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ARTICLE

Effect of Aging Time on Physicochemical Meat Quality and Sensory Property of Hanwoo Bull Beef

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Abstract

This study was conducted to investigate the meat quality and sensory properties of 12 major cuts from 10 Hanwoo bulls (25-32 mon of age) after they were aged at 2°C for 0, 7, 14, and 21 d. Protein content (%) was between 19.17 and 22.50%. Intramuscular fat content ranged from 2.79 to 8.39%. The collagen content of the chuck roll, chuck tender, and short plate muscles was higher (1.97-2.04%) than that of the striploin muscles (1.48%) (p<0.05). CIE lightness (L*) values increased with an increase in aging days for tenderloin, loin, chuck roll, oyster blade, short plate, top sirloin, and eye of round muscles (p<0.05). Most muscles, except the short plate, showed no significant changes in redness CIE (a*) and yellowness (b*) color values during aging. The tenderloin, loin, and striploin showed significantly higher water holding capacity (58.60-62.06%) than that of chuck roll and short plate (53.86-57.07%) muscles (p<0.05). The Warner-Bratzler shear force values of most muscles decreased significantly as the aging period increased (p<0.05), exception the tenderloin. The chuck tender muscles showed the highest cooking loss, whereas tenderloin muscle showed the lowest (p<0.05). The tenderloin muscle had the longest sarcomere length (SL) (3.67-3.86 μm) and the bottom round muscle had the shortest SL (2.21-2.35 μm) (p<0.05). In the sensory evaluation, tenderness and overall-likeness scores of most muscles increased with increase in aging days. The tenderloin and oyster blade showed relatively higher tenderness and overall-likeness values than did the other muscles during the aging period. No significant differences were noted in juiciness and flavor-likeness scores among muscles and aging days.

Keywords: Hanwoo bull beef, meat quality, sensory property

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Introduction

The production of Hanwoo bull beef accounted for 3.2% of the total production of Hanwoo cattle in 2014. Steers accounted for 48.1% and cows for 48.7% of the total. The frequency of quality grading above grade 1 for Hanwoo bulls was only 2.9% compared with that for steers, 84%, and cows, 50.4% (KAPE, 2014). In general, intact bulls that are provided adequate nutrition grow faster and more efficiently and produce carcasses with less fat than that in castrated steers (Mach *et al*., 2009). However, meat from bulls is reported to show lesser tenderness and palatability than meat from steers (Dikeman *et al*., 1986). The reason is thought to be related to increased levels of testosterone in bulls, which stimulates collagen synthesis (Cross *et al*., 1984) and results in higher amounts of intramuscular collagen than is found in castrated steers. Gerrard *et al*. (1987) found that the thermal stability of collagen from bulls increases more rapidly than collagen from steers, indicating that testosterone may play a role in the maturation of collagen by decreasing the collagen degradation rate. On the other hand, Morgan *et al*. (1993) determined that *longissimus* muscle (LM) steaks from bulls had higher shear force values and 81% higher calpastatin (endogenous calpain activity inhibitor) activity than LM steaks from steers. They concluded that the higher calpastatin activity in bull LM likely causes a reduction in proteolysis of myofibrillar protein by μ-calpain, resulting in less tender meat. Therefore, tenderness differences between steaks from bulls and steers can be partially attributed to both collagen and myofibrillar protein characteristics. Arce and Murillo (2004) found LM steaks from steers were more tender than those from bulls and found that aging improved *longissimus* tenderness for

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both sexes.

Consumers are willing to pay a premium for guaranteed tender beef (Shackelford *et al*., 2001). Postmortem aging is a technology that enhances beef tenderness and flavor development which had been shown to be a major contributing factor to consumers' perception of taste (Sitz *et al.,* 2006). The vacuum aging is a widely used industry due to its increased ease and flexibility of storage (Smith *et al,* 2008). However, inconsistency in meat tenderness has been identified as one of the major problems facing the beef industry. The lower quality cuts make up a majority of the carcass and have been declining in value (Rhee *et al.,* 2004). Certain cuts of beef have been identified as needing improvement in tenderness relative to consumer expectations (Brooks *et al*., 2000). Individual muscles can respond differently in the degree to which their tenderness improves after postmortem aging periods owing to differences in connective tissue (Rhee *et al*., 2004), in activity of calpains (Ilian *et al*., 2001), and in the extent of proteolytic degradation (Rhee *et al*., 2004).

To date, the extensive research on variation in meat tenderness and meat palatability has been conducted using the *longissimus* muscle or has included only a few muscles. Relative to most muscles, the *longissimus* has low variation in detectable connective tissue and sarcomere length; thus, most of the variation in tenderness results from variation in the extent of proteolysis of myofibrillar and cytoskeletal proteins (Koohmaraie, 1994). The objective of this study was to investigate and compare the physicochemical and sensory properties of 12 major cuts from Hanwoo bull beef during aging at 2ºC for 21 d.

