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The effects of dry or wet aging on the quality of the longissimus muscle from 4-year-old Hanwoo cows and 28-month-old Hanwoo steers

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Abstract. This study was conducted to discover the differences in physicochemical and sensory qualities of beef from 4-year-old Hanwoo cows and 2-year-old Hanwoo steers after undergoing different meat aging methods. Additionally, the possibility of using 4-year-old cows as value-added aged meat was investigated. Loins from eight cows (average 51 months old) and eight steers (average 28 months old) of quality grade 2 were aged for 28 days using dry and wet aging. Analyses were conducted to evaluate meat quality, including moisture content, pH, cooking loss, shear force, nucleotides, free amino acids (FAA), and sensory evaluation. After 28 days of aging, the moisture and shear force for loins from steers and cows were reduced compared with those of non-aged meat ($P < 0.05$). Cooking loss was reduced by dry aging. Regardless of aging method and gender, aging decreased inosine-5′-monophosphate content but increased FAA content ($P < 0.05$). Dry aging increased glutamic acid content in meat, and aging the meat of steer increased the content of aspartic acid and glutamic acid ($P < 0.05$). Before aging, sensory scores for juiciness, tenderness, flavour, and overall acceptance between cow and steer were significantly different ($P < 0.05$), but the differences disappeared after aging. Therefore, the quality of lower grade meat from 4-year-old cows is comparable to that of meat from 2-year-old steers after aging, regardless of the aging method used.

Additional keywords: flavour-related substances, physicochemical traits, sensory evaluation.

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Introduction

In South Korea, a carcass grading system is implemented to manage beef quality. The system consists of the quality grade (QG) and yield grade (YG). QG is based on the marbling score and is determined by lean colour, fat colour, texture, and maturity, which are closely related to meat quality. QG has five values (1++, 1+, 1, 2, and 3), whereas YG has three values (A, B, and C; Moon *et al.* 2013). According to the Korean Institute for Animal Products Quality Evaluation (KAPE 2015), the number of Hanwoo cows was ~46.8% that of total slaughtered Hanwoo cattle, and 67.4% of cow beef showed low QG (2 and 3). Lee *et al*. (2010) also reported that the QG of cows (average 3.46 when QG 1++, 1+, 1, 2, and 3 were scored as 1, 2, 3, 4, and 5, respectively) was statistically higher than that of steers (average 2.75) ($P < 0.01$), indicating that cows tend to produce lower quality meat. In Korea, the main role of Hanwoo cows is calf production, with a negligible role in the supply of beef. To supply stable beef and stabilise beef prices in Korea, it is necessary to improve the quality of Hanwoo cows (Kim *et al.* 2010).

Hanwoo cows in Korea yield low-quality meat because most cows are old and have produced calves before slaughter, thus yielding meat that is tougher and drier when chewed than that from young cows (Shorthose and Harris 1990). According to Xiong *et al*. (2007), the meat from old cows has a tougher texture because of slower proteolysis that causes muscle fibre fragmentation and produces a higher connective tissue collagen content than that from young cows. Additionally, 4-year-old Hanwoo cows have a lower crude fat content and marbling score because of slower fat accumulation than in young steers and cows (Lee *et al.* 2010). Lee *et al*. (2010) noted that crude fat content is positively correlated with sensory acceptability

(r^2 = 0.69), juiciness (r^2 = 0.59), tenderness (r^2 = 0.71) and flavour (r^2 = 0.55) ($P < 0.01$). Therefore, the adverse effects of physicochemical properties associated with flavour and tenderness on old cows limit marketability (Stelzleni *et al.* 2007; Pivotto *et al.* 2014).

Aging is a method used to enhance meat quality, particularly flavour and tenderness, and is commonly used in the meat industry (Khan *et al.* 2016). In wet aging, a widely used aging method, meat is stored in vacuum bags under refrigeration. This aging method is generally used in Korea because it has the advantage of usability, safety, and high yield (Obuz *et al.* 2014). Another aging method, dry aging, is known to produce excellent flavour because of the concentration of flavour-related substances by moisture evaporation. After dry aging, the content of glutamic acid, which is associated with meat flavour, is increased (Kim *et al.* 2016), and tenderness and juiciness are improved (Campbell *et al.* 2001). The ability to enhance consumer preference and meat quality by dry aging has been previously reported (Campbell *et al.* 2001; Kim *et al.* 2016).

