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ARTICLE

Effect of Quality Grade and Storage Time on the Palatability, Physicochemical and Microbial Quality of Hanwoo Striploin Beef

Dong-Gyun Yim[1], Yu-Jin Kim, and Ku-Young Chung*

Department of Animal Science and Biotechnology, Sangji University, Wonju 220-702, Korea
[1]Department of Health Administration and Food Hygiene, Jinju Health College, Jinju 660-757, Korea

Abstract

The effects of quality grade and storage time on physicochemical, sensory properties and microbial population of Hanwoo striploin beef were investigated. After a total of 30 Hanwoo beef were slaughtered, the cold carcasses were graded by official meat grader at 24 h postmortem. The carcasses were categorized into five groups (quality grade 1++, 1+, 1, 2, and 3) and were vacuum-packaged and stored. The samples were kept for 1, 4, 6, 8, 11, 13, 15, 18, 20, 22 and 25 d for analyses. As the quality grade was increased, moisture, protein and ash contents decreased ($p<0.05$). Higher quality grade corresponded with higher fat contents. The shear force values decreased with increasing quality grade and showed decreases sharply during the first 4 d ($p<0.05$). pH, water holding capacity, cooking loss, and volatile basic nitrogen for grade 1++ groups were lower than for grade 3 ($p<0.05$). CIE L* and b* values increased as increased quality grade ($p<0.05$). Meat color decreased until 13 d and fluctuated after 15 d of storage ($p<0.05$). Regarding the sensory scores, higher quality grade corresponded with higher juiciness, tenderness, flavor, fatty and palatability scores ($p<0.05$). Generally, increased storage time for 15 d improved sensory scores attributes. Results indicate that a high quality grade could positively influence physicochemical and sensory properties.

Keywords: quality grade, Hanwoo, physicochemical trait, sensory scores, microbial population

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Introduction

The Korean native cattle, Hanwoo, is a hybrid of Bos Taurus×Bos zebu. Korean consumers demand high quality grade of beef and they prefer Hanwoo beef to imported beef because they believe sensory properties, such as juiciness and flavor, and Hanwoo beef is better than that of imported beef (Hwang *et al*., 2010). Therefore, Hanwoo beef regards as the most expensive and high quality meat in Korea (Kim and Lee, 2003). Presently, the prime Hanwoo striploin received a more than 40 US dollars premium per kilogram compared to top round received 20 dollars for an average quality.

Beef quality is primarily determined by the marbling score and consequently breeders and producers have forced on improving of marbling (Park *et al*., 2002). In Korean beef industry, marbling is a prime factor to Hanwoo beef palatability, as consumer judge meat quality on the basis of the degree of marbling, and they are willing to pay premium for highly marbled meat (Savell *et al*., 1986). Better quality grades have a heavier carcass weight with a higher marbling score, redder meat colour and whiter fat colour (Moon *et al.,* 2006). Korean beef carcass grading specification has been introduced to be evaluated by beef quality since 1992. The beef carcasses are graded by Korea Institute for Animal Products Quality Evaluation (KAPE) both in meat quality and quantity terms before distribution in accordance with the Livestock Production Act (KAPE report, 2013). The quality grade has five possible values (1++, 1+, 1, 2, and 3), and the yield grade (YG) has three possible values (A, B, C) for the evaluation of beef quality in Korean beef carcass grade system (KAPE, 2013). The quality of beef carcasses is graded into “Grade 1++”, “Grade 1+”, “Grade 1”, “Grade 2” and “Grade 3”. Quality grade in beef carcass is mainly determined by the marbling score and additionally determined by color of lean meat and fat, texture and firmness of lean meat, and maturity of the exposed *longissimus dorsi* (LD) muscle at the 13th rib interface (Moon *et al*., 2006; NLCF, 1998). A marbling score of Beef Marbling Standard (BMS; 1=devoid, 9=very abundant) No. 8 or 9 is the marbling

*Corresponding author: Ku-Young Chung, Department of Animal Science and Biotechnology, Sangji University, Wonju 220-702, Korea. Tel: +82-33-730-0534, Fax: +82-33-744-6118, E-mail: kychung@sangji.ac.kr

degree for grade 1++; 6 or 7 is the marbling degree for grade 1+; 4 or 5 is the marbling degree for grade 1; 2 or 3 is the marbling degree for grade 2; and 1 is the marbling degree for grade 3. A quality grade 1++ is the highest or most desirable grade and grade 3 indicates the lowest degree of quality (Kim and Lee, 2003). While Korean consumers preferred the high quality graded beef, there is few data on the effect of storage time and marbling score on the palatability, physicochemical and microbial quality of Hanwoo beef according to Korean carcass quality grade system. Therefore, the aim of this research was to investigate the effect of quality grade (which reflects relative marbling) on the physicochemical, and microbial traits of M. *longissimus lumborum* (striploin) of Hanwoo beef during storage.

Materials and Methods

Sample preparation

A total of 30 Hanwoo (28 to 30 mon old) were randomly selected from a local cattle farm, South Korea, slaughtered without electrical stimulation, and then immediately cooled at 0°C for 24 h in a chilling room. The carcass weight was ranged 213 to 477 kg (average 409 kg). The cold carcasses were graded by official meat grader at 24 h postmortem with the loin surface according to the Korean carcass grading procedure (NLCF, 1998). Based on their Korean quality grade, five quality grade groups of carcasses were classified: grade 1++, grade 1+, grade 1, grade 2 and grade 3. Immediately after grading, striploin (M. *longissimus lumborum*) ribbed between the 13^{th} rib and the 1^{st} lumbar vertebrae were removed. After 24 h of chilling the carcasses, the samples were transported 1 h to laboratory at university in fresh state at 5±1°C, South Korea. Immediately on arrival the samples were removed from vacuum packages. All subcutaneous fat and visible connective tissue of muscles were trimmed and revacuum packaged using vacuum package system (TAEVAC, 600L, Korea). Packaged samples were stored in refrigerator (CAH17DZ, LG, Korea) in which temperatures were controlled within 1±1°C of designated storage temperature. The samples from each treatment were kept for 1, 4, 6, 8, 11, 13, 15, 18, 20, 22 and 25 d and examined for physicochemical, sensory evaluation and microbiological analyses.