Materials and Methods

Sample preparation

Ten Hanwoo bulls (25-30 mon of age, live weight 640-780 kg) were obtained from a National Institute of Animal Science (NIAS) feeding program at Hanwoo Research Institute, Daegwanryeong, Korea. They were fed at the growth stage for 7-12 mon (Concentrate, CP 15%, TDN 70%; Forage, Hay and rice straw, *ad libitum*), the early fattening stage for 13-22 mon (Concentrate, CP 11-12%, TDN 71-72%; Forage, rice straw 2 kg/d), and the late fattening stage after 23 mon (Concentrate, CP 12%, TDN 73%; Forage, rice straw 1.5kg/d). The animals were randomly selected, transported to the NIAS abattoir, and fasted for approximately 12 h, but were given access to water prior to slaughter. After slaughter, the right side of each carcass was hung by the *Achilles* tendon and cooled at 4°C. Approximately 24 h post-mortem, the right side of the carcass was deboned and trimmed as directed in the domestic fabrication manual (National Livestock Cooperatives Federation, 1998). The following 12 muscles were separated from the carcass: tenderloin (*m. psoas major*), loin *(m. longissimus dorsi*), striploin (*m. longissimus lumborum*), chuck roll (*m. bicep brachii caput longum*), chuck tender (*m. supraspinatus*), oyster blade (*m. infraspinatus*), short plate (*m. superficial pectoral*), top sirloin (*m. gluteus medius*), eye of round (*m. semitendinosus*), top round (*m. semimembranosus*, SM), bottom round (*m. biceps femoris*) and brisket (*rectus abdominis*). For the composition and quality analysis, muscles were vacuum-packaged and stored at 2°C for 0, 7, 14, or 21 d. For sensory evaluation, a sample of each muscle was vacuum-packaged and stored at 20°C until the test was conducted (approximately 21 d post-mortem).

Chemical composition

Protein, fat, moisture, and collagen content were analyzed using the Food Scan^{TM} Lab 78810 (Foss Tecator Co., Ltd., Denmark), according to the method of the Association of Official Analytical Chemists (AOAC, 2006).

Meat quality analysis

Color values on a freshly cut surface of the Warner–Bratzler shear force (WBSF) block were measured using a CR-400 chroma meter (Konica Minolta Sensing, Inc., Japan) for CIE standard lightness (L*), redness (a*), and yellowness (b*), after a 30 min blooming period at 2°C (Commission Internationale de I'Eclairage, 1986). Water-holding capacity (WHC) was determined by a centrifugation method (Kristensen and Purslow, 2001), with the following modification. 0.5 gram of homogenized tissue was placed in a 2 mL centricon tube (VIDAS, France). The sample containing tube was then placed in a 50 mL centrifugation tube, heated in a 70°C water bath for 30 min, and centrifuged at 100 g (Hitatchi, SCR20BA, Japan) for 10 min at room temperature (ca. 18°C). WHC was expressed as a percentage of weight loss of sample tissue during the centrifugation. WBSF was measured on cooked meat blocks (50 × 50 × 25 mm) in a pre-heated water bath for 40 min until the core temperature reached 80º and then cooled in running water (ca. 18ºC) for 30 min to reach a core temperature below 30ºC. Eight cores of 1.27-cm diameter were made for each sample, and peak force was determined using a V-shaped shear blade of an Instron Universal Testing Machine (Model 5543, USA) with a cross-head speed of 400 mm/min (Wheeler *et al*., 2000).

Cooking loss (%) was calculated as the percentage of weight change during cooking for the WBSF measurement. For cooking loss determination, the samples were freshly cut into blocks and weighed (initial weight). Individual cooked meat block samples were removed from the water-bath, cooled in cold water, and weighed. Cooking loss was then expressed as the percentage of the initial sample weight (Honikel, 1998). Sarcomere length was measured using a Helium-Neon laser diffraction technique according to the method described by Cross *et al.* (1981).

Sensory evaluation

For sensory evaluation of the loin and top round muscles, the beef strips (50 × 75 × 40 mm) were cooked by placing them on a tin plate equipped with a water jacket (at approximately 245-255°C). Strips were turned at the first pooling of liquid on the surface of the sample or at the start of shrinkage. The cooked strips were immediately served to 7 trained sensory panelists for evaluation. The panelists were asked to score the samples for tenderness, juiciness, flavor, and overall liking. Scoring was performed on a single sheet using 6-point line scale. Tenderness ranged from very tough (1) to very tender (6); juiciness ranged from very dry (1) to very juicy (6). Flavor ranged from extreme dislike (1) to extreme liking (6); overall liking ranged from extreme dislike (1) to extreme liking (6).

Statistical analysis

Each animal within the same slaughtering age group was treated as a replicate. Data were analyzed using the Student-Newman-Keuls' multiple comparison, using the General Linear Model procedure of the SAS program (2010). The significance level was set at $p<0.05$.