This study was conducted to test whether dry and wet aging methods could improve the quality of beef from 4-year-old Hanwoo cows and to compare the differences in beef quality of 4-year-old cows and 2-year-old steers subjected to the same aging methods. It was expected that improving the quality of beef from 4-year-old cows by aging could stabilise the beef supply and Hanwoo prices in Korea.

Materials and methods

Sample preparation

A total of 32 loins (two per carcass) were obtained from carcasses of Hanwoo cows (n = 8) and steers (n = 8), which were slaughtered and graded in a local slaughterhouse (Anseong, Korea). A sample of ~3 kg of the *longissimus lumborum* muscle between the first and sixth lumbar vertebrae was taken from each side of each carcass. Information on the carcasses are shown in Table 1. Information about the carcasses is provided in Table 1. Each side loin of a carcass was divided into two cuts. One of the two cuts was designated the Control at 2 days postmortem (n = 32), and the other was aged by dry or wet aging (n = 16 for each treatment). The wet-aged loin samples were vacuum-packaged in oxygen-impermeable nylon bags (2 mL O_2/m^2.24 h at 0°C, 0.09-mm thickness; Sunkyung Co. Ltd, Seoul, Korea) and stored at a temperature of 2 ± 1°C, whereas the dry-aged loin samples were stored under controlled conditions (air velocity, 2–7 m/s; temperature, 1 ± 1°C; humidity, 85 ± 10%). After aging, the samples were vacuum-packaged and frozen at −73°C until analysed.

Moisture content

The moisture content was determined using a Foss FoodScan analyser (FoodScan Laboratory, Type 78800, FOSS, Hillerod, Denmark) at the National Institute of Animal Science, RDA (Jeonju, Korea) following the method of the Association of Official Analytical Chemists (AOAC 2006). The meat samples were ground, and 250 g of the ground meat was loaded into a sample cup and placed in the analyser.

Shear force

Meat samples (30 g) were vacuum-packaged, heated in a water bath at 72°C for 40 min. After cooling in iced water, six 10 × 10 × 30-mm cores were cut and the shear force of each was measured using a Warner –Bratzler blade on a texture analyser (AMETEK Lloyd Instruments Ltd, Fareham, UK) with the following parameters: maximum cell load 10 kg, target load 10 g, target value 25 mm, and target speed 2.0 mm/s. The samples were sheared perpendicularly to the direction of the muscle fibre.

pH

Each meat sample (1 g) was homogenised with 9 mL of distilled water using a homogeniser (T10 basic, IkaWorks, Staufen, Germany). The homogenates were centrifuged (Continent 512R, Hanil Co., Ltd, Incheon, Korea) at 2265*g* for 10 min and filtered (Whatman No. 4, Whatman PLC, Buckinghamshire, UK). The pH value of each filtrate was measured using a pH meter (SevenGo, Mettler-Toledo International Inc., Schwerzenbach, Switzerland), which was pre-calibrated using standard buffers (pH 4.01, 7.00, and 9.21).

Cooking loss

Cooking loss was determined as the percentage weight loss of each meat sample after cooking. Meat samples (30 g) were vacuum-packaged (HFV-600 L, Hankook Fujee Co., Ltd, Hwaseong, Korea), heated in a water bath at 90°C for 15 min until a core temperature of 72°C was reached, and cooled in ice water. After recording the final weight, the cooking loss was calculated as follows:

$$\text{Cooking loss } (\%) = \frac{\text{Weight before cooking} - \text{Weight after cooking}}{\text{Weight before cooking}} \times 100$$

Nucleotide content

The meat samples (3 g) were mixed with 20 mL of 0.6 M perchloric acid and homogenised at 1130*g* for 30 s at room temperature to extract nucleic acids. The extracted nucleic acids were then centrifuged at 2265*g* for 15 min at 4°C (Continent 512R, Hanil Co., Ltd, Incheon, Korea) and filtered

Table 1. Slaughter age, weight and fat depth of carcass from Hanwoo cows and steers (mean value ± standard deviation)

