Korean consumers prefer Hanwoo beef to imported beef even though it costs about twice as much, mainly because they strongly believe that Hanwoo beef is fresher and of superior quality (Han and Lee 2010; Jo *et al*. 2012).

Beef producers have begun paying increased attention to the accumulation of IMF in beef muscles because Korean consumers prefer to purchase highly marbled meats. This preference has led to an extension of the marketing age of Hanwoo to an average of 31 months (average marketing weight, 694 kg), primarily aiming for beef with a higher IMF percentage, compared with cattle harvested at the previous age of ~24 months (average marketing weight, 425 kg; Park *et al*. 2002; Dashdorj *et al*. 2012; Jo *et al*. 2012). Therefore, most Korean cattle farmers are highly interested in extended feeding using specific feeding regimes – in particular, high levels of concentrate diet – to reach a better quality grade with high marbling scores, because beef price is currently determined by quality grade.

In the Korean beef grading system, marbling score and fat thickness are the most significant determinants of quality and yield grades, respectively, where high marbling and less back fat result in good quality and yield grades (Moon *et al*. 2003). Park *et al*. (2002) have reported that the quality grade of Hanwoo can be improved by extending the feeding period. Heavier carcasses produced by extended feeding result in higher quality grades but lower yield grades, primarily owing to the significant effect of back fat thickness on yield grade (Hermesmeyer *et al*. 2000). Similarly, lighter carcasses received higher USDA yield grades but lower-quality grades with lower marbling score (Lorenzen *et al*. 1993). Moon *et al*. (2003) have confirmed that better carcass quality is achievable through extended feeding, although low yield grade may also result. By contrast, Hong *et al*. (1996) have found that extended feeding of Hanwoo steer above 550 kg was undesirable for both quality and yield grades. Moon *et al*. (2003) have reported that every steer and heifer in their study lost $219.25 owing to excessive fat production, of which $111.99 and $62.94 were due to excess subcutaneous fat and excess intermuscular fat, respectively. This finding confirms that extended feeding eventually burdens stakeholders of the beef industry. Therefore, the feeding practices of Hanwoo should be carefully monitored and strategies tailored with an economic point of view because retail carcass price is a sum of quality and yield grades (Moon *et al*. 2003).

Several studies have been carried out on the relationship between quality grade and various characteristics of Hanwoo beef. However, no research has been conducted to elucidate the relationship between carcass weight and the quality and functional properties of Hanwoo beef. Hence, this study was conducted to determine (1) the association of carcass weight with quality and functional properties of Hanwoo beef, and (2) the carcass weight group of Hanwoo beef with superior sensory and health benefits with reduced economic disadvantages of growing cattle to heavier weights.

Materials and methods

Animals and carcass evaluation

A total of 250 Hanwoo steers (27–30 months old) were randomly selected for slaughter from a local cattle farm in NongHyup (Anseong), South Korea where they were raised under similar commercial conditions and fed with the same diet *ad libitum*. Recommendations described in 'The Guide for the Care and Use of Laboratory Animals' published by the Institutional Animal Care and Use Committee of National Institute of Animal Science (NIAS) in Korea were followed in this farm. In addition, cattle care facilities and the procedures were carried out to meet or exceed the standards established by the Committee for Accreditation of Laboratory Animal Care at NIAS in Korea. Cattle were slaughtered at a local municipal slaughterhouse and warm carcass weights were recorded after splitting the carcasses and before post-mortem treatment. Carcasses were not electrically stimulated. The carcasses were then washed and immediately cooled at 0°C for 24 h in a chilling room without packaging. The weight of the carcasses ranged from 213 to 477 kg. They were then categorised into three groups: light (<375 kg), medium (375–425 kg), and heavy (>425 kg). The average carcass weights for light, medium and heavy groups were given in Table 1. The left sides of the carcasses were then ribbed between the 13th rib and the 1st lumbar vertebrae 24 h postmortem and evaluated for back fat thickness, rib eye area, and beef marbling score by an official meat grader according to the Korean carcass grading procedure (KAPE 2010).

Sample preparation

Immediately after grading, the *M. longissimus dorsi* (LD) at the 14th–18th vertebrae from both carcass sides were removed from all carcasses and transferred to the laboratory. After aging at 4°C for 7 days, the LD muscles were trimmed of all subcutaneous fat and visible connective tissues. The completely trimmed left LD muscles were used to analyse meat composition, quality, and functional parameters, whereas those from the right were used to evaluate sensory qualities. For ease of storage and analyses, LD muscles were subdivided and vacuum packaged separately in polyethylene bags. These samples were stored in a freezer at −80°C until further analysis. Before determining meat composition, quality, and functional parameters, samples were thawed in a refrigerator at 4°C for 12 h and minced thoroughly using a food mixer (CH180, Kenwood, Shenzhen, China).

Analytical procedures

Proximate composition and pH

The proximate composition of each LD muscle was determined using a slightly modified AOAC International

Table 1. Proximate composition and cholesterol concentration of *M. longissimus dorsi* of Hanwoo beef from different carcass weight groups
Results are given as least-square means with standard errors. Average carcass weights (±s.d.) for light, medium and heavy groups were 336.28 ± 32.61, 399.29 ± 13.62 and 450.90 ± 15.67 kg, respectively. Means within a row followed by the same letter are not significantly different from each other ($P = 0.05$)

Item	Carcass weight group			Regression parameters [x = carcass weight (kg)]			
	Light (n = 74)	Medium (n = 76)	Heavy (n = 100)	Intercept	Slope	R^2	P-value (slope)
Proximate composition							
Moisture (%)	65.52a ± 0.55	62.82b ± 0.56	63.76b ± 0.49	70.946	–0.0173 ± 0.0060	0.0330	0.004
Crude protein (%)	19.57 ± 0.20	19.51 ± 0.21	19.09 ± 0.19	21.437	–0.0052 ± 0.0022	0.0221	0.02
Crude fat (%)	12.87b ± 0.55	16.24a ± 0.62	15.73a ± 0.44	4.325	0.0267 ± 0.0058	0.0776	<0.0001
Crude ash (%)	1.11 ± 0.02	1.05 ± 0.02	1.05 ± 0.03	1.276	–0.0005 ± 0.0003	0.0133	0.07
Cholesterol (mg/100 g)	60.65 ± 0.56	60.71 ± 0.62	61.05 ± 0.68	58.485	0.0058 ± 0.0071	0.0027	0.41

method (AOAC 1995). Briefly, moisture content was determined by drying each sample (3 g) in an aluminium dish at 104°C for 15 h. Crude protein content was measured using the Kjeldahl method (VAPO45, Gerhardt Ltd, Idar-Oberstein, Germany). The amount of nitrogen was multiplied by a factor of 6.25 to calculate crude protein content. Crude fat content was measured using the Ether extraction method for 8 h in a Soxhlet extraction system (TT 12/A, Gerhardt, Idar-Oberstein, Germany). Crude ash content was determined by igniting each sample (2 g) in a furnace at 600°C overnight. The pH of each meat sample was determined with a pH meter (Orion 2 Star, Thermo Scientific, Beverly, MA, USA) as described by Jung *et al*. (2013).