Results and Discussion

Chemical composition

The protein, moisture, fat, and collagen contents of the 12 muscles from Hanwoo bull beef are shown in Table 1. The protein content (%) of loin, striploin, top round, eye of round, and bottom round muscles is between 21.97 and 22.50% and is significantly higher than the protein content of chuck roll, chuck tender, oyster blade and short plate muscles (19.17-20.66%) ($p<0.05$). The moisture content of bottom round muscle (73.98%) is significantly higher than that of tenderloin, loin, and short plate muscles (68.55-70.20%) ($p<0.05$). Intramuscular fat content is the highest in the short plate muscle (8.39%), whereas eye of round (2.79%) and bottom round (2.40%) muscles are the lowest ($p<0.05$). The collagen content of chuck roll (2.04%), chuck tender (1.97%), and short plate (1.99%) muscles was significantly higher than that of striploin muscle (1.48%) ($p<0.05$). No significant difference in the total collagen content is found among the other eight muscles ($p>0.05$; Table 1). Many workers have observed variation in the composition of muscles from cattle carcasses. The sex of the animal, quality grade, weight of the carcass, and location of muscle can all play a part in variation of muscle composition (Brackebusch *et al*., 1991; Von Seggern *et al*., 2005). The intramuscular fat is an important meat characteristics for consumers because of its positive effects on taste, juiciness, and tenderness (Platter *et al*., 2005). Jeremiah *et al*. (2003b) reported that fat and moisture are correlated with juiciness. Nishimura *et al*. (1999) also reported that intramuscular fat affects juiciness and flavor directly and tenderness indirectly and accounts for 12-14% of the variation in all palatability traits. Intramuscular fat deposited between fasciculi dis-

Table 1. Chemical compositions of 12 cuts from Hanwoo bull beef

Cut	Protein (%)	Moisture (%)	Fat (%)	Collagen (%)
Tenderloin	$21.72±0.18^{ab}$	$70.20±0.58^{e}$	$6.64±0.30^{b}$	$1.57±0.17^{bc}$
Loin	$21.97±0.30^{a}$	$70.03±0.42^{e}$	$6.16±0.34^{bc}$	$1.52±0.0^{bc}$
Striploin	$22.07±0.33^{a}$	$70.36±0.42^{de}$	$6.09±0.27^{bc}$	$1.48±0.07^{c}$
Chuck roll	$20.33±0.38^{c}$	$70.82±0.62^{de}$	$5.25±0.25^{bc}$	$2.04±0.09^{a}$
Chuck tender	$20.66±0.35^{b}$	$72.23±0.20^{bcd}$	$5.19±0.46^{bc}$	$1.97±0.13^{a}$
Oyster blade	$20.39±0.24^{c}$	$71.44±0.25^{abc}$	$4.64±0.36^{c}$	$1.66±0.10^{abc}$
Short plate	$19.17±0.21^{d}$	$68.55±0.60^{f}$	$8.39±0.38^{a}$	$1.99±0.08^{a}$
Top sirloin	$21.64±0.32^{ab}$	$71.44±0.25^{cde}$	$5.21±0.36^{bc}$	$1.66±0.10^{abc}$
Top round	$22.07±0.3^{a}$	$71.34±0.32^{cde}$	$5.13±0.32^{bc}$	$1.63±0.09^{abc}$
Eye of round	$22.50±0.40^{a}$	$73.40±0.34^{ab}$	$2.79±0.27^{d}$	$1.74±0.09^{abc}$
Bottom round	$22.12±0.4^{a}$	$73.98±0.23^{a}$	$2.40±0.26^{d}$	$1.92±0.07^{ab}$
Brisket	$21.31±0.27^{abc}$	$71.48±0.70^{cde}$	$5.62±0.83^{bc}$	$1.92±0.09^{ab}$

*Mean±SE.

[a,b]Means in the same column within the same category with different letters are significantly different ($p<0.05$).

rupts the honeycomb structure of the endomysium and separates and the perimysial fibers, thereby increasing tenderness. Collagen is the main connective tissue protein in animals and it forms the structural framework for muscle and adipose tissue (Flint and Pickering, 1984). It also is one of the factors affecting tenderness in beef. Collagen with few intermolecular cross-linkages is converted to gelatin, which improves tenderness, but when many intermolecular cross-linkages are present, moisture is squeezed out of the muscle, decreasing tenderness (Ledward, 1984). In the study by Jeremiah *et al*. (2003a), insoluble collagen was associated more closely with palatability traits than were total or soluble collagen. A majority of the tenderest muscles, such as tenderloin, striploin, and rib-eye cap, had low insoluble collagen, whereas the shank meat, neck, and deckle point contained the highest insoluble collagen contents. Rhee *et al*. (2004) reported that *m. psoas major* (PS) had the lowest concentration of collagen, followed by *gluteus medius* (GM) and *longissimus dorsi* (LD) while *biceps femoris* (BF), *semitendinosus* (ST) and *supraspinatus* (SS) muscles had the highest concentration of collagen. Overall, muscles from the loin and rib had a lower collagen concentration than that in the chuck and round muscles.