	Slaughter age (months)	Weight of half carcass (kg)	Fat depth (mm)
Cows (n = 8) (Min.–Max.)	51.50 ± 17.52 (31–87)	318.25 ± 32.46 (258–370)	11.06 ± 4.20 (5–18)
Steers (n = 8) (Min.–Max.)	28.00 ± 3.80 (22–29)	344.00 ± 33.09 (297–376)	12.50 ± 5.49 (8–21)
P-value	<0.0001	0.0340	0.41

through filter paper (Whatman No. 1, Whatman PLC, Buckinghamshire, UK). The supernatant was then adjusted to pH 5.5 with 6 N KOH. The pH-adjusted supernatant was placed in a volumetric flask, and the volume was adjusted to 50 mL with 0.6 M perchloric acid (pH 5.5). After 30 min of cooling, the supernatant was filtered through a 0.2-μm poly vinylidene fluoride syringe filter (Whatman 13 mm diameter, 0.2-μm pore size, Cat. no. 6779–1302). The filtrate (1.5 mL) was analysed using high-performance liquid chromatography (Ultimate 3000, Dionex, Idstein, Germany) under the following analytical conditions: Synergi Hydro-RP column (250 × 4.6 mm^2, 4-μm particles; Phenomenex Inc., Seoul, Korea) with a mobile phase of 20 mM monopotassium phosphate at pH 5.5; mobile phase flow rate 1.0 mL/min; and injection volume 10 μL. The column temperature was maintained at 30°C, and detection was performed at a wavelength of 254 nm. The peaks of the individual nucleotides were identified using the retention times for the following standards: hypoxanthine, inosine, inosine-5′-monophosphate (IMP), and adenosine-5′-monophosphate (AMP) from Sigma Chemical Co. (St Louis, MO, USA); the concentration was calculated using the area for each peak. Nucleotides were analysed as flavour-related compounds according to Lee *et al*. (2017).

Free amino acids

The meat samples (3 g) were mixed with 27 mL of 2% trichloroacetic acid solution and homogenised (Polytron PT 10–35 GT, Kinematica, Lucerne, Switzerland) at 1130*g* for 1 min at room temperature. The homogenate was centrifuged (LaboGene 1736R, Gyrozen, Seoul, Korea) at 17 000*g* for 15 min at 4°C and filtered through a 0.45-μm membrane filter. The filtrate was injected into an high-performance liquid chromatography (S 1125, Sykam, Eresing, Germany) fitted with a post-column derivatisation system (Delta, Pinnacle PCX high-performance liquid chromatography post-column system, Pickering, Mountain View, CA, USA). The column (4.6 × 150 mm^2, Sykam, Eresing, Germany) temperature was held at 20 ± 2°C, and a UV/Vis detector (S3245, Sykam) was set to 540 nm. The separation was performed by using buffers: A, B, C, and D solutions (Ajoo Scientific, Gunpo, Korea). Ninhydrin reagent was mixed with 750 mL of methyl cellosolve, 250 mL of 4 M sodium acetate buffer (pH 5.51), 20 g of ninhydrin and 5.5 mL of a titanium(III) chloride solution (not more than 6.0 mL). The solvent pumping rates were 0.45 mL/min (buffer solution) and 0.3 mL/min (ninhydrin). A Control sample of known amino acid composition was included with the samples before hydrolysis to ensure analysis accuracy and repeatability. The peaks of the individual free amino acids were identified using the retention times for standards from Standard Solution Amino Acids (Sykam).

Sensory evaluation

The sensorial quality of samples was evaluated by an untrained consumer panel (30 sensory panellists). The sensory evaluation was carried out over eight different sessions by the same 30 panellists. In each session, samples from four treatments (two aging times and two aging methods) from one steer and one cow were evaluated, resulting in eight samples per panellist. The samples were thawed at 4°C for 16 h before evaluation, cut into pieces of a similar size (50 × 20 × 6 mm^3), and roasted on each side on an electrical tin plate grill with a water jacket (~250 ± 5°C) until the sample was no longer red. Each sample was scored on a single sheet using a 7-point hedonic scale (1 = dislike extremely, 7 = like extremely). The sensory evaluation was performed based on four individual traits: juiciness, tenderness, flavour, and overall acceptance. The mean scores of the 30 panellists were used for statistical analysis.