Colour, water-holding capacity, and drip loss

Colour values [CIE L^* (lightness), a^* (redness), and b^* (yellowness)] on the surface of meat samples were measured using a colourimeter (CR-410, Minolta, Osaka, Japan) as explained by Jung *et al*. (2013). Values were obtained from five random measurements taken from different locations on each sample surface after blooming at room temperature for 30 min. Water-holding capacity (WHC) was determined using the centrifugation method of Kang *et al*. (2012). WHC was calculated as the moisture remaining in the sample relative to the moisture content of the original sample. Drip loss was measured as the percentage weight loss of a standardised (3 by 3 by 3 cm) meat sample during suspension at 4°C and stored for 2 days (Kim and Lee 2003).

Cooking loss and shear force

Cooking loss was determined as the percentage weight loss of a standardised (3 by 3 by 3 cm) meat sample after cooking (Jung *et al*. 2013). In this regards, three replicate samples from each animal were separately sealed in polyethylene bags, heated in a water bath at 75°C for 30 min and cooled at room temperature for 30 min. Average value of the three replicates was used as the cooking loss percentage of each animal. The maximum shear force value (kg) was measured according to the method described by Kim and Lee (2003) with some modifications. Each replicate sample of cooking loss was cut into a 1-cm^2 cross section with the fibre direction and 1.5 cm in length. The shear force was then measured using a Warner–Bratzler shear attachment on a texture analyser (TA-XT2, Stable Micro System Ltd, Surrey, UK) with a load cell of 50 kg and cross-head speed of 200 mm/min. Each replicate sample was sheared once across the centre of the sample perpendicular to the muscle fibre. The average of the maximum forces required to shear each set of replicate samples was used as the shear force value of each animal.

Fatty acid and cholesterol contents

Lipids were extracted from meat samples (5 g) using 30 mL of Folch solution (chloroform : methanol = 2 : 1) according to the method of Folch *et al*. (1957). After 0.88% KOH solution was added, the filtrate was thoroughly mixed. After phase separation, the upper layer was removed, and the remaining organic layer was dried using nitrogen gas (99.999%). The dried lipid was dissolved with an aliquot of hexane (100 mg lipid/mL hexane) and used for analysis.

Fatty acid methyl esters were prepared from the extracted lipids with BF3-methanol (Sigma-Aldrich, St Louis, MO, USA), followed by separation on a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA) as explained by Jung *et al*. (2011*a*). Relative quantities were expressed as weight percent of total fatty acids identified via comparison of retention times to known standards (37 fatty acid methyl esters mix, conjugated linoleic acids mix, Sigma-Aldrich).

The cholesterol analysis was performed using the procedure of Jung *et al*. (2011*a*) with some modifications. The lipid extract was first saponified with 10 mL saponification reagent [33% KOH : ethanol (w/v), 6 : 94]. The sample was homogenised (Polytron PT 10–35 GT, Kinematica AG, Lucerne, Switzerland) and incubated at 50°C for 1 h. After cooling, 5 mL of distilled water and 5 mL of hexane were added. The resulting aliquot of hexane containing cholesterol was dried under nitrogen (99.999%), then mixed with 200 µL of pyridine and 100 µL of Sylon BFT [99% N,O-bis(trimethylsilyl)trifluoroacetamide + 1% trimethylchlorosilane; Sigma-Aldrich] and derivatised at 50°C for 1 h. Analysis was performed with a gas chromatograph (HP 6890, Agilent Technologies) equipped with an on-column capillary injector and a flame ionisation detector. The amounts were calculated using an internal standard, 5α-cholestane.

Free amino acid content

Free amino acid content was analysed using the method described by Hughes *et al*. (2002) with modification. Defatted meat (5 g) was mixed with 20 mL of 2% trichloroacetic acid solution and homogenised at 1130*g* for 1 min. The homogenate was centrifuged at 17 000*g* for 15 min and filtered through a 0.45-µm membrane filter. The filtrate was derivatised using AccQ-Tag (Waters Co., Milford, MA, USA) according to the manufacturer protocol, and 5 µL was injected into a reverse-phase high-performance liquid chromatograph (HPLC, 3.9 by 150 mm, AccQ-Tag column, Waters Co.). Individual amino acids were identified by comparison of their retention times with those of calibration standards. Peak areas were processed using Millennium 32 software and the concentration of individual amino acids was expressed as mg/100 g of fresh sample.

Histidyl dipeptides, creatine, and creatinine concentrations

Histidyl dipeptides, creatine, and creatinine concentrations of the meat samples were determined according to the method of Mora *et al*. (2007) with some modifications. Each minced sample (2.5 g) was homogenised with 7.5 mL of 0.01 N HCl at 13 500 rpm for 1 min and centrifuged at 17 000*g* for 15 min. The supernatant was mixed with 750 µL of acetonitrile, and after holding at 4°C for 20 min, it was centrifuged at 10 000*g* for 10 min. The supernatant was filtered through a 0.2-µm PVDF syringe filter (Whatman) and injected into an HPLC column with a Waters 1525 pump and a Waters 717 plus auto sampler (Waters Co.) with an Atlantis HILIC silica column (4.6 by 150 mm, 3 µm, Waters Co.). Standards (creatine, anserine, carnosine, and creatinine) were obtained from Sigma (USA).