Proximate composition

Immediately before keeping in a chilling room at 1±1°C, samples from each treatment were analyzed for proximate composition. All determinations were carried out on the homogenized samples, in triplicate. Moisture, fat, protein and ash were determined on samples using with a slightly modified method of AOAC (2000).

Physicochemical analyses

The pH of samples was determined with a pH meter (PHM201, Radiometer, France). The pH values of samples were measured by blending a 10 g sample with 90 mL distilled water for 1 min in a homogenizer (Ultra-turrax, T25-S1, Germany). Color measurements were taken using a Minolta chromameter (CR-410, Minolta Co. Ltd., Japan). CIE L*, a* and b* values were determined with measurements standardized with respect to a white calibration plate (L*=94.4, a*=0.313, b*=0.319) after 30 min blooming at room temperature. Color measurements for each of three replicates, always trying to avoid area with excess fat were taken and the value was recorded. WHC was conducted by a modification of the procedure of Grau and Hamm (1953). Briefly, a 300 mg sample of muscle was placed in a filter-press device and compressed for 2 min. WHC was calculated from duplicate samples as a ratio of the meat film area to the total area; hence, a larger value suggests a higher WHC. WHC (%) was calculated as follows: WHC (%) = 100 − (total meat area / meat film area × 100). For cooking loss, after the samples were thawed at 4°C overnight before analyses and sliced with a thickness of 2 cm. The samples were weighed and cooked in an electric grill (EMG-533, AIJIA electric appliance, China) until they reached a final internal temperature of 70°C. Cooking loss was determined by the ratio of the difference between raw weight and final cooked weight as follows: Cooking loss (%) = 100 × (raw weight − final cooked weight) / raw weight.

Shear force values were measured by the method described by the procedure of Bourne (1978). The samples were prepared a cubic form (30 × 30 × 20 mm) and six cores of 1.27 cm in diameter were drilled parallel to the muscle fiber from each sample. Each core was sheared once with a Warner-Bratzler shear attachment using a texture analyzer (TA-XT2, Stable Micro System Ltd., U.K.). The maximum shear force value (kg) was recorded for each sample. Test and post-test speeds were set at 1.0 mm/s. The TBARS of samples were analyzed by the modification method described by the procedure of Witte (1970). Readings were made on a spectrophotometer (X-MA 3000, Human Ltd., Korea) at 530 nm. A micro-diffusion method described by Conway (1950) was modified for the determination of VBN values in samples. Each sample (10 g) was homogenized (Ultra-turrax, T25-S1, IKA, Germany) for 1 min with 90 ml of distilled water. The supernatant solution was filtered using a filter paper (No. 4, Whatman). A 0.01 N of boric acid was placed in the inner section of a Conway micro-diffusion cell (Sibata Ltd., Japan). A 1 mL sample solution and 1 mL of saturated K_2CO_3 were also placed into the outer section of the same cell, and the lid was immediately closed. The cell was incubated at 25°C for 60 min, and it was then titrated against 0.02 N H_2SO_4. The VBN value was reported as mg%.

Microbiological analysis

Ten grams of samples from each treatment was also weighed and then homogenized with 90 mL distilled water using a stomacher (STOMACHER® 400 CIRCULATOR, Seward, Ltd., UK) for 2 min. Total aerobic plate counts were analyzed according to the Standards for Processing and Ingredients Specifications of Livestock Products, Animal, Plant and Fisheries Quarantine and Inspection Agency Notification (QIA, 2014). Homogenized microbial extracts were serially diluted with distilled water by 10-fold. Portions of the samples (0.1 mL) were plated separately on each plate and spread thoroughly. TACs were enumerated on plate count agar (DifcoTM, Laboratories, USA) and colonies were counted after incubation at 35±1°C for 48 h. *Pseudomonas* spp. were assessed by spread technique on *Pseudomonas* Agar (DifcoTM, Laboratories, USA), incubation at 30±1°C for 48 h. All analyses were performed in duplicate, and results expressed as logarithm colony-forming units per gram of samples (Log CFU/g).

Sensory evaluations

Each steak was cooked on pre-heated grilling units (Tefal, TG-60051, France) at approximately 150°C to an internal temperature of 35°C, turned, and removed when they reached 70°C internally. Temperature was monitored with a digital thermometer (Testo-925, Germany) placed in the geometric center of the steak. Steaks were wrapped in aluminum foil and placed in a preheated oven (65°C) until served to panelists. After cooking, steaks were cooled for 2 min and were cut into 20 × 10 × 10 mm thickness. All cooked steaks were evaluated by 10 panelists for random cubes of each sample using an eight-point hedonic scale descriptive method. Samples were rated on numerical scale ranging from 1 to 8 for juiciness (1 = extremely dry, 8 = extremely juicy), tenderness (1 = extremely tough, 8 = extremely tender), flavour intensity (1 = extremely bland, 8 = extremely intense), fatty (1 = none, 8 = abundant), and overall acceptability (1 = extremely unacceptable, 8 = extremely acceptable). Each panel member was supplied natural water to rinse in mouth.

Statistical methods

Two-way analysis of variance was performed on all the variables measured using the General Linear Model (GLM) procedure of the SAS statistical package (SAS Inst., 2002). The Duncan's multiple range test ($p<0.05$) was used to determine differences among the treatment means. The mean values and the standard errors of the means (SEM) were reported.

Results and Discussion

Proximate composition

The proximate composition of M. *longissimus lumborum* (striploin) from five different quality grades is compared in Table 1. The differences among the quality grades on proximate composition were significant ($p<0.05$). Moisture, protein and ash contents significantly decreased with increasing quality grade from grade 3 to grade 1++ ($p<0.05$). Grade 1++ muscles had the highest fat contents (26.01%), followed by grade 1+ (19.00%), 1 (15.25%), 2 (11.47%), and 3 (6.05%) which is understandable because the most predominating parameter to determine the quality grade is intramuscular fat content (marbling) in Korean beef carcass grade system (KAPE, 2013). The relationship between quality grade and the protein content of beef cuts has been well documented in previous studies, with the protein content of beef cuts decreasing as quality grade

Table 1. Proximate composition of M. *longissimus lumborum* of Hanwoo beef from different quality grades

Quality grade	Moisture (%)	Fat (%)	Protein (%)	Ash (%)
1++	55.00±4.19^{d}	26.01±4.18^{a}	17.71±0.48^{d}	0.76±0.08^{c}
1+	60.57±2.63^{c}	19.00±3.72^{b}	19.48±0.47^{c}	0.85±0.09^{b}
1	63.44±0.64^{b}	15.25±1.30^{c}	19.33±0.38^{c}	0.87±0.05^{b}
2	65.38±1.58^{b}	11.47±3.66^{d}	20.46±0.64^{b}	0.98±0.05^{a}
3	71.29±1.58^{a}	6.05±1.18^{e}	21.29±0.63^{a}	0.99±0.02^{a}

Values are Mean±SE (n=6)

$^{a-e}$Figures with different letters within a same column differ significantly ($p<0.05$).