Statistical analyses

The data were analysed using the SAS statistical software program (SAS, Release 9.4, SAS Institute Inc., Cary, NC, USA). The statistical significance of differences in slaughter age, weight and fat depth between cows and steers was determined by student's *t*-test. The data were then analysed by using PROC GLM with the following nested model: Y = Gender + Carcass (Gender) + Method + Day + Gender × Method + Gender × Day + Method × Day + Gender × Method × Day. Because there were no significant interactions between sex and method ($P > 0.05$), the data were pooled by sex and method. Significant differences between aged and unaged samples with respect to aging method and gender were assessed by a paired *t*-test considering the aging effect (moisture, pH, cooking loss, shear force, nucleotide content, free amino acids and sensory evaluation). Statistically significant differences between dry and wet aging and between cows and steers were determined by student's *t*-test. In the tables presented herein, the significance of the aging effect in the two aging methods and within cow and steer samples are presented first, followed by the effect of aging method or animal gender on characteristics after 2 or 28 days of aging and the difference between 2 and 28 days of aging.

Results and discussion

Physicochemical traits

The aging effect according to aging method and age/gender was confirmed by the decreased moisture content of the beef aged for 28 days ($P < 0.05$, Tables 2, 3). The amount by which moisture was reduced by dry aging was greater than that achieved by wet aging, as shown in Table 2. The decrease in moisture content with dry aging was due to the evaporation of water in the meat (Campbell *et al.* 2001), whereas the wet aging method did not affect the moisture content of the beef during aging (Ba *et al.* 2014). There was no difference in moisture content after aging according to age/gender (Table 3). It is known that moisture and fat content have a negative correlation (Pflanzer and de Felício 2011), and Lee *et al*. (2010) reported that steers have a higher fat content and lower moisture content than cows. However, instead of using different QG of steers and cows (Lee *et al.* 2010), the present study used the same QG containing a similar fat content (12.14% in steers vs 12.06% in cows). Because of the similar fat content, there were no significant changes in moisture content with age/gender.

pH is closely related to water-holding capacity and tenderness (Weatherly *et al*. 1998). In both aging methods and with respect to age/gender, pH_u increased after aging ($P < 0.05$, Tables 2, 3). Boakye and Mittal (1993) reported an increase in pH during aging because of changes in protein charge caused by the postmortem action of proteolytic enzymes. No significant

Table 2. Effects of aging method (dry vs wet) on the physicochemical traits of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means (n = 16)

		Moisture (%)	pH_u	Cooking loss (%)	Shear force (kg)
Dry aging	2-day value	67.31	5.47	26.66	5.35
	28-day value	63.78	5.57	19.30	3.32
	Difference (28 days–2 days)	–3.53	0.10	–7.37	–2.03
	s.e.m.	0.768	0.024	0.957	0.355
	P-value	0.0003	0.0009	<0.0001	<0.0001
Wet aging	2-day value	67.49	5.53	26.49	5.79
	28-day value	65.76	5.58	26.08	3.22
	Difference (28 days–2 days)	–1.73	0.05	–0.40	–2.57
	s.e.m.	0.665	0.022	1.128	0.566
	P-value	0.0221	0.0412	0.73	0.0007
P-value	Dry versus Wet on Day 2	0.75	0.40	0.50	0.89
	Dry versus Wet on Day 28	0.0407	0.87	<0.0001	0.74
	Dry versus Wet on Day 28–Day 2	0.0913	0.16	<0.0001	0.41

Table 3. Effects of age/gender (cow versus steer) on the physicochemical traits of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means (n = 16)

		Moisture (%)	pH_u	Cooking loss (%)	Shear force (kg)
Cow	2-day value	67.13	5.51	27.86	6.54
	28-day value	64.83	5.58	22.89	3.82
	Difference (28 days–2 days)	–2.31	0.07	–4.97	–2.73
	s.e.m.	0.814	0.026	1.580	0.391
	P-value	0.0126	0.0253	0.0072	<0.0001
Steer	2-day value	67.69	5.48	25.22	4.48
	28-day value	64.56	5.57	21.57	2.70
	Difference (28 days–2 days)	–3.13	0.09	–3.47	–1.79
	s.e.m.	0.673	0.020	1.114	0.490
	P-value	0.0005	0.0009	0.0082	0.0030
P-value	Cow vs Steer on Day 2	0.37	0.61	0.0002	0.0012
	Cow vs Steer on Day 28	0.79	0.60	0.53	0.0037
	Cow vs Steer on Day 28–Day 2	0.45	0.54	0.45	0.14

differences in pH were found between the different aging methods or between different ages/genders, as shown in Tables 2 and 3.