Meat quality

In terms of meat color, CIE L* (lightness) values increased with an increase in aging days for tenderloin, loin, chuck roll, oyster blade, short plate, and top sirloin muscles ($p<0.05$; Table 2). The CIE a* (redness) and b* (yellowiness) values of the short plate muscle are significantly higher at 7, 14, and 21 d than at 0 d, respectively ($p<0.05$). However, no significant differences in the CIE a* and b* values is seen among the other 11 muscles with an increase in aging days. The CIE L*, a*, b* values are compared for the 12 muscles at each aging day in Table 2. The eye of round muscle has the numerically highest CIE L* value at 0 d (35.96), 7 d (40.48), and 14 d (39.42) among the 12 muscles. The loin, striploin, chuck roll, chuck tender, oyster blade, short plate, top sirloin, top round, and brisket muscles have significantly lower CIE L* values than eye of round muscle at day 7 ($p<0.05$). The chuck tender (35.14) muscle has the lowest CIE L* values among the 12 muscles at 14 d ($p>0.05$). No significant differences in the CIE L* values are found among the 12 muscles at 21 d ($p>0.05$). When the CIE a* and b* values are compared with aging day, only the CIE b* values of the brisket muscle are significantly higher than those of the oyster blade muscle at 7 d ($p<0.05$). Other than brisket,

Table 2. Meat color (CIE) of 12 cuts from Hanwoo bull beef during 21 d of aging at 2°C

Cut	Aging days	Meat color		
		L*	a*	b*
Tender loin	0	34.07 ± 0.76^{bAB}	17.08 ± 0.60	7.16 ± 0.50
	7	38.02 ± 0.98^{aAB}	21.55 ± 3.07	8.08 ± 0.32^{AB}
	14	37.28 ± 0.41^{aAB}	18.61 ± 0.40	7.76 ± 0.23
	21	36.77 ± 0.85^{a}	18.45 ± 0.47	7.85 ± 0.31
Loin	0	33.12 ± 0.83^{bAB}	16.46 ± 0.75	6.37 ± 0.72
	7	36.00 ± 1.07^{aB}	17.97 ± 0.93	7.31 ± 0.74^{AB}
	14	36.41 ± 1.28^{aAB}	18.11 ± 0.96	7.20 ± 0.83
	21	36.17 ± 1.41^{a}	18.09 ± 0.98	7.31 ± 0.79
Striploin	0	32.06 ± 1.01^{B}	16.69 ± 0.96	6.581 ± 0.94
	7	35.08 ± 0.74^{B}	17.79 ± 0.81	7.17 ± 0.73^{AB}
	14	35.43 ± 1.23^{AB}	18.64 ± 1.02	7.91 ± 0.85
	21	35.93 ± 1.17	18.23 ± 0.70	7.65 ± 0.77
Chuck roll	0	33.38 ± 0.61^{bAB}	18.37 ± 0.60	7.78 ± 0.65
	7	36.41 ± 0.61^{aB}	19.32 ± 0.45	8.64 ± 0.28^{AB}
	14	36.11 ± 0.61^{aAB}	18.92 ± 0.69	7.51 ± 0.36
	21	36.19 ± 0.65^{a}	19.15 ± 0.42	7.79 ± 0.37
Chuck tender	0	33.40 ± 0.63^{AB}	18.46 ± 0.74	7.88 ± 0.59
	7	36.14 ± 0.81^{B}	19.36 ± 0.52	7.87 ± 0.38^{AB}
	14	35.14 ± 0.58^{B}	18.72 ± 0.22	7.02 ± 0.19
	21	35.03 ± 0.84	18.63 ± 0.62	7.05 ± 0.50
Oyster blade	0	32.63 ± 0.40^{bAB}	17.88 ± 0.38	6.49 ± 0.29
	7	34.37 ± 0.68^{aB}	18.59 ± 0.59	6.96 ± 0.39^{B}
	14	36.32 ± 0.51^{aAB}	19.37 ± 0.46	7.54 ± 0.41
	21	35.52 ± 0.67^{a}	19.39 ± 0.24	7.70 ± 0.27
Short plate	0	33.74 ± 0.85^{bAB}	16.99 ± 0.50^{b}	5.69 ± 0.58^{b}
	7	36.98 ± 0.98^{aB}	18.74 ± 0.57^{a}	7.70 ± 0.54^{aAB}
	14	37.39 ± 0.45^{aAB}	19.62 ± 0.47^{a}	7.89 ± 0.33^{a}
	21	37.80 ± 0.89^{a}	19.05 ± 0.48^{a}	8.06 ± 0.48^{a}
Top sirloin	0	32.01 ± 0.62^{bB}	16.95 ± 0.98	6.59 ± 0.73
	7	35.36 ± 1.22^{aB}	18.59 ± 0.91	8.35 ± 0.82^{AB}
	14	36.09 ± 0.81^{aAB}	18.81 ± 0.85	8.10 ± 0.65
	21	35.08 ± 0.92^{a}	17.93 ± 0.68	7.14 ± 0.65
Top round	0	34.09 ± 0.70^{AB}	17.74 ± 0.44	7.55 ± 0.61
	7	35.07 ± 0.75^{B}	19.00 ± 0.66	7.93 ± 0.77^{AB}
	14	36.22 ± 1.16^{AB}	19.98 ± 0.91	8.59 ± 0.82
	21	34.94 ± 1.22	18.64 ± 0.90	7.66 ± 0.78
Eye of round	0	35.86 ± 1.07^{A}	17.45 ± 0.91	8.29 ± 0.83
	7	40.48 ± 1.52^{A}	17.78 ± 0.55	9.12 ± 0.69^{AB}
	14	39.42 ± 1.12^{A}	18.53 ± 0.88	8.48 ± 0.72
	21	38.85 ± 1.28	18.34 ± 0.82	9.07 ± 0.9
Bottom round	0	34.21 ± 1.06^{AB}	18.10 ± 0.89	8.28 ± 0.85
	7	37.51 ± 1.01^{AB}	19.39 ± 0.57	8.90 ± 0.51^{AB}
	14	36.34 ± 0.98^{AB}	18.37 ± 0.50	8.35 ± 0.52
	21	34.62 ± 1.04	18.34 ± 0.75	7.55 ± 0.65
Brisket	0	34.17 ± 0.68^{AB}	19.24 ± 0.48	8.77 ± 0.39
	7	36.23 ± 0.83^{B}	21.19 ± 0.45	9.78 ± 0.37^{A}
	14	36.30 ± 0.54^{AB}	20.10 ± 0.92	8.98 ± 0.52
	21	35.57 ± 0.85	20.88 ± 0.36	9.39 ± 0.26