(intramuscular fat) increases (Smith *et al*., 2011). Moon *et al*. (2006) demonstrated that crude fat content was closely related to marbling score and fat contents were higher in high marbling group. Similar finding was reported by Kim *et al*. (2008), who found that fat contents in Hanwoo loin muscles were higher in high quality grade group. On the other hand, grade 3 contained the highest moisture (71.29%) and crude protein (21.29%) and crude ash (0.99%) ($p<0.05$). Generally, intramuscular fat and moisture in bovine muscles are inversely related (Kim and Lee, 2003; Savell *et al.,* 1986). This result agreed to the previous studies (Cho *et al*., 2010; Lee *et al*., 2010) reported that moisture and protein contents in Hanwoo significantly decreased with increasing quality grade, whereas the fat content increased. This is also confirmed an earlier report by Luchak *et al.* (1998) who mentioned the higher marbling scores in US beef, the more fat and less moisture and ash content.

Physicochemical traits

Changes of physicochemical traits of M. *longissimus lumborum* (striploin) from different quality grades during storage were shown in Table 2. The pH values of muscles were different in all quality groups (all mean values were 5.23 and 5.47 during storage), and generally pH value of the grade 3 muscles was the highest ($p<0.05$). Previous studies (Cho *et al*., 2010; Kim and Lee, 2003; Kim *et al.,* 2008) showed that pH values among the quality grade groups from Hanwoo muscles were not statistically different. The pH values of samples fluctuated slightly during the 25 d and showed higher at 13 d compared to other storage periods ($p<0.05$). A similar trend has been reported by previous studies (Aksu *et al*., 2005; Kim *et al*., 2007). Proteolysis may have produced nitrogenous compounds which may have caused increase in the pH values (Aksu *et al*., 2005).

As shown in Table 2, WHC of the grade 3 muscles was significantly higher than those of other grades ($p<0.05$). Many studies (Cho *et al*., 2010; Kim and Lee, 2003; Lee *et al.,* 2010) indicated that WHC among the quality grade groups did not differ. WHC showed higher during the 8 to 11 d of storage compared to other storage periods ($p<0.05$). Low WHC could be explained by exhibiting moisture release due to excessive protein denaturation (Barbut, 2010). The cooking loss of samples were only higher in grade 3 than in other quality grades ($p<0.05$), but storage had no effect on cooking loss ($p>0.05$). Ozawa *et al*. (2000) reported that cooking loss of Japanese black steer meat was significantly lower for samples with the highest marbling score. This is also demonstrated by the findings that the high marbling score had lower cooking loss (Moon *et al*., 2006). Previous reports have indicated that beef grades did not differ in cooking losses (Cho *et al*., 2010; Kim and Lee, 2003; Kim *et al.,* 2008). The cooking loss is a combination of liquid and soluble matters lost from the meat and the water is lost due to heat induced protein denaturation during cooking of the meat, which causes less water to be entrapped within the protein structures (Aaslying *et al*., 2003).

The shear force values significantly decreased with increasing quality grade from grade 3 to grade 1++ ($p<0.05$). Grade 3 muscles had the highest shear force values. The higher intramuscular fat in grade 1++ could be a crucial factor for the lower shear force values. This is in agreement with previous studies (Cho *et al.,* 2010; Kim *et al.,* 2008; Moon *et al*., 2006) have indicated shear force values of LD muscles were lower for the high quality grade group compared with low ones. Shear force values were negatively related to intramuscular fat content in numerous studies (Fiems *et al*., 2000; Park *et al*., 2000). Wulf and Page (2000) also reported that fat content of beef muscle had a correlation with shear force values. The shear force values of samples showed initial rapid decreases during the first 4 d, with subsequent slowly decreasing or steady. A sharp decrease response could be expected if the myofibrillar component underwent structural disruption with increasing time (Kim and Lee, 2003). Kim *et al*. (2007) mentioned shear force values of LD muscles decreased with ageing time.

Total VBN concentration is an important indicator for estimation of meat freshness, because it is increased by the levels of microbial contamination (Lee and Joo, 1999). The VBN values of grade 1++ sample was significantly lower than that of grade 3 ($p<0.05$). The VBN contents in all grades significantly increased throughout storage from 1 to 25 d ($p<0.05$). However, it remained up to 25 d at values less than 20 mg/%, considered as serious spoilage. The higher VBN of meat is explained by bacterial activity and accelerated enzymatic degradation of protein (Egan *et al*., 1981).

As shown in Table 2, TBARS values of grade 3 sample had lower than that of grade 1++ and 1+ throughout storage from 1 to 25 d ($p<0.05$). This could be explained by differences in lipid stability as the result of higher fat content in high quality grade groups (1++ and 1+). The TBARS values of samples continuously increased during storage ($p<0.05$). In day 4 and 6, TBARS values of grade 1 sample showed higher compared to other grades ($p<$

Table 2. Changes of physicochemical traits of M. *longissimus lumborum* from different quality grades during storage