Cooking loss refers to the water loss from the meat caused by protein denaturation during cooking because less water is entrapped within the protein structures held by capillary forces (Aaslyng *et al*. 2003). Aaslyng *et al*. (2003) reported that low water-holding capacity and low pH caused a high cooking loss in meat. In accord with this relationship (Aaslyng *et al*. 2003), the cooking loss of the Control sample (2 days postmortem) was higher than that of meat dry aged for 28 days (Table 2) and that of meat from cows and steers (Table 3). With respect to aging method (Table 2), there were no differences between the cooking loss of unaged aged and that of wet-aged beef. However, dry aging caused a significant reduction in cooking loss ($P < 0.05$), mainly because water had already evaporated from the meat during dry aging. However, the ratio of cooking loss to moisture content of dry-aged beef (30.26%) was lower than that of wet-aged beef (39.66%). This finding indicates that dry-aged beef has a higher water-holding capacity than wet-aged beef during cooking. Consumers may experience nutritional and sensory losses for beef if cooking loss is high. Water loss during cooking can reduce the water-soluble vitamin and mineral content of beef (Severi *et al.* 1997), which may be undesirable for the consumer. With respect to age/gender, there was a difference in cooking loss between cow and steer meat before aging ($P < 0.05$), but the difference disappeared after aging for 28 days (Table 3).

Meat tenderness is the most important quality for consumer evaluation, and shear force is a reliable measure of tenderness (Destefanis *et al.* 2008). Aging of meat causes degradation of myofibrillar and cytoskeletal proteins by proteolytic enzymes. As a result, the structural weakness of muscle leads to increased tenderness (Nowak 2011). As observed for the aging effect, it could be confirmed that the shear force of beef loin aged for 28 days was lower than that of unaged beef loin, regardless of aging method or age/gender ($P < 0.05$, Tables 2, 3). However, the

shear force of cow was higher than that of steer for both the unaged and aged varieties ($P < 0.05$, Table 3). Similarly, Moon *et al*. (2006) reported that the higher shear force of cow meat increased with age, and Shorthose and Harris (1990) reported that the tenderness of beef decreased with age regardless of the cut of meat. The present study confirms that dry and wet aging improve tenderness (Table 2) (Khan *et al.* 2016).

Nucleotide content

Nucleotides not only act as flavour precursors but also possess taste properties through the interaction of FAA (Koutsidis *et al.* 2008). Among the nucleotides, it is well known that IMP imparts good umami taste to meat, whereas hypoxanthine provides a bitter taste (Tikk *et al.* 2006). Recently, however, Ichimura *et al*. (2017) reported that hypoxanthine could enhance the taste of meat by a synergy between hypoxanthine and other components related to taste. No difference in the content of AMP in meat before and after aging was observed when analysed with respect to aging method (Table 4), but with respect to age/gender, only steer showed an increase in AMP content after aging ($P < 0.05$, Table 5). Regardless of aging method and age/gender, the content of IMP decreased and that of inosine and hypoxanthine increased in each sample (Tables 4, 5). This effect was caused by the hydrolysis of IMP to hypoxanthine and ribose 5-phosphate or by dephosphorylation during aging (Koutsidis *et al.* 2008). This trend is supported by Kim *et al*. (2011) and Lee *et al*. (2015). With respect to aging method, the increase in hypoxanthine was higher in wet-aged meat than in dry-aged meat ($P < 0.05$, Table 4). Before aging, steer samples had a higher hypoxanthine content than cow samples ($P < 0.05$), but the content became similar after aging (Table 5).

Free amino acid content

FAA contribute to various taste and aroma compounds through the Maillard reaction of cooked meat, although some amino acids have an unpleasant taste (Koutsidis *et al.* 2008).