Nucleotide content

Nucleotide content in the meat samples was measured according to Jung *et al*. (2011*b*). Nucleic acids were extracted from the samples (5 g each) using 25 mL of 0.7 M perchloric acid. The extract was then adjusted to pH 7 with 5 N KOH, placed into a volumetric flask, and made up to a volume of 100 mL with 0.7 M perchloric acid (pH 7). After 30 min of cooling, the mixture was centrifuged at 1130*g* (0°C), and the supernatant was filtered through a 0.2-µm polyvinylidene difluoride syringe filter (Whatman International). The filtrate (5 mL) was analysed using an HPLC (ACME 9000, Younglin Instruments, Seoul, Korea) with a Waters-Atlantis dC18 reverse-phase column (4.6 by 250 mm, 5 µm particle; Waters Co.) The peaks of individual nucleotides were identified using the retention times for standards – hypoxanthine, inosine, inosine-5′-phosphate (IMP), adenosine-5′-phosphate (AMP; Sigma) – and concentration was calculated using the area for each peak.

Sensory evaluation

For sensory evaluation, meat samples (2 by 4 by 1.5 cm) from each treatment replicate were cooked on a pre-heated clam-type electric grill with double heating surfaces (1400 W, Nova EMG-533, Evergreen Enterprise, Yongin, Korea). Internal temperature was monitored with a digital thermometer placed in the centre of meat samples. Meat samples were removed from the grill after they reached an internal temperature of 72°C and then wrapped in aluminium foil and placed in a preheated oven (65°C) until served to panellists. The samples were placed into randomly coded white dishes and served with drinking water. Ten semi-trained panellists recorded their preferences for each sample using a 9-point hedonic scale (1 = profoundly dislike; 5 = like moderately; 9 = profoundly like) after training with the Hanwoo beef with quality grade 1^+ as a reference. The tested sensory parameters for cooked Hanwoo beef were colour, odour, tenderness, juiciness, and overall acceptance.

Statistical analyses

ANOVA was performed on all variables by applying the general linear model with SAS statistical package (SAS 1999). The Duncan's multiple-range test was used to determine differences among the treatment means at $P < 0.05$. Furthermore, a linear regression was performed to test the significance level of the relationship between each parameter and the carcass weight of Hanwoo using the following model.

$$Y = \hat{a}_0 + \hat{a}_1 x + \mathring{a}$$

A quadratic linear regression was also fitted to the relationship between carcass weight and IMF/crude fat and marbling score using the following model.

$$Y = \hat{a}_0 + \hat{a}_1 x + \hat{a}_2 x^2 + \mathring{a}$$

The least-square mean values and standard errors are reported.

Results and discussion

The significance values obtained using the linear regression analysis clearly showed that carcass weight of Hanwoo had positive relationships ($P < 0.05$) with crude fat, IMP, creatinine, cysteine, glutamic acid, phenylalanine, oleic acid, and unsaturated fatty acid (USFA) contents, rib eye area, back fat thickness and marbling score of LD muscles in addition to the sensory characteristics such as tenderness, juiciness and overall acceptance (Tables 1–6). As the animals used in this study were from a similar age category, heavy carcasses might be resulted from animals with higher growth rate and *vice versa*. Therefore, the differences shown may have been due in part to the different growth rates as well as to the different carcass weights.

Proximate composition and cholesterol concentration

The proximate compositions of the three carcass weight groups are compared in Table 1. Light carcasses had higher ($P < 0.05$) moisture content compared with those of medium and heavy carcasses, which had significantly higher crude fat/IMF content (Table 1, Fig. 1). Higher crude fat content can be attributed to higher back fat thickness of these muscles. Similar to our results, those of Kim and Lee (2003) showed that moisture content of Hanwoo beef significantly decreased and crude fat content increased ($P < 0.05$) as carcass weight increased among three quality grade groups with different average carcass weights. In addition, our results agree with the general rule that IMF content is inversely related to moisture content in meat (Kim and Lee 2003) and with reports by other authors showing a negative correlation between the moisture and fat contents of bovine muscle (Li *et al*. 2006; Okumura *et al*. 2007). Compared with our data, Cho *et al*. (2005) found similar IMF content in beef from Hanwoo (11.29%; average carcass weight, 371 kg) but lower content in Australian Angus (5.72%; average carcass weight, 386 kg).

Protein and ash contents did not differ ($P > 0.05$) among the groups compared in this study and were comparable to the findings of Kim and Lee (2003). However, the crude protein content of LD muscles with higher IMF content was lower than that of muscles with lower IMF content (Okumura *et al*. 2007). In addition, no significant differences ($P > 0.05$) occurred in cholesterol concentration among the groups. The cholesterol concentration determined in this study fell within the limits

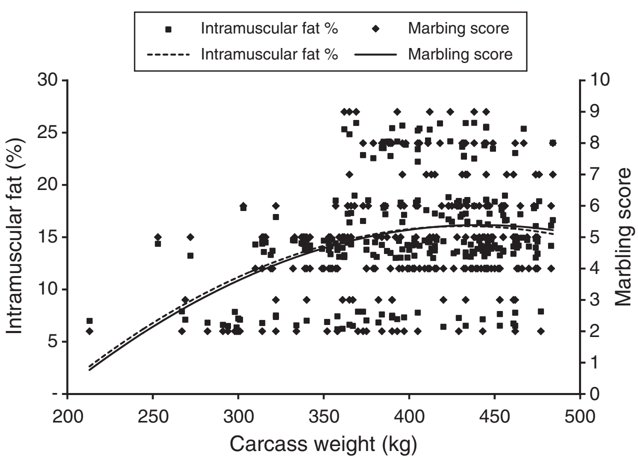

Fig. 1. Quadratic linear regression of intramuscular fat % or marbling score and carcass weight. Regression for intramuscular fat % is $y = -36.142 + 0.2416x - 0.0003\ x^2$ ($R^2 = 0.1149$) and for marbling score is $y = -11.887 + 0.0783\ x - 0.00\,009\ x^2$ ($R^2 = 0.1103$), where x is carcass weight.

(59–68 mg/100 g) for beef reported by Bureš *et al.* (2006). However, much lower cholesterol levels in various cuts of Hanwoo bull beef (26.74–31.08 mg/100 g) were reported by Cho *et al*. (2007).

Meat grading parameters

The effect of carcass weight on rib eye area, back fat thickness, and marbling score are shown in Table 2. The largest rib eye area and highest back fat thickness were detected in heavy carcasses, followed by medium and light carcasses ($P < 0.05$). In addition, heavy and medium carcasses had significantly higher marbling scores compared with those of light carcasses (Table 2, Fig. 1), a finding comparable to those of Hong *et al*. (1996) and Park *et al*. (2002) showing that marbling score did not differ in Hanwoo steers when slaughter weight was above 550 kg. However, both average marbling score and IMF content showed only little increases with wide variability in each parameter beyond the carcass weight of 375 kg (Fig. 1). Hanwoo beef with carcass weights (average 378.50 kg) similar to that of the medium weight group of this study have shown higher back fat thickness (16.25 mm) and lower loin eye area (76.25 cm^2) and marbling score (3.00; Oh *et al.* 2012). By contrast, higher marbling score (6.21) was reported for Hanwoo beef (average carcass weight, 313 kg) by Park *et al.* (2002).