*Mean±SE.
^{a,b}Means in the same cuts among the aging days within the same category with different letters are significantly different ($p<0.05$).
^{A,B}Means in the same aging day among 12 cuts within the same category with different letters are significantly different ($p<0.05$).

no significant differences are seen among the 11 muscles (*p*>0.05). Myoglobin comprises 80-90% of the color pigment in beef, and it binds oxygen and maintains the purple red color of the beef muscle. Myoglobin quantity varies with species, age, sex, muscle and physical activity. Muscle to muscle differences in myoglobin contents are due to the type of muscle fibers present. Those muscles with relatively high proportion (30-40%) of red fibers appear dark red in color (Judge *et al.,* 1989). The positive correlation between pigment content and color intensity is generally accepted. Dikeman *et al.* (2013) reported that the lightness (CIE L*) value of USDA Choice grading beef was the highest for wet aged beef when compared to those for dry aged or special bag aged beef. Color is also correlated with the ultimate pH, such that lightness, redness, and reflectance decrease with an increase in the ultimate pH (Guignot *et al.*, 1993). Muscles vary in their rate of decline in pH post mortem.

The water-holding capacity (WHC), Warner-Bratzler shear force (WBSF), cooking loss (CL), and sarcomere length (SL) of the 12 muscles are compared in Table 3. The WHC of tenderloin, top sirloin, and bottom round muscles increases as the aging periods increases, however, the other muscles do not show significant differences in WHC during 21 d of aging (*p*>0.05). With the exception of the tenderloin, the WBSF values of the other muscles in this study decrease significantly as the aging period increases (*p*<0.05). Tenderloin muscles show little change in WBSF values (3.21-3.67 kg) during the 21-d aging period. Chuck tender muscle has the higher CL than tenderloin, loin, striploin and short plate muscles at 0, 7, 14, and 21 d (*p*<0.05). Top round muscle has the highest CL at 0 d, however, it is not significantly different from the striploin, chuck roll, oyster blade, top sirloin, eye of round, bottom round, and brisket muscles during overall aging (*p*>0.05). Tenderloin muscle has the longest SL and it is not significantly changed during aging. Bottom round muscle has the shorter SL than tenderloin, loin, striploin, oyster blade and short plate muscles during the overall aging period (*p*<0.05). Rhee *et al*. (2004) reported that the PS muscle was most tender and was followed by IS (infraspinatus) muscle in both shear force and tenderness ratings. In their study, the *biceps femoris* (BF) muscle had the lowest tenderness rating. Also, the *psoas major* muscle had the lowest collagen content and the longest sarcomeres compared with other muscles; however, they also found that it showed less desmin degradation, which relates to less improvement in tenderness due to aging. In the present study, WBSF of muscle rankings for tenderness generally agree with those of Rhee *et al*. (2004). During refrigerated storage for 28 d, different protein patterns and degradation rates of structural proteins, such as titin, nebulin, and filamin, were found over time, depending on meat pH. The fast degradation of these proteins corresponding to myosin family members is a key factor in the improvement of meat tenderness. According to Rhee *et al.* (2004), cooking loss was the lowest for *biceps femoris* (BF) and was followed by *longissimus dorsi* (LD), and *infraspinatus* (IS) muscles, while it was highest for *semitendinosus* (ST). Although the tenderness rating was highly correlated with shear force, connective tissue rating, sarcomere length, and collagen content for all muscles, Rhee *et al*. (2004) reported that sarcomere length might contribute more to the variability than that by connective tissue. The *psoas major* (PS), *supraspinatus* (SS), *triceps brachii* (TB), *infraspinatus* (IS) and *semitendinosus* (ST) muscles had relatively long sarcomere lengths, whereas the *gluteus medius* (GM) muscle had the shortest sarcomere length. These results were in general similar to the results of the present study, although the overall sarcomere length was longer in this study than in Rhee *et al*. (2004).