	Quality grade	Days											SEM[a]
		1	4	6	8	11	13	15	18	20	22	25	
pH	1++	5.30^{Db}	5.24^{Ec}	5.27^{DEb}	5.39^{ABbc}	5.40$^{AB b}$	5.37^{BCd}	5.34^{Cb}	5.41^{Ab}	5.40^{ABb}	5.37^{BCb}	5.33^{Cb}	0.01
	1+	5.27^{Ec}	5.23^{Fc}	5.36^{Ca}	5.40^{Aab}	5.37^{Cb}	5.41^{Ac}	5.41^{Aa}	5.40^{Ab}	5.31^{Dd}	5.38^{Bab}	5.41^{Aa}	0.01
	1	5.30^{Fb}	5.26^{Gb}	5.27^{Gb}	5.37^{Dc}	5.39^{Cab}	5.42^{Abc}	5.34^{Eb}	5.40^{BCb}	5.41^{Bb}	5.34^{Ec}	5.40^{BCa}	0.01
	2	5.37^{Ca}	5.27^{Eb}	5.37^{Ca}	5.37^{Cc}	5.36^{Cc}	5.43^{Ab}	5.41^{Ba}	5.40^{Bb}	5.33^{Dc}	5.38^{Cab}	5.33^{Db}	0.01
	3	5.37^{Da}	5.29^{Fa}	5.36^{Ea}	5.42^{BCa}	5.42^{BCa}	5.47^{Aa}	5.42^{BCa}	5.43^{Ba}	5.47^{Aa}	5.40^{BCa}	5.41^{Ca}	0.01
	SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
WHC (%)	1++	54.19^{Bab}	50.04^{DEc}	53.47^{BCb}	59.29^{Ab}	58.1^{Ab}	50.91^{CDEc}	49.47^{Ec}	48.86^{Ec}	49.42^{Ec}	51.4^{Cb}	54.09^{Bb}	2.53
	1+	52.59^{BCb}	54.04^{Bb}	57.39^{Aa}	59.43^{Ab}	59.72^{Aa}	50.41^{Cc}	51.46^{BCbc}	50.9^{BCbc}	57.17^{Aa}	53.95^{Bb}	53.74^{Bb}	2.98
	1	52.54^{CDb}	50.26^{DEc}	53.52^{Cb}	56.99^{Bbc}	60.41^{Aa}	53.97^{Cb}	52.67^{CDb}	51.02^{Dab}	49.84^{Ec}	51.76^{CDEb}	50.76^{DEc}	1.63
	2	54.18^{Bab}	53.91^{Bb}	53.87^{Bb}	54.30^{Bc}	57.72^{Ab}	53.71^{Bb}	49.26^{Cd}	52.81^{Bb}	53.81^{Bb}	47.51^{Cc}	53.00^{Bbc}	1.77
	3	57.10^{CDa}	60.08^{Ba}	59.21^{BCa}	64.77^{Aa}	59.29^{BCa}	60.42^{Ba}	55.44^{Da}	59.76^{BCa}	56.07^{Dab}	58.89^{BCa}	57.66^{BCDa}	2.19
	SEM	2.49	1.13	3.17	2.93	2.31	2.23	1.58	1.51	2.64	1.97	2.45	
Cooking loss (%)	1++	20.90^{b}	21.20^{b}	21.20^{b}	21.50^{b}	21.20^{b}	21.20^{b}	21.20^{b}	21.60^{b}	21.50^{b}	21.20^{b}	21.20^{b}	0.01
	1+	21.00^{b}	20.30^{b}	20.30^{b}	21.30^{b}	21.90^{b}	21.70^{b}	20.30^{b}	20.70^{b}	20.30^{b}	22.30^{b}	22.70^{b}	0.01
	1	21.20^{b}	20.20^{b}	20.20^{b}	20.20^{b}	21.30^{b}	20.20^{b}	20.20^{b}	21.30^{b}	20.20^{b}	22.20^{b}	22.50^{b}	0.01
	2	21.50^{b}	21.50^{b}	21.50^{b}	21.70^{b}	21.10^{b}	21.80^{b}	21.50^{b}	21.10^{b}	21.30^{b}	21.50^{b}	22.10^{b}	0.01
	3	23.70^{a}	23.10^{a}	23.20^{a}	23.00^{a}	23.50^{a}	23.40^{a}	23.10^{a}	23.60^{a}	23.20^{a}	23.10^{a}	23.90^{a}	0.01
	SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Shear force (kg)	1++	21.79^{Ae}	3.43^{De}	4.66^{Ce}	6.47^{Bc}	4.35^{Ce}	3.78^{De}	3.59^{Dd}	3.60^{Dd}	3.98^{Dd}	2.93^{Ee}	3.95^{Dd}	0.01
	1+	22.15^{Ad}	5.24^{Cd}	6.25^{Bd}	6.12^{Bd}	4.78^{Dd}	4.88^{Dd}	4.87^{Dc}	4.77^{Dc}	4.39^{Dc}	4.48^{Dd}	4.61^{Db}	0.02
	1	26.07^{Ab}	5.26^{Dc}	6.70^{Bc}	6.14^{Cd}	5.34^{Dc}	5.55^{Dc}	4.90^{Ec}	4.68^{Fc}	4.39^{Hc}	5.19^{Dc}	4.37^{Gc}	0.01
	2	24.65^{Ac}	5.89^{Db}	7.00^{Bb}	7.32^{Bb}	5.99^{Db}	6.12^{Cb}	5.59^{Db}	5.14^{Eb}	5.23^{Db}	5.68^{Db}	4.69^{Fb}	0.01
	3	29.47^{Aa}	7.89^{Ca}	9.68^{Ba}	9.59^{Ba}	6.65^{Da}	6.88^{Da}	6.10^{Da}	5.43^{Ea}	5.92^{Ea}	6.38^{Da}	6.76^{Da}	0.01
	SEM	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
VBN (mg/kg)	1++	6.58^{Gb}	6.63^{Gc}	6.80^{FGb}	6.39^{Gc}	7.08^{EFb}	7.48^{DEc}	9.04^{Cb}	7.69^{Db}	8.68^{Cc}	10.58^{Bb}	11.31^{Ab}	0.06
	1+	8.18^{Ca}	7.38^{Db}	7.58^{Da}	7.62^{Db}	7.52^{Db}	7.74^{Dbc}	8.34^{Cc}	8.23^{Cb}	9.40^{Bb}	11.77^{Aa}	11.82^{Ab}	0.06
	1	8.17^{DEa}	7.91^{Eb}	7.68^{Ea}	7.89^{Eb}	8.01^{DEa}	8.47^{Da}	9.58^{Ca}	9.59^{Ca}	10.22^{Ba}	9.38^{Cc}	11.81^{Ab}	0.09
	2	8.18^{CDa}	7.38^{Eb}	7.58^{Ea}	7.62^{Eb}	7.52^{Eb}	7.74^{DEbc}	8.34^{Cc}	8.23^{CDb}	9.40^{Bb}	11.77^{Aa}	11.82^{Ab}	0.09
	3	8.30^{Da}	8.52^{Da}	8.06^{Da}	8.23^{Da}	8.42^{Da}	8.18^{Dab}	9.32^{Ca}	9.36^{Ca}	10.36^{Ca}	11.27^{Ba}	13.29^{Aa}	0.07
	SEM	0.03	0.11	0.11	0.03	0.06	0.12	0.06	0.11	0.06	0.11	0.05	
TBA (mg malo-naldehyde/kg)	1++	0.47^{Ha}	0.63^{Gc}	0.74^{Eb}	0.80^{Dc}	0.72^{EFa}	0.70^{Fa}	0.94^{Cb}	0.93^{Ca}	1.31^{Bb}	1.33^{Bb}	2.86^{Aa}	0.01
	1+	0.47^{Ia}	0.71^{Fb}	0.69^{Fc}	0.89^{Ea}	0.54^{Hb}	0.60^{Gb}	1.68^{Ba}	0.93^{Da}	1.39^{Ca}	1.42^{Ca}	2.38^{Ab}	0.02
	1	0.44^{Ia}	0.79^{Ga}	0.86^{Da}	0.69^{Hd}	0.25^{Je}	0.68^{Ha}	0.82^{Fc}	0.90^{Cb}	0.96^{Bd}	0.83^{Ee}	1.22^{Ac}	0.02
	2	0.36^{Hb}	0.52^{Fd}	0.42^{Gd}	0.83^{Db}	0.36^{Hc}	0.36^{Hd}	0.89^{Cb}	0.64^{Ec}	1.17^{Ac}	1.01^{Bd}	1.18^{Ad}	0.01
	3	0.31^{GHb}	0.46^{Ee}	0.41^{Fd}	0.36^{FGe}	0.29^{Hd}	0.50^{Ec}	0.52^{Dd}	0.62^{Cd}	0.74^{Be}	1.10^{Ac}	0.73^{Be}	0.01
	SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	