Therefore, in general, rib eye area, back fat thickness, and marbling score significantly increased with increasing carcass weight, which agrees with the findings of Park *et al*. (2002) and Moon *et al*. (2003). Similarly, lighter carcasses reportedly have lower back fat thickness and lower marbling scores (Lorenzen *et al*. 1993). The data of Kim and Lee (2003) suggest that marbling score and loin eye area increase as carcass weight increases, with a significant effect only on marbling score. In addition, carcass weight had highly positive correlations with rib eye area (0.61), back fat thickness (0.51), and marbling score (0.29) in the present study. Confirming our results, Moon *et al.* (2003) stated that rib eye area had highly positive correlations with slaughter weight and degree of marbling in Hanwoo steers. The correlation reported in the present study between rib eye area and degree of marbling was 0.35. A positive relationship between IMF content and marbling score was also observed (Fig. 1) with a correlation coefficient value of 0.94 (data not shown). Similarly, Li *et al*. (2006) found that crude fat (IMF) content of LD muscle of pure Luxi steers increased when the marbling score increased.

Meat-quality parameters

Table 2 further shows that carcass weight had no effect on meat colour, pH, WHC, drip loss, or cooking loss ($P > 0.05$). However, compared with the other groups, light carcasses had significantly higher shear force values. Dashdorj *et al*. (2012) recently indicated that increased Hanwoo steer carcass weight was associated with significantly decreased shear force and cooking loss values and increased CIE L^* values. The average carcass weights they studied fell within the light and medium weight groups of the present study. In the present study, carcass weight was not significantly ($P > 0.05$) related to pH or CIE a^* and b^* values. Kim and Lee (2003) reported no significant differences in pH, WHC, cooking loss, L^* and b^* values, or shear force values among three quality grade groups with significantly different average carcass weights, but a^* value increased when carcass weight increased. Moreover, Hur *et al.* (2008) reported similar a^* values but lower L^* and b^* values for Hanwoo and Holstein beef compared with those of the present study. Data similar to the present study for pH were reported by Cho *et al*. (2005), Dashdorj *et al*. (2012), and Oh *et al*. (2012) for Hanwoo beef. Kim and Lee (2003) showed that pH values of LD muscles from Hanwoo ranged between 5.47 and 5.49 with no differences among the quality groups ($P > 0.05$). In addition, they reported lower WHC (51.26–55.69) and higher cooking loss (27.72–29.11) values than we did for Hanwoo beef. Further, Okumura *et al*. (2007) observed no significant differences in WHC and cooking loss values among loins with various fat contents, which agrees with our findings. By contrast,

Table 2. Major meat-grading and -quality parameters of *M. longissimus dorsi* of Hanwoo beef from different carcass weight groups
Results are given as least-square means with standard errors. Marbling score: 7 = very abundant, 1 = devoid. Means within a row followed by the same letter are not significantly different from each other ($P = 0.05$)

Item	Carcass weight group			Regression parameters [x = carcass weight (kg)]			
	Light (n = 74)	Medium (n = 76)	Heavy (n = 100)	Intercept	Slope	R^2	P-value (slope)
			Grading parameters				
Rib eye area (cm^2)	81.24c ± 1.01	89.59b ± 0.90	94.23a ± 0.72	44.619	0.1105 ± 0.0093	0.3671	<0.0001
Back fat thickness (mm)	9.66c ± 0.51	13.95b ± 0.60	15.87a ± 0.50	–8.379	0.0544 ± 0.0058	0.2634	<0.0001
Marbling score	4.26b ± 0.20	5.33a ± 0.23	5.31a ± 0.17	0.950	0.0101 ± 0.0021	0.0825	<0.0001
			Quality parameters				
CIE							
L^*	39.21 ± 0.33	39.29 ± 0.34	39.09 ± 0.29	40.201	–0.0025 ± 0.0035	0.0020	0.48
a^*	21.94 ± 0.23	21.81 ± 0.20	21.35 ± 0.22	24.128	–0.0061 ± 0.0024	0.0252	0.01
b^*	13.30 ± 0.18	13.40 ± 0.18	13.07 ± 0.17	14.344	–0.0028 ± 0.0019	0.0081	0.16
Ultimate pH	5.55 ± 0.02	5.53 ± 0.02	5.54 ± 0.01	5.636	–0.0002 ± 0.0002	0.0058	0.23
Water-holding capacity (%)	70.51 ± 0.49	70.47 ± 0.54	70.31 ± 0.50	72.253	–0.0046 ± 0.0057	0.0026	0.42
Drip loss (%)	18.61 ± 0.28	18.63 ± 0.30	18.26 ± 0.24	19.312	–0.0021 ± 0.0030	0.0019	0.49
Cooking loss (%)	21.41 ± 0.34	21.67 ± 0.38	21.27 ± 0.29	22.371	–0.0023 ± 0.0037	0.0016	0.53
Shear force (kg)	28.96a ± 0.80	25.62b ± 0.96	24.77b ± 0.73	39.463	–0.0329 ± 0.0092	0.0494	0.0004

Li *et al*. (2006) reported that the cooking losses of beef from pure Luxi cattle were significantly lower in the samples with the highest IMF content (marbling score) compared with those of other samples. The correlation coefficient between cooking loss and crude fat content was –0.79 (Li *et al*. 2006).

Significantly higher shear force values in light carcasses can be attributed to their lower fat content and marbling score. Shear force values are negatively related to IMF content (Kim and Lee 2003). Li *et al*. (2006) showed negative and positive correlations of shear force value with crude fat content (–0.54; $P < 0.05$) and cooking loss (0.75; $P < 0.01$), respectively, in beef. According to Cho *et al*. (2005), shear force values of LD muscles were significantly lower for Hanwoo beef of quality grade 1^{++} (3.5 kg) with higher marbling compared with quality grade 2 (4.9 kg). By contrast, several authors demonstrated that shear force showed no significant relationship with IMF content or marbling score (Okumura *et al*. 2007; Hur *et al*. 2008).