Sensory evaluation

The results of the sensory evaluation are shown in Table 4. Tenderness and overall-likeness scores increase with an increase in aging days for most muscles except tenderloin, oyster blade, and eye of round (*p*<0.05; Table 2). The tenderloin and oyster blade show relatively higher values in tenderness and overall-likeness during the entire aging period. No significant differences in juiciness and flavor-likeness scores are found among all muscles with an increase in aging days (*p*>0.05). The tenderloin and oyster blade muscle have the highest tenderness and overall-likeness scores at 0 and 7 d. The tenderloin muscle has the high scores for tenderness, flavor-likeness, and overall-likeness at 0, 7, 14, and 21 d when compared with the other muscles (*p*<0.05). The loin and oyster blade muscles have the higher juiciness scores than chuck tender, top round, eye of round and bottom round muscles at 14 d and 21 d (*p*<0.05). Both the tenderloin and loin muscles have the highest flavor-likeness and overall-likeness scores at 14 d and 21 d (*p*<0.05). Although aging improves sensory properties such as tenderness and overall-likeness, chuck tender, top round, eye of round, and bottom round muscles (2.96-3.91) have relatively lower scores than those of tenderloin, loin, striploin, and oyster blade muscles (4.07-5.19) for 14 d and 21 d (*p*<0.05). When

Table 3. Water-holding capacity (WHC), Warner-bratzler shear force (WBSF), cooking loss (CL) and sarcomere length (SL) of 12 cuts from Hanwoo bull beef during 21 d of aging at 2°C

Cut	Aging days	WHC (%)	WBSF (kg)	CL (%)	SL (μm)
Tender loin	0	58.60±0.85^{bA}	3.67±0.09^{B}	29.98±0.52^{E}	3.67±0.08^{A}
	7	59.98±0.24^{abAB}	3.36±0.10^{BC}	30.37±0.52^{D}	3.67±0.06^{A}
	14	59.94±0.80^{abABC}	3.25±0.20^{CD}	30.28±0.61^{E}	3.79±0.09^{A}
	21	61.11±0.50^{aA}	3.21±0.13^{CDE}	30.67±0.54^{D}	3.86±0.06^{A}
Loin	0	57.01±1.11^{AB}	5.36±0.75^{aAB}	32.58±1.90^{CDE}	2.99±0.03^{bCD}
	7	61.97±1.53^{A}	4.23±0.17^{abAB}	30.10±2.01^{D}	2.98±0.06^{bC}
	14	61.94±1.14^{A}	3.15±0.20^{bcCD}	31.84±1.07^{DE}	3.17±0.07^{abBC}
	21	61.27±1.44^{A}	2.79±0.15^{cDE}	30.59±1.61^{D}	3.37±0.11^{aB}
Striploin	0	57.80±0.84^{bAB}	5.15±0.78^{aAB}	30.69±1.88^{DE}	3.02±0.09^{bCD}
	7	62.05±0.92^{aA}	3.90±0.37^{abABC}	33.09±1.35^{BCD}	3.38±0.04^{aAB}
	14	61.41±0.75^{abAB}	2.85±0.28^{bD}	32.34±1.35^{CDE}	3.38±0.04^{aAB}
	21	60.37±1.51^{abA}	2.62±0.25^{bE}	31.71±1.61^{CD}	3.51±0.08^{aB}
Chuck roll	0	54.13±1.14^{B}	5.18±0.18^{aAB}	34.88±0.77^{ABCD}	2.78±0.06^{aCDE}