Table 4. Effects of aging method (dry vs wet) on the nucleotide content (mg/100 g) of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means ($n = 16$)

		AMP	IMP	Inosine	Hypoxanthine
Dry aging	2-day value	1.32	153.10	20.12	17.09
	28-day value	1.66	71.63	27.78	35.28
	Difference (28 days–2 days)	0.34	–81.48	7.66	18.19
	s.e.m.	0.298	7.046	0.979	1.169
	P-value	0.27	<0.0001	<0.0001	<0.0001
Wet aging	2-day value	1.00	155.20	20.55	15.29
	28-day value	1.02	58.80	25.03	37.36
	Difference (28 days–2 days)	0.02	–96.44	4.47	22.07
	s.e.m.	0.160	4.920	1.585	1.387
	P-value	0.93	<0.0001	0.0144	<0.0001
P-value	Dry vs Wet on Day 2	0.27	0.90	0.56	0.40
	Dry vs Wet on Day 28	0.07	0.08	0.19	0.24
	Dry vs Wet on Day 28–Day 2	0.49	0.16	0.10	0.0398

Table 5. Effects of age/gender (cow vs steer) on the nucleotide content (mg/100 g) traits of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means ($n = 16$)

		AMP	IMP	Inosine	Hypoxanthine
Cow	2-day value	1.30	147.00	20.41	15.07
	28-day value	1.20	63.17	26.53	36.25
	Difference (28 days–2 days)	–0.10	–83.86	6.12	21.18
	s.e.m.	0.256	6.021	1.682	1.432
	P-value	0.71	<0.0001	0.0024	<0.0001
Steer	2-day value	1.03	162.20	20.22	17.59
	28-day value	1.54	68.46	26.46	36.25
	Difference (28 days–2 days)	0.51	–93.72	6.23	18.65
	s.e.m.	0.214	6.860	0.682	1.175
	P-value	0.0319	<0.0001	<0.0001	<0.0001
P-value	Cow vs Steer on Day 2	0.35	0.10	0.83	0.0421
	Cow vs Steer on Day 28	0.25	0.48	0.97	1.00
	Cow vs Steer on Day 28–Day 2	0.08	0.29	0.95	0.19

Chen and Zhang (2007) reported that glutamic and aspartic acids enhance savoury and umami tastes, which many consumers describe as 'delicious'. With respect to both aging method and age/gender, the contents of total FAA of beef loin increased significantly after 28 days of aging ($P < 0.05$, Tables 6, 7). Dry aging caused a significant increase in glutamic acid in meat (Table 6), and steer samples showed a significant increase in aspartic acid and glutamic acid (Table 7). Cow samples showed higher aspartic acid, glutamic acid, and total FFA than steer samples before aging (Table 7), but only the total FFA content of steer was significantly higher than that of cow after aging. The increases in the amounts of aspartic acid, glutamic acid, and total FFA caused by the aging process were higher in the samples from steer than in those from cow ($P < 0.05$, Table 7). Increased amounts of FAA (particularly alanine, taurine, leucine, serine, valine, and glutamic acid) in beef during wet aging have been reported (Dashdorj *et al*. (2015). The increase in FAA during aging is due to proteolysis of the muscle by enzymes such as calpain (Feidt *et al.* 1996).

Sensory evaluation

No differences in sensory scores between dry-aged and wet-aged meat were observed among cow and steer samples (Table 8). This result is in agreement with that of Laster *et al*. (2008), who observed no differences in flavour, juiciness, tenderness level or overall preference of US beef aged by wet or dry methods. Khan *et al*. (2016) reported the possibility of enhancing beef flavour by dry aging, which can concentrate flavour compounds by evaporation. Sitz *et al*. (2006) also confirmed no significant differences in sensory evaluation between dry aged and wet aged choice strip loins and mentioned that although a majority of consumers prefer wet-aged beef, those who enjoy the unique flavour of dry-aged beef are willing to pay more.

Table 6. Effects of aging method (dry vs wet) on free amino acids (FAA) (mg/100 g) of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means ($n = 16$)

		Aspartic acid	Glutamic acid	Total FAA
Dry aging	2-day value	2.73	12.65	120.80
	28-day value	3.01	21.92	214.80
	Difference (28 days–2 days)	0.29	9.27	94.00
	s.e.m.	0.522	3.420	27.875
	P-value	0.60	0.0302	0.0119
Wet aging	2-day value	2.60	14.60	123.90
	28-day value	4.16	27.02	260.60
	Difference (28 days–2 days)	1.57	12.42	136.70
	s.e.m.	0.757	6.309	50.367
	P-value	0.15	0.11	0.0428
P-value	Dry vs Wet on Day 2	0.79	0.80	0.59
	Dry vs Wet on Day 28	0.09	0.44	0.35
	Dry vs Wet on Day 28–Day 2	0.29	0.65	0.44