Nucleotide content

Amino acids, inosine, IMP, and peptides are mainly responsible for the sensory quality of meat (Jayasena *et al*. 2013*b*). However, IMP is generally considered the major nucleotide in muscle that imparts flavour to meat (Jo *et al*. 2012). With the increasing carcass weight, IMP concentration in the studied carcasses increased whereas hypoxanthine concentration decreased (Table 3; $P < 0.05$). However, AMP and inosine concentrations did not differ among carcass weight groups ($P > 0.05$). IMP alone or when conjugated with monosodium glutamate has been identified to generate the 'umami' (savoury) taste (Kawai *et al*. 2002; Koutsidis *et al*. 2008). By conjugating certain amino acids and peptides, hypoxanthine may, however, add a bitter taste to meat (Tikk *et al*. 2006). The higher IMP and lower hypoxanthine concentrations of medium and heavy carcasses could lead to superior sensorial characteristics in these carcasses compared with light carcasses. Jung *et al*. (2013) recently explained that both high carcass weight and back fat thickness can reduce the rate of temperature decline in cattle carcasses (Park *et al*. 2007). High temperatures increased the degradation rate of nucleotides in meat (Vani *et al*. 2006) resulting in higher IMP concentrations in heavier carcasses with higher back fat thickness.

Histidyl dipeptides, creatine, and creatinine concentration

Histidyl dipeptides and creatine concentrations fluctuated as carcass weight increased (Table 3). By contrast, creatinine concentration increased ($P < 0.05$) with increasing carcass weight. Medium and heavy carcasses had significantly higher carnosine and creatinine concentration, respectively. Creatinine concentrations of the *longissimus* muscle from Angus cattle showed a positive correlation with carcass weight and back fat thickness (Liu 2011). Purchas *et al*. (2004) explained that the breakdown of creatine to creatinine was positively affected by temperature. Therefore, the significant difference in creatinine concentration among carcass weight groups might be affected by the rate of temperature decline of the carcasses as described above.

Histidyl dipeptides such as carnosine and anserine, and creatine are functional/bioactive components in meat (Purchas *et al*. 2004; Peiretti *et al*. 2012). Carnosine has a buffering role and significant antioxidant properties in tissues (Zhou and Decker 1999). Creatine and creatinine display sensory properties; creatine is a recommended additive to broth because it contributes to the full flavour of meat extracts (Mora *et al*. 2010). Carnosine concentration was quantified in raw and cooked beef by Park *et al*. (2005), who reported that both meats had much lower concentrations of carnosine – 124 and 134 mg/100 g beef, respectively – compared with those measured in the present study. Average carnosine and anserine concentrations of 1380 and 180 mg/100 g beef fillet, respectively, were detected by Peiretti *et al*. (2011). Peiretti *et al*. (2012) also found 1680–1720 mg of carnosine and 160–270 mg of anserine in 100 g of freeze-dried beef. The highest concentrations of creatine and creatinine were found in the skeletal and heart muscles, whereas very low levels occur in the liver of cattle (Wyss and Kaddurah-Daouk 2000). Furthermore, Purchas *et al*. (2004) reported lower creatine and creatinine concentrations – 401 and 5.82 mg/100 g, respectively – in beef compared with those in the present study.

Free amino acid content

In the present study, carcass weight showed no significant association with free amino acid contents except for aspartic acid, glutamic acid, and cysteine (Table 4). Light and medium

Table 3. Nucleotides, histidyl dipeptides, creatine and creatinine contents of *M. longissimus dorsi* of Hanwoo beef from different carcass weight groups
Results are given as least-square means with standard errors. AMP = adenosine-5′-phosphate. IMP = inosine-5′-phosphate. Means within a row followed by the same letter are not significantly different from each other ($P = 0.05$)

Item (mg/100 g	Carcass weight group			Regression parameters [x = carcass weight (kg)]			
of fresh sample)	Light (n = 74)	Medium (n = 76)	Heavy (n = 100)	Intercept	Slope	R^2	P-value (slope)
AMP	195.55 ± 6.97	194.74 ± 7.18	203.31 ± 6.44	146.193	0.1301 ± 0.0757	0.0118	0.09
IMP	228.37b ± 10.39	272.88a ± 14.08	286.12a ± 10.56	76.849	0.4689 ± 0.1297	0.0500	0.0004
Hypoxanthine	1098.12a ± 46.85	961.59b ± 48.52	850.50b ± 43.79	1676.996	–1.7928 ± 0.5167	0.0463	0.0006
Inosine	79.44 ± 1.96	81.11 ± 1.92	79.78 ± 1.42	75.503	0.0114 ± 0.0192	0.0014	0.55
Anserine	121.99 ± 5.64	128.44 ± 7.50	112.99 ± 4.86	158.629	–0.0954 ± 0.0661	0.0083	0.15
Carnosine	692.33b ± 17.94	745.73a ± 18.72	693.78b ± 13.96	755.910	–0.1165 ± 0.1862	0.0016	0.53
Creatine	1502.40 ± 14.70	1528.48 ± 17.12	1500.34 ± 13.99	1567.485	–0.1445 ± 0.1694	0.0029	0.39
Creatinine	16.43b ± 0.80	17.80b ± 0.86	21.22a ± 0.86	3.046	0.0392 ± 0.0095	0.0646	<0.0001

Table 4. Free amino acid content of *M. longissimus dorsi* of Hanwoo beef from different carcass weight groups
Results are given as least-square means with standard errors. Means within a row followed by the same letter are not significantly different from each other (P = 0.05)