	7	55.85±0.75^{C}	4.20±0.21^{bAB}	35.37±0.93^{BC}	2.52±0.05^{bDE}
	14	56.26±1.04^{C}	3.52±0.17^{cCD}	34.22±1.18^{BCD}	2.71±0.05^{aDE}
	21	56.47±0.76^{BC}	3.06±0.17^{cCDE}	35.57±0.66^{B}	2.72±0.06^{aCD}
Chuck tender	0	55.50±0.70^{AB}	5.27±0.28^{aAB}	38.08±0.76^{A}	2.70±0.08^{DEF}
	7	55.70±0.96^{C}	4.24±0.26^{bAB}	39.61±0.61^{A}	2.57±0.06^{DE}
	14	57.97±0.65^{AB}	4.38±0.26^{bAB}	40.23±0.83^{A}	2.67±0.12^{DE}
	21	57.77±0.50^{ABC}	4.01±0.23^{bAB}	40.20±0.48^{A}	2.56±0.09^{DE}
Oyster blade	0	55.04±0.80^{AB}	3.73±0.23^{aB}	32.17±1.46^{bCDE}	3.41±0.20^{AB}
	7	57.40±1.05^{BC}	3.10±0.12^{bC}	32.35±1.00^{bCD}	3.38±0.18^{AB}
	14	57.70±0.40^{BC}	3.22±0.09^{bCD}	35.37±0.19^{abBC}	3.26±0.11^{BC}
	21	56.35±0.45^{C}	2.85±0.13^{bDE}	36.29±0.62^{aB}	3.26±0.09^{B}
Short plate	0	53.80±0.80^{B}	4.30±0.15^{aB}	30.37±1.34^{bDE}	3.16±0.25^{BC}
	7	55.26±0.99^{C}	3.94±0.15 ^{abABC}	30.96±0.80^{abD}	3.07±0.20^{BC}
	14	57.07±0.89^{C}	3.88±0.12 ^{abABC}	3.17±0.23^{abE}	3.17±0.23^{BC}
	21	56.65±1.15^{BC}	3.75±0.14^{bBC}	3.37±0.21^{aBCD}	3.37±0.21^{B}
Top sirloin	0	57.26±0.86^{bAB}	5.18±0.26^{aAB}	34.98±0.07^{ABCD}	2.28±0.07^{cF}
	7	59.60±0.46^{abAB}	4.12±0.27^{bAB}	34.85±0.57^{BC}	2.37±0.07^{cE}
	14	59.17±0.82^{abABC}	3.97±0.19^{bABC}	36.49±0.75^{B}	2.62±0.09^{bDE}
	21	60.68±0.48^{aA}	3.26±0.10^{cCDE}	34.82±0.85^{BC}	2.84±0.06 ^{aCD}
Top round	0	57.82±0.72^{AB}	6.18±0.44^{aA}	38.93±0.074^{aA}	2.48±0.07^{EF}
	7	58.78±0.53^{ABC}	4.52±0.27^{bA}	36.48±0.48^{bAB}	2.31±0.04^{E}
	14	59.87±0.73^{ABC}	3.85±0.21^{bcABC}	34.40±0.64^{bBCD}	2.42±0.10^{EF}
	21	60.11±0.57^{AB}	3.40±0.11^{cBCDE}	34.65±1.17^{bBC}	2.52±0.08^{DE}
Eye of round	0	56.16±1.47^{AB}	5.17±0.31^{aAB}	36.13±1.29^{ABC}	2.48±0.06^{bED}
	7	58.67±0.84^{AB}	4.38±0.25^{bAB}	35.95±1.07^{ABC}	2.50±0.05^{abDE}
	14	57.54±1.18^{BC}	3.39±0.22^{cCD}	35.63±0.91^{BC}	3.03±0.08^{aCD}
	21	58.36±0.79^{ABC}	3.14±0.18^{cCDE}	35.86±1.29^{B}	2.97±0.10^{aC}
Bottom round	0	53.91±1.15^{bB}	6.14±0.30^{aA}	37.26±0.58^{AB}	2.33±0.02^{EF}
	7	58.26±0.64^{aBC}	4.74±0.44^{bA}	37.01±0.46^{AB}	2.21±0.07^{E}
	14	57.51±1.47^{aABC}	4.03±0.36^{bABC}	37.06±0.73^{B}	2.22±0.08^{F}
	21	59.93±0.64^{aABC}	3.55±0.34^{bBCD}	35.97±0.12^{B}	2.35±0.12^{E}
Brisket	0	56.25±0.79^{AB}	5.01±0.16^{aAB}	37.04±0.06^{AB}	2.42±0.06^{EF}
	7	58.12±0.71^{BC}	4.61±0.13^{bA}	36.67±0.71^{AB}	2.80±0.09^{CD}
	14	58.15±0.83^{ABC}	4.47±0.14^{bA}	36.73±0.53^{B}	2.76±0.05^{DE}
	21	58.63±0.54^{ABC}	4.38±0.09^{bA}	37.58±0.10^{AB}	2.85±0.10^{CD}