Means in the same row with different letters (A-J) are significantly different ($p<0.05$).
Means in the same column with different letters (a-e) are significantly different ($p<0.05$).
[a]SEM: standard error of the means (n=6 for each treatment).

0.05). The samples had TBA values lower than 1 mg malonaldehyde/kg up to 13 d, which is considered the limit of acceptability for rancidity for fresh meat (Ockerman, 1976). TBARS was influenced by lipid content or storage periods in this study.

Meat color

Changes of meat color of Hanwoo striploin muscles among quality grades during storage are presented in Table 3. CIE L* (lightness) and b* (yellowness) value significantly increased with increasing quality grade from quality group 3 to 1++ ($p<0.05$). Quality grade 1++ showed a higher CIE L* and b* value when compared to the other grades ($p<0.05$). Similar findings were obtained by Kim and Lee (2003) who observed high quality grade loin muscles had higher b* value than low quality grade. Other studies have shown CIE L*, a* and b* values were higher in the high quality grade loin muscles than in the low ones (Kim *et al.,* 2008). Lee *et al*. (2010) also showed that L* values were significantly higher in quality grade 1++ compared to the other grades. Quality grade 3 showed the lowest L* and b* values regardless of storage ($p<0.05$).

Table 3. Changes of meat color of M. *longissimus lumborum* from different quality grades during storage

	Quality grade	Days											SEM^{a}
		1	4	6	8	11	13	15	18	20	22	25	
L*	1++	50.00^{Aa}	47.25^{Ca}	44.60^{Ea}	47.91^{Ca}	46.26^{Da}	47.52^{Ca}	48.75^{Ba}	47.28^{Ca}	46.37^{Da}	47.20^{Ca}	47.31^{Ca}	0.13
	1+	46.00^{Bb}	42.93^{Gd}	44.44^{Eab}	45.14^{Db}	43.53^{Cb}	43.64^{Fc}	45.09^{Dc}	46.37^{Ab}	43.51^{Fb}	44.67^{Ec}	44.44^{Ec}	0.03
	1	45.20^{Bb}	44.79^{Cb}	43.23^{Ec}	45.18^{Bb}	43.27^{Ec}	43.67^{Dbc}	45.97^{Ab}	46.15^{Ab}	43.07^{Ec}	45.02^{Eb}	44.95^{BCb}	0.05
	2	44.10^{Db}	44.36^{BCc}	44.22^{CDb}	43.66^{Gc}	43.25^{Hc}	43.93^{EFb}	44.85^{Ac}	43.76^{FGc}	43.70F^{Gb}	44.57^{Bc}	43.91^{EFGd}	0.02
	3	41.70^{Ac}	42.35^{Fe}	40.89^{Id}	42.70^{Ed}	41.72^{Hd}	40.93^{Id}	44.43^{Bd}	43.46^{Dd}	42.49^{EFd}	44.15^{Cd}	42.09^{Ge}	0.02
	SEM	0.25	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.04	0.03	
a*	1++	19.53^{Ca}	19.83^{Ba}	18.21^{Ea}	20.31^{Aa}	17.70^{Fa}	15.78^{Ib}	16.34^{Hd}	16.69^{Gd}	19.38^{Ca}	19.51^{Ja}	18.70^{Kbc}	0.02
	1+	19.33^{Ba}	19.90^{Aa}	17.03^{Fb}	20.01^{Ab}	15.71^{Hc}	16.75^{Ga}	16.88^{FGc}	18.24^{Da}	18.78^{Cb}	17.71^{Ec}	19.89^{Aa}	0.02
	1	18.06^{CDc}	17.80^{Dc}	17.93^{CDa}	18.98^{Ab}	16.94^{Fb}	15.06^{Gc}	19.03^{Aa}	17.46^{Ec}	17.37^{Ee}	18.24^{BCb}	18.45^{Bc}	0.04
	2	18.92^{Bb}	19.00^{Bb}	17.27^{Db}	18.19^{Cc}	15.48^{Ed}	13.78^{Fd}	19.07^{Ba}	18.23^{Ca}	18.19^{Cc}	18.50^{Cb}	19.97^{Aa}	0.05
	3	17.45^{Ed}	17.53^{DEc}	16.63^{Fc}	16.76^{Fd}	14.97^{Ge}	15.27^{Gc}	18.54^{Bb}	17.87^{Cb}	17.65^{CDEd}	17.83^{CDc}	19.03^{Ab}	0.03
	SEM	0.04	0.03	0.03	0.04	0.02	0.02	0.03	0.03	0.02	0.03	0.05	
b*	1++	7.24^{Ba}	7.20^{Ba}	5.83^{Ea}	7.64^{Aa}	6.72^{Ca}	5.99^{Ea}	5.86^{Ea}	6.26^{Da}	6.37^{Da}	6.88^{Ca}	5.94^{Ea}	0.02
	1+	6.57^{Bb}	6.36^{Bb}	5.43^{Db}	7.02^{Ab}	5.11^{Ebc}	5.02^{Eb}	5.83^{Ea}	6.32^{Ba}	5.93^{Cb}	5.80^{Db}	5.69^{CDb}	0.03
	1	6.05^{Bc}	5.71^{CDc}	5.34^{EFb}	6.43^{Ac}	5.37^{Eb}	4.52^{Hc}	5.79^{Ca}	5.50^{EDb}	5.11^{FGc}	5.78^{Cb}	5.55^{Gb}	0.02
	2	5.96^{Bc}	6.17^{Ab}	4.98^{Fc}	5.73^{CDd}	4.82^{Fc}	4.56^{Gc}	5.07^{BCb}	5.54^{Db}	5.22^{Ec}	5.50^{BCc}	4.95^{Dc}	0.01
	3	4.76^{Cd}	4.96^{Bd}	3.92^{Ed}	4.77^{Ce}	4.08^{Dd}	3.60^{Fd}	5.18^{Ab}	5.28^{Ac}	4.76^{Cd}	5.23^{Ad}	4.81^{Ad}	0.01
	SEM	0.01	0.02	0.02	0.02	0.03	0.02	0.01	0.02	0.01	0.01	0.01	