Item (mg/100 g of fresh sample)	Carcass weight group			Regression parameters [x = carcass weight (kg)]			
	Light (n = 74)	Medium (n = 76)	Heavy (n = 100)	Intercept	Slope	R^2	P-value (slope)
Alanine	47.29 ± 1.57	47.51 ± 1.83	48.67 ± 1.59	43.704	0.0105 ± 0.0185	0.0013	0.57
Aspartic acid	2.60a ± 0.21	2.14ab ± 0.15	2.01c ± 0.15	4.353	–0.0053 ± 0.0019	0.0311	0.005
Glutamic acid	10.50b ± 0.78	11.58b ± 0.80	13.85a ± 0.74	1.533	0.0265 ± 0.0086	0.0368	0.002
Glycine	11.59 ± 0.49	11.58 ± 0.56	11.64 ± 0.46	11.650	–0.0001 ± 0.0056	0.0000	0.99
Serine	13.17 ± 0.66	13.24 ± 0.78	13.91 ± 0.68	11.656	0.0046 ± 0.0079	0.0014	0.56
Threonine	33.96 ± 1.47	36.99 ± 1.92	35.12 ± 1.50	34.554	0.0020 ± 0.0182	0.0000	0.91
Arginine	292.23 ± 8.34	308.85 ± 10.70	294.51 ± 7.93	323.266	–0.0625 ± 0.0996	0.0016	0.53
Cysteine	4.80b ± 0.34	5.86ab ± 0.44	6.55a ± 0.38	–0.436	0.0156 ± 0.0043	0.0500	0.0004
Histidine	109.81 ± 4.32	100.50 ± 4.20	105.02 ± 4.08	122.182	–0.0427 ± 0.0469	0.0033	0.36
Isoleucine	5.16 ± 0.32	5.93 ± 0.44	6.16 ± 0.36	2.876	0.0073 ± 0.0042	0.0118	0.09
Leucine	9.17 ± 0.52	10.30 ± 0.72	10.78 ± 0.61	5.444	0.0117 ± 0.0069	0.0114	0.09
Lysine	11.46 ± 0.57	12.38 ± 0.67	12.84 ± 0.59	7.239	0.0126 ± 0.0068	0.0137	0.06
Methionine	3.99 ± 0.27	4.61 ± 0.37	4.94 ± 0.32	1.740	0.0070 ± 0.0036	0.0152	0.05
Phenylalanine	5.48 ± 0.33	6.32 ± 0.46	6.70 ± 0.38	2.594	0.0090 ± 0.0044	0.0167	0.04
Proline	5.53 ± 0.19	5.53 ± 0.24	5.80 ± 0.23	5.011	0.0016 ± 0.0025	0.0015	0.54
Tyrosine	6.22 ± 0.34	6.85 ± 0.42	7.10 ± 0.36	4.391	0.0059 ± 0.0042	0.0080	0.16
Valine	7.56 ± 0.44	8.49 ± 0.59	8.87 ± 0.53	4.842	0.0088 ± 0.0059	0.0088	0.14

carcasses had significantly higher aspartic acid concentration compared with that in heavy carcasses, which had the highest (P < 0.05) glutamic acid concentration. Cysteine concentration was significantly greater in heavy and medium carcasses. A previous study reported that an increase in the slaughter age of Wagyu cattle decreased aspartic acid concentration (Watanabe *et al*. 2004). However, no significant effect of increasing age on glutamic acid concentration was observed by the same authors and this was opposite to our results. It can be expected that the slaughter age of Hanwoo steers of heavier carcass groups may be older than that of light carcass group in the present study. However, the total amount of free amino acids among the carcass weight groups did not differ (P > 0.05; data not shown). Furthermore, Watanabe *et al*. (2004) reported that alanine and glutamine were the main amino acids found in the meat from Wagyu cattle. Nevertheless, glutamine was not detected in Hanwoo beef during this study. The main free amino acids found in this study were arginine and histidine. The differences in the levels of amino acids between the Wagyu and Hanwoo beef might be attributed to breed effect (Field and Chang 1969), different experimental conditions used in the two studies such as slaughter age of cattle (Watanabe *et al*. 2004), feed regime, experimental methods used to determine the free amino acid contents.

Free amino acids and peptides are responsible for improving the taste, flavour, and aroma of meat during storage (Jo *et al*. 2012). Amino acids such as asparagine, threonine, serine, glutamic acid, glycine, and alanine are associated with a tasty (sweet) flavour, whereas valine, isoleucine, leucine, phenylalanine, methionine, arginine, histidine, and proline are associated with a bitter taste in meat (Sforza *et al*. 2001). Additionally, cysteine reacts with reducing sugars leading to characteristic meat flavour during cooking (Jayasena *et al*. 2013*a*) and the synergistic effect of inosinic acid and glutamic acid can results in 'umami' flavour in meat (Cho *et al*. 2007; Jo *et al*. 2012). Hence, the higher concentrations of glutamic acid and cysteine in medium and heavy carcasses might result in higher sensory quality compared with lighter carcasses.

Fatty acid composition

In general, Hanwoo beef has a fatty acid profile characteristic of high concentrate-fed animals. Alfaia *et al*. (2006) and Iwamoto *et al*. (2009) showed that feed regimen, genotype, duration of fattening, age, carcass weight and degree of fat deposition affect the fatty acid composition of beef fat. However, the effect of genotype and feed on fatty acid composition of IMF from LD muscles studied in the present study was restricted because Hanwoo steers were raised on the same commercial feed. Table 5 presents the relationship between fatty acid composition and carcass weight groups in Hanwoo cattle. Total saturated fatty acid (SFA) content and n-6 : n-3 ratio were significantly higher in light carcasses, whereas total USFA content, and total monounsaturated fatty acid (MUFA) content were significantly higher in medium and heavy carcasses. Similarly, Dashdorj *et al*. (2012) found an increase in MUFA and a decrease in SFA content as carcass weight increased. However, polyunsaturated fatty acid (PUFA) content did not differ among carcass groups studied (Table 5; P > 0.05). Oleic acid (C18 : 1) was the predominant fatty acid found in Hanwoo beef from the three carcass weight groups, followed by palmitic (C16 : 0) acid. This finding is comparable to those of Cho *et al*. (2005, 2007), and Dashdorj *et al*. (2012). Medium and heavy carcasses had higher oleic acid content (P < 0.05).