*Mean±SE.

^{a,b}Means in the same cuts among the aging days within the same category with different letters are significantly different (p<0.05).

^{A,B}Means in the same aging day among 12 cuts within the same category with different letters are significantly different (p<0.05).

Table 4. Sensory evaluation of Hanwoo bull beef during 21 d of aging at 2°C

Cut	Aging days	Tenderness	Juiciness	Flavor-likeness	Overall likeness
Tender loin	0	5.28±0.09^{A}	3.94±0.21^{BC}	4.43±0.13^{A}	4.33±0.09^{A}
	7	5.20±0.17^{A}	3.89±0.26^{ABC}	4.69±0.16^{A}	4.49±0.14^{A}
	14	5.07±0.12^{A}	3.85±0.16^{ABC}	4.47±0.13^{A}	4.36±0.14^{A}
	21	5.19±0.08^{A}	3.95±0.18^{CDE}	4.56±0.13^{A}	4.54±0.11^{A}
Loin	0	3.15±0.33^{cCD}	4.04±0.34^{BC}	4.31±0.19^{ABC}	3.30±0.16^{cBC}
	7	3.90±0.31^{bcB}	4.09±0.38^{ABC}	4.34±0.18^{ABC}	3.87±0.19^{bB}
	14	4.34±0.24^{abB}	4.39±0.25^{A}	4.43±0.23^{A}	4.33±0.16^{abA}
	21	5.08±0.14^{aAB}	4.64±0.17^{A}	4.57±0.15^{A}	4.69±0.14^{aA}
Striploin	0	3.58±0.34^{bC}	4.21±0.18^{AB}	4.14±0.18^{ABC}	3.44±0.15^{bB}
	7	3.63±0.25^{bBC}	4.22±0.23^{AB}	4.24±0.19^{ABC}	3.78±0.16^{abB}
	14	4.44±0.20^{abAB}	4.21±0.20^{AB}	4.29±0.19^{AB}	4.07±0.17^{aAB}
	21	4.58±0.19^{aB}	4.42±0.13^{AB}	4.24±0.20^{AB}	4.23±0.19^{aAB}
Chuck tender	0	2.89±0.16^{bCD}	3.51±0.14^{C}	3.61±0.14^{C}	3.04±0.14^{abBCD}
	7	2.38±0.08^{aE}	3.18±0.22^{C}	3.59±0.13^{D}	2.74±0.07^{bE}
	14	3.17±0.19^{aC}	3.65±0.14^{BC}	3.86±0.11^{B}	3.37±0.17^{aCD}
	21	3.39±0.18^{aC}	3.31±0.16^{D}	3.61±0.16^{BC}	3.27±0.10^{aD}
Oyster blade	0	4.64±0.20^{B}	4.63±0.11^{A}	4.31±0.16^{AB}	4.47±0.12^{A}
	7	4.72±0.15^{A}	4.56±0.18^{A}	4.53±0.09^{AB}	4.53±0.12^{A}
	14	4.49±0.16^{AB}	4.43±0.13^{A}	4.18±0.16^{AB}	4.24±0.16^{AB}
	21	4.80±0.11^{AB}	4.54±0.12^{A}	4.26±0.16^{AB}	4.22±0.18^{AB}
Top sirloin	0	3.00±0.19^{bCD}	3.81±0.16^{C}	3.95±0.08^{ABC}	3.22±0.14^{bBCD}
	7	3.35±0.24^{abBCD}	3.64±0.24^{BC}	4.00±0.15^{BCD}	3.49±0.20^{abBC}
	14	3.62±0.18^{abC}	3.89±0.14^{ABC}	4.20±0.17^{AB}	3.70±0.15^{abBC}
	21	4.02±0.18^{aC}	4.21±0.14^{ABC}	4.17±0.09^{ABC}	3.97±0.11^{aBC}
Top round	0	2.37±0.22^{bD}	3.52±0.17^{BC}	3.83±0.13^{BC}	2.78±0.13^{bCD}
	7	2.90±0.18^{bCDE}	3.28±0.19^{C}	3.71±0.11^{CD}	3.00±0.11^{abCDE}
	14	3.26±0.21^{aC}	3.74±0.14^{BC}	3.80±0.12^{B}	3.36±0.15^{aCD}
	21	3.43±0.17^{aC}	3.43±0.17^{D}	3.63±0.11^{C}	3.28±0.16^{aD}
Eye of round	0	3.36±0.24^{C}	3.68±0.21^{BC}	3.92±0.16^{ABC}	3.40±0.19^{B}
	7	3.35±0.21^{BCD}	3.50±0.11^{BC}	3.89±0.14^{CD}	3.41±0.12^{BCD}
	14	3.43±0.17^{C}	3.49±0.20^{C}	3.80±0.11^{B}	3.42±0.13^{CD}
	21	3.91±0.19^{C}	3.72±0.15^{CD}	4.00±0.14^{ABC}	3.71±0.12^{BCD}
Bottom round	0	2.42±0.12^{bD}	3.64±0.15^{BC}	3.76±0.10B^{C}	2.74±0.12^{bD}
	7	2.72±0.18^{bDE}	3.39±0.21^{BC}	3.78±0.11^{CD}	2.91±0.14^{bDE}
	14	2.96±0.30^{bC}	3.35±0.24^{C}	3.58±0.14^{B}	3.09±0.22^{abD}
	21	3.45±0.15^{aC}	3.61±0.16^{D}	3.85±0.14B^{C}	3.46±0.15^{aCD}

*Mean±SE.

^{a,b}Means in the same cuts among the aging days within the same category with different letters are significantly different (p<0.05).

^{A,B}Means in the same aging day among 9 cuts within the same category with different letters are significantly different (p<0.05).

deciding to purchase beef, palatability is the primary sensory trait of consumer acceptance. The main attribute of palatability influencing consumer acceptance is tenderness (Jeremiah *et al*., 2003b; Mennecke *et al.,* 2007). In this study, the tenderloin muscle had the highest sensory ratings, followed by loin and oyster blade, whereas bottom round muscles received the lowest ratings. These results are consistent with previous reports (Jeremiah *et al*., 2003a; Rhee *et al*., 2004; Shackelford *et al*., 1995). Jeremiah *et al*. (2003b) analyzed the relationships between sensory panel scores and certain chemical components of 33 muscles and showed that fat and moisture are correlated with juiciness. Bulls have been reported to possess lean meat containing greater quantities of connective tissue, with lower solubility (Crouse *et al*., 1985; Peachy *et al.,* 2002). Young and Braggins (1993) reported panel tenderness was closely related to collagen content, especially for better predicting meat tenderness in less tender muscles. On the other hand, the toughness of meat has been attributed to low activity of proteolytic enzymes in the muscle samples, especially calpains, which are considered to play a key role in the degradation of specific muscle proteins (Huff-Lonergan *et al*., 1996; Marino *et al*., 2013). It is well documented that degradation of titin, nebulin, desmin, and troponin T in myofibrils during refrigerated storage contributes to meat tenderness (Huff-Lonergan *et al*., 2010; Lomiwes *et al*., 2014).

Conclusions

Beef cuts traditionally have been marketed using labels for anatomical sections of a carcass. The results of this study have shown that 12 cuts of bull beef varied considerably in their physical and sensory properties. Although bull beef cuts such as chuck roll, chuck tender, top round, and bottom round usually have less intramuscular fat and are tougher than tenderloin, loin and striploin muscle, acceptable meat quality and sensory properties possibly improved with the aging treatments. To provide consumers with consistently tender beef products, cut-specific aging strategies should be developed to improve the value of bull beef by targeting muscle characteristics. This will increase consumer satisfaction and increase consumption of bull beef, thus reintroducing bulls into the production chain.

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