Means in the same row with different letters (A-J) are significantly different ($p<0.05$).
Means in the same column with different letters (a-e) are significantly different ($p<0.05$).
[a]SEM: standard error of the means (n=6 for each treatment).

The darker lean (low L* values) may be attributed to increased myoglobin, decreased muscle glycogen, or both, and the yellow fat (Priolo *et al*., 2001). L*, a* and b* value of samples decreased very slightly during the first 13 d and fluctuated after 15 d of storage ($p<0.05$). The decrease in a* values of samples may be due to the formation of the metmyoglobin (Gøtterup *et al*., 2008). Previous studies have shown CIE L* values did not appear to be influenced by duration of storage, but b* values decreased with storage time (Jeremiah and Gibson, 2001).

Microbiological analyses

Changes of microbial populations of M. *longissimus lumborum* (striploin) from different quality grades during the 25 d of storage period are shown in Fig. 1. The population of total aerobic and *Pseudomonas* increased slowly regardless of quality grade during storage ($p<0.05$). The populations of total aerobic and *Pseudomonas* of grade 1 samples showed higher than that of other grades throughout storage from 1 to 25 d ($p<0.05$). It is assumed that these differences might be due to contamination of beef carcass in quality grade 1 samples during slaughtering, which cause the higher population of grade 1. Total aerobic counts closely paralleled the *Pseudomonas* bacteria counts (Fig. 1). The growth of *Pseudomonas* followed closely sensory changes during storage and thus a growth model for this group could be used for predicting spoilage of stored meat (Koutsoumanis *et al*., 2006). Total aerobic and *Pseudomonas* counts during storage were similar to those reported by authors in beef (Lorenzo and Gomez, 2012). Except quality grade 1, the samples remained below the microbiological guidelines for meat maximum limit (below 7 Log CFU/g) (MFDS, 2011) up until 15 d. However, they exceeded the criteria as recommended after 18 d. In reviewing the literature, vacuum packaging provides a means for extending the storage life of meat during prolonged periods of distribution and merchandising (Seideman and Durland, 1983). Vacuum packaging retards microbiological growth, and delays the development of spoilage due to slow proliferation of bacteria capable of tolerating anaerobic conditions (Gill, 1992). Maximum bacterial numbers are reached after 5 wk of vacuum packaged storage (Johnson, 1974). The bacterial counts of 7 Log CFU/g is the approximate point at which meat would be considered to be spoiled or unacceptable (Dainty and Mackey, 1992). The maximum acceptable counts for packed meat, not matured, are below 10^7 for total counts as recommended (MFDS, 2011). In the present work, vacuum-packaged beefs during the cold storage period for 15 d remained within the acceptable limits established by Korea MFDS. Therefore, the shelf-life of beef samples stored at 1°C under vacuum conditions would be 15 d. Bacteria