The compositions of lauric (C12 : 0), myristic (C14 : 0), pentadecycilic (C15 : 0), margaric acids (C17 : 0), and stearic acid (C18 : 0) were higher in light carcasses than medium and heavy carcasses (P < 0.05). In contrast, the MUFA composition of IMF fat was higher in medium and heavy carcasses

Table 5. Fatty acid composition of *M. longissimus dorsi* of Hanwoo beef from different carcass weight groups

Results are given as least-square means with standard errors. SFA = saturated fatty acids (sum of C10 : 0, C12 : 0, C14 : 0, C15 : 0, C17 : 0, C18 : 0, and C20 : 0). USFA = unsaturated fatty acids; (sum of MUFA and PUFA). MUFA = monounsaturated fatty acids (sum of C14 : 1, C16 : 1, C17 : 1, C18 : 1, C18 : 1_{11t}, C20 : 1, and C24 : 1). PUFA = polyunsaturated fatty acids (sum of C18 : 2, C18 : 2_{9c11t}, C18 : 2_{10t12c}, C18 : 3, C20 : 2, C20 : 3, and C20 : 4). n-6 : n-3 = (sum of C18 : 2, C20 : 2, and C20 : 4) : (sum of C18 : 3 and C20 : 3). Means within a row followed by the same letter are not significantly different from each other (P = 0.05)

Item (%)	Carcass weight group			Regression parameters [x = carcass weight (kg)]			
	Light (n = 74)	Medium (n = 76)	Heavy (n = 100)	Intercept	Slope	R^2	P-value (slope)
C10 : 0	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.050	-2.29×10^{-5} ± 0.0000	0.0118	0.09
C12 : 0	0.09a ± 0.00	0.09a ± 0.00	0.08b ± 0.00	0.139	–0.0001 ± 0.0000	0.0477	0.0005
C14 : 0	2.88a ± 0.07	2.68b ± 0.06	2.63b ± 0.05	3.582	–0.0022 ± 0.0007	0.0377	0.002
C14 : 1	0.81 ± 0.03	0.81 ± 0.03	0.82 ± 0.03	0.759	0.0001 ± 0.0004	0.0007	0.68
C15 : 0	0.28a ± 0.02	0.23b ± 0.01	0.22b ± 0.01	0.457	–0.0005 ± 0.0001	0.0790	<0.0001
C16 : 0	24.83 ± 0.25	24.50 ± 0.23	24.71 ± 0.19	25.192	–0.0013 ± 0.0024	0.0011	0.60
C16 : 1	3.99 ± 0.16	4.16 ± 0.11	4.03 ± 0.14	3.813	0.0006 ± 0.0016	0.0006	0.70
C17 : 0	0.73a ± 0.02	0.60b ± 0.01	0.61b ± 0.01	1.090	–0.0011 ± 0.0002	0.1273	<0.0001
C17 : 1	0.78a ± 0.03	0.68b ± 0.01	0.70b ± 0.02	1.048	–0.0008 ± 0.0002	0.0539	0.0002
C18 : 0	11.75a ± 0.29	11.03b ± 0.24	11.01b ± 0.18	13.942	–0.0067 ± 0.0026	0.0267	0.01
C18 : 1	45.99b ± 0.30	47.52a ± 0.40	47.48a ± 0.29	41.693	0.0133 ± 0.0037	0.0505	0.0003
C18 : 1_{11t}	2.15 ± 0.09	2.24 ± 0.07	2.36 ± 0.09	1.470	0.0020 ± 0.0010	0.0164	0.04
C18 : 2 (n-6)	3.33 ± 0.13	3.21 ± 0.15	3.11 ± 0.11	4.038	–0.0021 ± 0.0014	0.0085	0.15
C18 : 2_{9c11t}	0.39 ± 0.03	0.35 ± 0.01	0.36 ± 0.01	0.414	–0.0001 ± 0.0002	0.0020	0.49
C18 : 2_{10t12c}	0.02 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.003	0.0001 ± 0.0000	0.0145	0.06
C18 : 3 (n-3)	0.11 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	0.145	–0.0001 ± 0.0001	0.0038	0.33
C20 : 0	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.053	3.59×10^{-6} ± 0.0000	0.0001	0.89
C20 : 1	0.32 ± 0.01	0.35 ± 0.01	0.35 ± 0.01	0.221	0.0003 ± 0.0001	0.0195	0.03
C20 : 2 (n-6)	0.23a ± 0.04	0.12b ± 0.02	0.13b ± 0.02	0.442	–0.0007 ± 0.0003	0.0172	0.04
C20 : 3 (n-3)	0.33 ± 0.01	0.34 ± 0.02	0.33 ± 0.01	0.345	-2.32×10^{-5} ± 0.0002	0.0001	0.89
C20 : 4 (n-6)	0.70 ± 0.04	0.67 ± 0.05	0.66 ± 0.04	0.859	-0.0005 ± 0.0005	0.0041	0.31
C24 : 1	0.19 ± 0.01	0.19 ± 0.01	0.17 ± 0.01	0.247	–0.0002 ± 0.0001	0.0121	0.08
SFA	40.67a ± 0.39	39.23b ± 0.40	39.36b ± 0.29	44.504	–0.0120 ± 0.0039	0.0359	0.003
USFA	59.33b ± 0.39	60.77a ± 0.40	60.64a ± 0.29	55.496	0.0120 ± 0.0039	0.0359	0.003
MUFA	54.22b ± 0.37	55.95a ± 0.42	55.92a ± 0.29	49.251	0.0154 ± 0.0039	0.0587	0.0001
PUFA	5.11 ± 0.17	4.83 ± 0.20	4.72 ± 0.15	6.245	–0.0034 ± 0.0019	0.0127	0.08
PUFA : SFA	0.13 ± 0.00	0.12 ± 0.01	0.12 ± 0.00	0.145	–0.0001 ± 0.0001	0.0038	0.33
n-6 : n-3	9.81a ± 0.40	8.89b ± 0.20	9.02b ± 0.19	11.550	–0.0058 ± 0.0030	0.0152	0.05

compared with light carcasses as a result of higher contents of oleic (C18 : 1) and eicosenoic (C20 : 1) acids in former carcasses (P < 0.05). Oleic acid and stearic acid had positive and negative correlations with the fat thickness, respectively (Xie *et al.* 1996). In addition, Chung *et al.* (2007) and Iwamoto *et al.* (2009) explained that an increased activity of stearoyl-CoA desaturase could be observed with an increase in the fattening period, which converted SFA to their respective MUFA. Hence, these results can be attributed to higher fat thickness of medium and heavy carcasses compared with light carcasses, which could have been primarily due to the prolongation of the fattening period. The fatty acid composition of beef has a significant relationship to palatability for Korean consumers, which may indicate their preferences (Cho *et al.* 2005). A vital relationship exists between fatty acid composition and flavour in beef. In particular, the oleic acid content present in IMF in LD muscles has a positive correlation with cooked beef fat flavour (Okumura *et al.* 2007). Furthermore, flavour scores were inversely related to total SFA and positively associated with total USFA, mainly owing to high levels of oleic acid. Hence, the fatty acid composition of medium and heavy carcasses may improve the sensory quality of LD muscles from those carcasses.