Table 7. Effects of age/gender (cow vs steer) on free amino acids (FAA) (mg/100 g) of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means ($n = 16$)

		Aspartic acid	Glutamic acid	Total FAA
Cow	2-day value	3.36	15.27	136.40
	28-day value	3.19	20.06	195.20
	Difference (28 days–2 days)	–0.17	4.80	58.77
	s.e.m.	0.333	2.069	14.099
	P-value	0.62	0.0536	0.0042
Steer	2-day value	2.05	11.11	103.10
	28-day value	3.93	29.50	286.80
	Difference (28 days–2 days)	1.88	18.39	183.70
	s.e.m.	0.707	5.802	45.474
	P-value	0.0448	0.0248	0.0099
P-value	Cow vs Steer on Day 2	0.0007	0.0395	0.0091
	Cow vs Steer on Day 28	0.29	0.14	0.0434
	Cow vs Steer on Day 28–Day 2	0.0143	0.0297	0.0119

Table 8. Effects of aging method (dry vs wet) on the sensory traits of *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 days–2 days)

s.e.m., standard error of the means (n = 16)

		Juiciness	Tenderness	Flavour	Overall acceptance
Dry aging	2-day value	4.68	4.54	4.20	4.25
	28-day value	4.12	4.41	4.24	4.17
	Difference (28 days–2 days)	–0.56	–0.14	0.04	–0.08
	s.e.m.	0.202	0.238	0.188	0.205
	P-value	0.0148	0.58	0.82	0.70
Wet aging	2-day value	4.40	4.36	4.10	4.11
	28-day value	4.34	4.54	4.16	4.21
	Difference (28 days–2 days)	–0.06	0.18	0.07	0.10
	s.e.m.	0.200	0.243	0.224	0.224
	P-value	0.76	0.48	0.77	0.66
P-value	Dry vs Wet on Day 2	0.66	0.98	0.99	0.98
	Dry vs Wet on Day 28	0.35	0.62	0.70	0.86
	Dry vs Wet on Day 28–Day 2	0.09	0.37	0.95	0.55

Table 9. Effects of age/gender (cow vs steer) on the sensory traits *longissimus lumborum* muscle from Hanwoo cows and steers in terms of values at 2 and 28 days of aging as well as the difference between 2 and 28 days of aging (28 day–2 day)

s.e.m., standard error of the means (n = 16)

		Juiciness	Tenderness	Flavour	Overall acceptance
Cow	2-day value	4.08	3.71	3.78	3.71
	28-day value	4.05	4.19	4.11	4.02
	Difference (28 days–2 days)	–0.03	0.48	0.33	0.31
	s.e.m.	0.179	0.208	0.177	0.168
	P-value	0.87	0.04	0.08	0.08
Steer	2-day value	5.05	5.25	4.54	4.69
	28-day value	4.41	4.76	4.30	4.37
	Difference (28 days–2 days)	–0.63	–0.49	–0.24	–0.32
	s.e.m.	0.213	0.202	0.205	0.228
	P-value	0.0106	0.0317	0.26	0.18
P-value	Cow vs Steer on Day 2	0.0011	<0.0001	0.0035	0.0009
	Cow vs Steer on Day 28	0.12	0.0196	0.34	0.13
	Cow vs Steer on Day 28–Day 2	0.0373	0.0025	0.0443	0.0328

Before aging, the sensory scores of steer were significantly higher than those of cow with respect to juiciness, tenderness, flavour and overall acceptance ($P < 0.05$, Table 9). Lee *et al.* (2010) reported that steers scored higher than cows on acceptability, tenderness, juiciness and flavour. However, the differences in sensory scores between cow and steer disappeared after aging, except for tenderness (Table 9). In the case of steer, the sensory scores for juiciness and tenderness decreased after aging ($P < 0.05$, Table 9). According to Moskowitz (1993), the results of a sensory evaluation conducted by scoring preference alone are difficult to analyse because of individual differences.

Conclusion

The results of this study indicate that beef from 4-year-old cows showed levels of quality characteristics similar to those of beef from 2-year-old steers after aging, except for tenderness. This finding indicates that sufficient aging improves the beef of 4-year-old cows such that it can fill a niche market. Further research into methods for overcoming toughness in 4-year-old cows would be helpful in increasing overall acceptance and competitiveness in the food market.

Conflicts of interest

The authors declare no conflicts of interest.

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