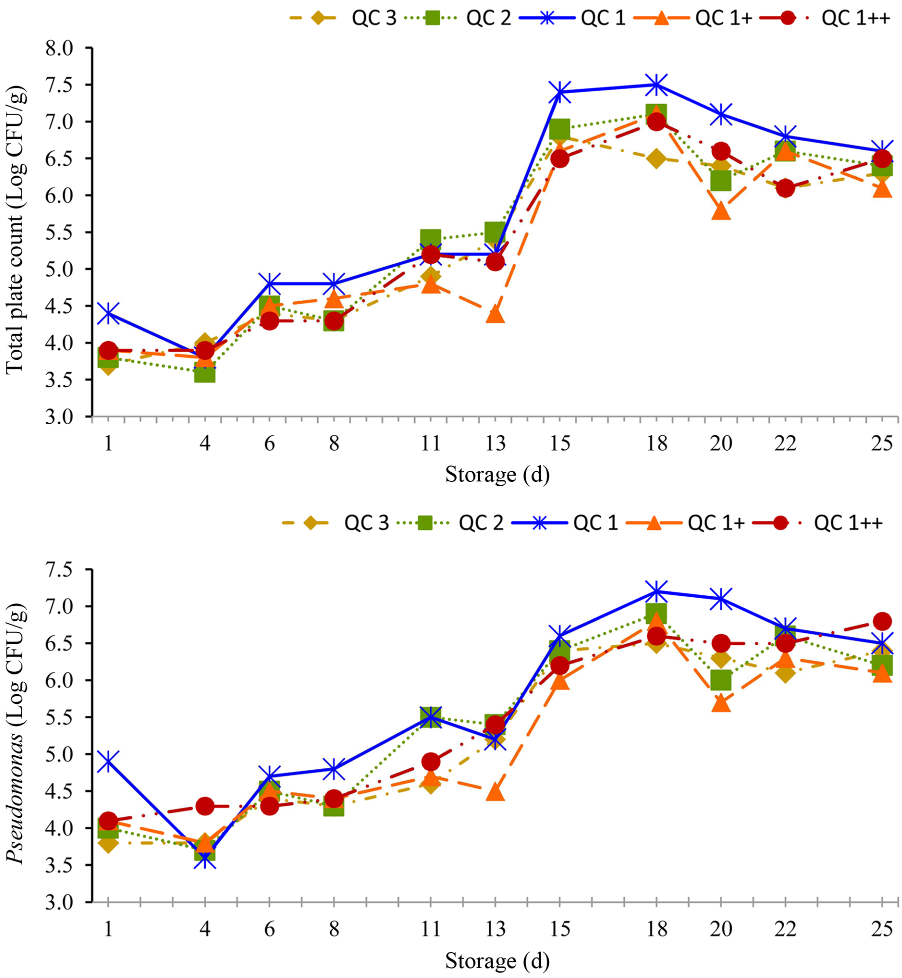

Fig. 1. Changes of total plate counts and *Pseudomonas* of M. *longissimus lumborum* from different quality grades during storage.

counts of samples appeared to be not related to marbling in this study.

Sensory evaluation

Changes of sensory evaluations of M. *longissimus lumborum* (striploin) from different quality grades during storage were indicated in Table 4. As expected, the sensory scores significantly increased with increasing quality grade from quality group 3 to 1++ ($p<0.05$). The juiciness, tenderness, flavor, fatty and palatability of grade 1++ sample had highest scores, whereas those of quality grade 3 showed the lowest during storage ($p<0.05$). These results are in agreement with previous findings high quality grade steaks had higher tenderness and juiciness score than low ones (Kim and Lee, 2003). Juiciness, tenderness, flavour was slightly positively related to intramuscular fat content in most studies (Fiems *et al*., 2000; Renand *et al*., 2001; Wheeler *et al*., 1996) and a similar trend has been reported in our studies. This supported the findings of Hilton *et al.* (1998), who increased marbling was associated with greater tenderness and juiciness. These data support the findings of previous research (Moon *et al*., 2006), which suggested that high marbling group was rated the highest in tenderness, juiciness, flavour and overall acceptability. Jost *et al.* (1983) mentioned correlations between marbling and palatability were usually positive and significant, but low in magnitude and the relationship of marbling to flavor attributes was variable and marbling more strongly related to juiciness than tenderness. Long aging periods may be related to more tender meat with a less amount of fibrous and residue (Campo *et al*., 1999). In our studies, sensory panelists reported aging beef for 15 d improved tenderness in grade 1++, 1+ and 2 ($p<0.05$). Similar finding was reported by Miller *et al*. (1997) noting that aging beef for 14 d could improve the consistency of beef tenderness. On the other hand, a tendency of the sensory scores decreased from 18 to 25 d. Our results agree with those of Monson *et al*. (2005). Same authors postulated

Table 4. Changes in sensory characteristics of M. *longissimus lumborum* from different quality grades during storage