Although no differences (P > 0.05) in α-linolenic, linoleic, eicosatrienoic (C20 : 3, n-6), or arachidonic (C20 : 4, n-6) acid contents were found among the LD muscles of carcass groups studied, n-6 : n-3 ratio was higher (P < 0.05) in LD muscles of light carcasses and lower in those of medium and heavy carcasses mainly due to higher eicosadienoic acid (C20 : 2) content in the particular muscles of former carcasses. An n-6 : n-3 ratio closer to the present results was detected in Australian Angus beef (7.60) by Cho *et al.* (2005). In addition, similar PUFA : SFA ratios were found in Aberdeen Angus (0.15) and Hereford (0.14) bulls (Bureš *et al.* 2006). PUFA : SFA ratio has been used as a dietary lipid quality indicator, and the British Department of Health recommends a ratio between 0.4 and 0.5 (Silva *et al.* 2013). In addition, Enser (2001) reported that n-6 : n-3 ratio is related to risk of coronary heart disease. Although much lower values were reported for PUFA : SFA ratio in this study, medium and heavy carcasses of Hanwoo had better fatty acid compositions, with higher USFA content and lower SFA content and n-6 : n-3 ratio. However, in contrast to the findings of Cho *et al.* (2005) and Bureš *et al.* (2006) and similar to that of Dashdorj *et al.* (2012), PUFA such as eicosapentaenoic, docosapentaenoic, and docosahexaenoic acids were not detected in the beef samples during the present study.

Table 6. Sensory characteristics of *M. longissimus dorsi* of Hanwoo beef from different carcass weight groups
Results are given as least-square means with standard errors. Means within a row followed by the same letter are not significantly different from each other (P = 0.05)

Item	Carcass weight group			Regression parameters [x = carcass weight (kg)]			
	Light (n = 74)	Medium (n = 76)	Heavy (n = 100)	Intercept	Slope	R^2	P-value (slope)
Colour[A]	5.19 ± 0.11	5.07 ± 0.10	5.32 ± 0.08	4.888	0.0008 ± 0.0011	0.0022	0.46
Odour[A]	5.18 ± 0.46	4.93 ± 0.13	5.15 ± 0.10	5.592	–0.0012 ± 0.0029	0.0008	0.66
Tenderness[B]	4.55b ± 0.17	5.04a ± 0.17	5.27a ± 0.12	2.762	0.0055 ± 0.0017	0.0432	0.0009
Juiciness[C]	4.63b ± 0.17	5.16a ± 0.15	5.42a ± 0.12	2.856	0.0056 ± 0.0016	0.0482	0.0005
Overall acceptance[A]	4.50b ± 0.16	5.07a ± 0.16	5.18a ± 0.12	2.772	0.0054 ± 0.0016	0.0446	0.0008

[A]1 = profoundly dislike, 9 = profoundly like.
[B]1 = extremely tough, 9 = extremely tender.
[C]1 = dry, 9 = juicy.

Sensory characteristics

Table 6 shows the results of the sensory evaluation of Hanwoo beef from the carcass weight groups. Colour and odour did not differ (P > 0.05), but significant differences were found for tenderness, juiciness, and overall acceptance (P < 0.05). Similarly, sensory qualities including tenderness and juiciness increased as carcass weight increased in previous studies of Hanwoo beef (Kim and Lee 2003; Dashdorj *et al*. 2012). Significantly higher tenderness and juiciness scores in medium and heavy carcasses can be attributed to higher IMF content (marbling score) in these carcasses. Many authors have proven that tenderness and juiciness are positively related to IMF content (marbling score) in beef (Li *et al*. 2006; Hocquette *et al*. 2010). Okumura *et al*. (2007) also showed that juiciness and overall acceptability scores were higher (P < 0.05) in muscles with higher IMF content. Joo and Kim (2011) explained that marbling improves juiciness by lubricating muscle bundles and enhances tenderness by disorganising the structure of intramuscular connective tissue owing to the separation of perimysial collagen fibres. The dilution of a more dense muscle matrix with less dense fat can also improve tenderness (Jo *et al*. 2012).

Overall acceptance is the sum of all sensory parameters. Cho *et al*. (2010) found that Korean consumers determined their overall acceptability of Hanwoo beef in the following proportions: weights of tenderness, 55%; juiciness, 18%; and flavour-likeness, 27%. Therefore, the higher overall acceptability scores of beef from medium and heavy carcasses might be associated with the synergistic effect of their higher (P < 0.05) tenderness and juiciness scores (see Table 6). In addition, higher IMF content (marbling) plays a vital role in determining overall acceptance (Okumura *et al*. 2007). Several other researchers reported that marbling was positively correlated with palatability (Li *et al*. 2006; Okumura *et al*. 2007). As mentioned earlier, increased palatability may have resulted from the higher oleic acid and USFA contents and lower SFA contents in Hanwoo beef. These findings are highly comparable to our data: medium and heavy carcasses with higher oleic acid and USFA and lower SFA had higher overall acceptance scores compared with those of light carcasses (P < 0.05).

Considering all chemical, physical, and sensory characteristics examined in the present study, medium and heavy carcasses of Hanwoo beef were better quality carcasses compared with light carcasses. This finding agrees well with those of Park *et al*. (2002), who showed a positive link between carcass weight and better quality grade of Hanwoo meat. A better USDA quality grade can also reportedly be achieved with higher carcass weight (Lorenzen *et al*. 1993; Moon *et al*. 2003). Regarding the fat content of carcass, several researchers have found that better quality grade is related to fatter carcasses in dairy cattle and *Bos indicus* breeds (Moon *et al*. 2003). In this study, medium and heavy carcasses contained higher fat contents as well. However, the medium (375–425 kg) carcass weight can be considered optimal in Hanwoo for achieving superior beef quality along with economic and health benefits because no differences in fat content, colour, shear force value, sensory scores, IMP concentration, USFA content, and n-6 : n-3 ratio occurred between the medium and heavy carcass groups, but the former reduces the feeding period, and thereby, feed costs.

Conclusions

Carcass weight was significantly associated with the quality and functional properties of Hanwoo beef. In particular, IMP and carnosine concentrations, and USFA content increased, whereas shear force, SFA content, and n-6 : n-3 ratio decreased with increasing carcass weight. However, both marbling score and IMF content showed wide variability in each parameter beyond the carcass weight of 375 kg, so that with only little increases in each average value. Considering all parameters examined in the present study, the medium (375–425 kg) carcass weight of Hanwoo appears optimal for sensory and health benefits while minimising the economic disadvantages of growing cattle to heavier weights.

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