	Quality grade	Days 1	4	6	8	11	13	15	18	20	22	25	SEM[a]
Juiciness	1++	5.57^{Fa}	6.37^{Da}	6.67^{Ba}	6.80^{Aa}	6.33^{Da}	6.50^{Ca}	6.13^{Ea}	6.10^{Ea}	5.57^{Fa}	5.64^{Fa}	5.47^{Ga}	0.01
	1+	5.53^{Da}	4.67^{Fc}	5.63^{Cb}	5.67^{BCd}	5.67^{BCc}	5.53^{Db}	6.10^{Aa}	5.73^{Bb}	4.73^{Fc}	5.10^{Eb}	5.13^{Eb}	0.01
	1	4.87^{Fc}	5.17^{Db}	5.07^{Ed}	6.17^{Ab}	6.19^{Ab}	5.70^{Cb}	6.03^{Ba}	5.70^{Cb}	5.13^{DEb}	4.90^{Fb}	4.17^{Gc}	0.01
	2	5.17^{Fb}	5.10^{Db}	5.50^{Ec}	5.90^{Ac}	5.71^{Ac}	5.53^{Cb}	5.50^{Bb}	4.03^{Cc}	5.20^{DEb}	4.50^{Fc}	3.80^{Gd}	0.01
	3	3.77^{CDd}	3.80^{Cd}	3.53^{Ee}	3.90^{Ce}	3.62^{DEd}	4.10^{Bc}	4.47^{Ac}	3.53^{Ed}	4.10^{Bd}	3.28^{Fd}	2.93^{Ge}	0.01
	SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.01	0.01	0.01	0.01	
Tenderness	1++	5.90^{Fa}	6.17^{CDEa}	6.40^{ABa}	6.57^{Aa}	6.24^{BCDa}	$6.40A^{Ba}$	6.57^{Aa}	6.33^{BCa}	6.07^{DEFa}	6.04^{EFa}	5.93^{Fa}	0.01
	1+	5.30^{Fb}	4.23^{Gd}	5.60^{DEb}	5.73^{CDc}	5.29^{Fc}	5.50^{Ec}	6.00^{Ac}	5.93^{ABb}	5.81^{Cb}	5.76^{Cb}	$5.8B^{Ca}$	0.01
	1	4.73^{Gc}	5.07^{Fb}	4.80^{Gd}	6.17^{Bb}	6.43^{Aa}	5.93^{Cb}	6.26^{Bb}	5.93^{Cb}	5.73^{Db}	5.28^{Ec}	4.80^{Gb}	0.01
	2	4.80^{Dc}	4.93^{Dc}	5.23^{Cc}	5.80^{Bc}	5.81^{Bb}	5.80^{Bb}	6.23^{Ab}	5.40^{Cc}	5.63^{Bb}	4.89^{Dd}	4.87^{Db}	0.02
	3	2.93^{Hd}	3.80^{Fe}	3.43^{Ge}	4.07^{Ed}	4.10^{Ed}	4.43^{CDd}	4.77^{Bd}	4.60^{CBd}	5.03^{Ad}	4.31^{De}	4.50^{CDc}	0.01
	SEM	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.02	
Flavour	1++	5.50^{Ca}	5.77^{Ba}	5.53^{Ca}	6.00^{Aa}	5.54^{Ca}	5.77^{Ba}	5.70^{Ba}	5.40^{CDa}	4.43^{Ea}	3.68^{Ga}	3.93^{Fa}	0.01
	1+	4.97^{DEb}	4.43^{Fc}	5.07^{CDb}	5.47^{Bb}	5.10^{CDb}	5.23^{Cb}	5.70^{Aa}	4.83^{Eb}	4.13^{Gab}	3.72^{Ha}	3.87^{Ha}	0.02
	1	5.03^{Cb}	4.57^{Dc}	5.00^{Cb}	5.57^{Ab}	5.52^{Aa}	5.17^{BCb}	5.37^{Ab}	5.50^{Aa}	4.00^{Eb}	3.07^{Gc}	3.73^{Fa}	0.02
	2	5.07^{Cb}	4.80^{Db}	4.87^{CDb}	5.57^{ABb}	4.90^{CDc}	5.60^{ABa}	5.33^{Bb}	4.27^{Ec}	4.00^{Fb}	3.39^{Gb}	3.23^{Gb}	0.02
	3	3.77^{Dc}	3.87^{CDd}	4.07^{BCc}	4.13^{Bc}	3.67^{Dd}	4.57^{Ac}	4.27^{Bc}	4.07^{BCd}	3.73^{Db}	3.17^{Ec}	3.20^{Eb}	0.02
	SEM	0.02	0.01	0.03	0.01	0.01	0.01	0.02	0.01	0.04	0.01	0.02	
Fatty	1++	4.80^{Ea}	5.80^{Ba}	5.57^{Ca}	5.93^{ABa}	5.52^{Ca}	6.00^{Aa}	5.57^{Ca}	5.12^{Da}	4.90^{Ea}	4.96^{Ea}	4.80^{Ea}	0.01
	1+	4.77^{CDa}	3.63^{Hc}	4.83^{CDb}	5.13^{Bc}	4.67^{Deb}	4.90^{Cc}	5.43^{Aa}	4.87^{Cb}	4.30^{Gc}	4.55^{EFb}	4.40^{FGb}	0.01
	1	4.33^{Cb}	4.57^{Cb}	4.53^{Cc}	5.43^{Ab}	5.43^{Aa}	5.10^{Bb}	5.07^{Bc}	5.07^{Ba}	4.57^{Cb}	4.34^{Cc}	3.43^{Dc}	0.02
	2	4.23^{DEb}	4.37^{Db}	4.90^{Bb}	5.13^{Ac}	4.90^{Bb}	4.93^{Bbc}	4.63^{Cd}	3.50^{Gc}	4.17^{Ec}	3.86^{Fd}	3.23^{Hc}	0.01
	3	2.77^{Dc}	3.20^{Bd}	2.97^{Cd}	3.47^{Ad}	3.10^{BCc}	3.50^{Ad}	3.47^{Ae}	3.03^{BCd}	3.47^{Ad}	3.07^{BCe}	2.60^{Dd}	0.01
	SEM	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	
Palatability	1++	5.20^{Da}	6.03^{ABa}	5.90^{BCa}	6.20^{Aa}	5.76^{Ca}	6.07^{ABa}	5.70^{Ca}	5.70^{Ca}	4.27^{Ea}	3.86^{Fa}	3.67^{Gba}	0.02
	1+	5.07^{Ca}	4.03^{Dc}	5.33^{BCb}	5.70^{Ac}	5.10^{Cc}	5.37^{Bb}	5.73^{Aa}	5.47^{ABb}	3.33^{Fc}	3.83^{DEa}	3.33^{Eb}	0.02
	1	4.83^{Db}	4.67^{Db}	4.70^{Dd}	6.00^{Ab}	5.95^{Aa}	5.40^{BCb}	5.53^{Ba}	5.20^{Cc}	3.77^{Eb}	2.62^{Gc}	3.30^{Fb}	0.03
	2	4.67^{Db}	4.63^{Db}	4.97^{Cc}	5.60^{Ac}	5.33^{Bb}	5.43^{ABb}	5.57^{Aa}	4.37^{Ed}	3.40^{Fc}	3.07^{Gb}	2.83^{Hc}	0.02
	3	3.03^{Cc}	3.47^{Bd}	3.13^{Ce}	3.90^{Ad}	3.52^{Bd}	3.87^{Ac}	3.87^{Ab}	3.93^{Ae}	3.00^{Cd}	2.79^{Dc}	2.93^{CDc}	0.01
	SEM	0.01	0.03	0.02	0.01	0.02	0.05	0.02	0.01	0.02	0.01	0.03	

Juiciness (1=extremely dry, 8=extremely juicy), tenderness (1=extremely tough, 8=extremely tender), flavour intensity (1=extremely bland, 8=extremely intense), fatty (1=none, 8=abundant), and overall acceptability (1=extremely unacceptable, 8=extremely acceptable).
Means in the same row with different letters (A-J) are significantly different (p<0.05).
Means in the same column with different letters (a-e) are significantly different (p <0.05).
[a]SEM: standard error of the means (n=6 for each treatment).

that the decrease in juiciness values could be partly explained by the weakening of muscle structure, which could produce higher losses of water. Especially, long ageing time could cause a gradual decline in the beef flavor due to increase of the undesirable aromatic bitter flavor (Monson *et al*., 2005). For all quality grades, the samples at day 1 had the lowest tenderness.

Conclusions

Quality grade and storage periods affect palatability and physicochemical characteristics of Hanwoo beef. Especially, a low quality grade group based on Korean grading system could negatively influence sensory traits of Hanwoo striploin beef. As a result of the physicochemical traits and sensory evaluation, we assume that a clear difference of Hanwoo striploin muscles was observed among the quality grade groups. Taking into account the results obtained, the consumption of Hanwoo striploin may be recommended within 15 d to obtain an optimum acceptance by the consumer. The results of this study will give information to help answer questions on the objective comparison of the quality depending on the beef quality grade. And this result could be used to determine the optimum quality grade group of Hanwoo beef to provide information for consumers. Further research should be done to develop a better beef quality grade system in the aspects of functional, sensory, economic and health benefits.

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