



Effects of Tethering and Loose Housing on the Meat Quality of Hanwoo Bulls

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ABSTRACT : This study was carried out to investigate the effects of housing system on the carcass and meat qualities of Hanwoo (Korean cattle) bulls. Fourteen 6 months-old male calves were randomly divided into two groups. The first group was individually tethered using double neck-bar tethers. The second group was collectively loose-housed in the pen. They were raised for 15 months prior to slaughter. At 24 h post-slaughter chilling, the carcasses were weighed and evaluated by official grader for carcass traits. At 48 h post-slaughter chilling, the *M. longissimus* at the 12-13th thoracic vertebra from each carcass was collected and stored at 4±0.2°C for 7 days for meat quality analysis. There were no significant differences in dressing percentage and carcass yield index between groups. Meat from loose bulls had lower marbling score ($p<0.05$) and fat content ($p<0.01$) but higher PUFA concentration ($p<0.001$) than that from tethered bulls. There were no significant differences physical and sensory properties, aroma pattern, TBARS value, metmyoglobin concentration and CIE color values during refrigerated storage between groups. Compared to tethering, loose-housing bulls produced lower fat content and healthier meat without different physical properties, acceptability, and lipid and color stabilities. (**Key Words** : Housing System, Tethering, Loose Housing, Meat Quality, Hanwoo Bull)

INTRODUCTION

Recently, human well-being and animal welfare become concerning issues related to beef production system. Human well-being requires high quality foods including beef. Animal welfare requires appropriate production systems. Hodges (2000) defined animal welfare as, "the care of animals kept in the service of mankind, so that their well-being is provided for, their natural needs are not restricted, and their worth and dignity as individuals are recognized". Animal housing is an important factor in animal welfare which may affect beef quality. There are two types of housing for cattle which are practiced in Korea, i.e. tethering and loosing.

Tethering may be practiced in order to improve the effectiveness and efficiency of production. Tethering restricts animals' movement and exercise opportunity so that improve the nutrient utilization for production such as

fat deposition and body weight gain. In rats, exercise per se seems to increase the utilization and handling of lipid and glucose overall and in addition to higher energy expenditure reduces body weight (Krestchmer et al., 2005). Tethering also decreases the content of collagen so that increase meat tenderness. Jurie et al. (1998) reported that tethered bulls had a lower collagen content compared to loose bulls. Collagen significantly influences meat tenderness; amount of collagen is associated with toughness (Judge et al., 1989). However, tethering is criticized for its reducing animal welfares, especially in relation to two points of five freedoms, i.e. freedom from discomfort and freedom to express normal behavior (FAWC, 2007). Restriction of performing normal behavior patterns is part of the specific psychological stressors on the rearing conditions (Sato, 2001). The physiological evidence that the hypothalamo-hypophysial-adrenal axis is stimulated and T-cell function affected also suggests that tethering reduces the welfare of cattle (Phillips, 2002).

An alternative housing system which may meet the animal welfare concern is loose housing in a group pens with an adequate space allowance. Gyax et al. (2007) concluded that space allowance up to 4 m²/head has several beneficial and no negative effects on indicators of the

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welfare of finishing bulls kept on a fully slatted rubber coated floor. This study was carried out to investigate the effects of housing system (i.e. loose housing and tethering) on the carcass and meat qualities of Hanwoo (Korean cattle) bulls.

MATERIALS AND METHODS

Animals and treatments

Fourteen heads of 6 months aged male calves were randomly divided into two groups ($n = 7/\text{group}$). The calves in the first group were individually tethered using double right and left neck-bar nylon tethers which were fixed at the end right and left width of the stall. The width of stall was 2 m/head and the length of tether was 0.9 m/piece. Each animal was separated by double 2 m-length metal pipes which were placed across the width at 0.5 m and 1 m from the floor. The calves in the second group were collectively loose housed in the pen. The pen size was $7 \times 8 \text{ m}^2$. The floors of pen were solid without litter for the first group and solid with 10 cm of sawdust-litter for the second group. The floor of the first group was cleaned everyday whereas the litter of the second group was changed every 2 months. All of calves were fed *ad libitum* with the same commercial concentrate and rice straw as a finishing diet. They were raised for 15 months prior to be slaughtered.

Carcass traits

At 24 h post-slaughter chilling, the carcasses were weighed and evaluated by official grader for carcass traits according to the Korean carcass grading standard (NLCF, 2004). Sides were cut between the last rib and the first lumbar vertebrae to determine backfat thickness, ribeye (*M. longissimus*) and quality traits. Backfat thickness was determined over the medial third part of ribeye. Dressing percentage was calculated as the percentage of carcass weight to live weight. Yield index was calculated as follows.

$$\begin{aligned} \text{Yield index} = & 68.184 - (0.625 \times \text{back fat thickness (mm)}) \\ & + (0.130 \times \text{ribeye area (cm}^2\text{)}) \\ & - (0.024 \times \text{carcass weight (kg)}) + 3.23 \end{aligned}$$

Marbling, lean meat color, fat color and firmness scores were based on the exposed ribeye at the 13th rib interface. Marbling was about marbling that appear to ribeye area and was scored from 1 (devoid) to 9 (abundant) according to the standard. Lean meat color was scored from 1 (brightly cherry red) to 7 (extremely dark red) according to the standard. Fat color was scored from 1 (white) to 7 (dark yellow) according to the standard. Firmness was water folding capacity and elasticity of ribeye area in grade decision region and was scored from 1 (firm) to 3 (soft)

according to the reference index. Maturity was about ossification of cartilage in left semiconductor backbone thorn promontory and was scored from 1 (youthful) to 9 (mature) according to the reference index. Carcass quality grade was scored as follows.

- 5 = 1⁺⁺ grade (marbling score No. 8 or 9)
- 4 = 1⁺ grade (marbling score No. 6 or 7)
- 3 = 1 grade (marbling score No. 4 or 5)
- 2 = 2 grade (marbling score No. 2 or 3)
- 1 = 3 grade (marbling score No. 1)

Muscle samples

At 48 h post-slaughter chilling, the *M. longissimus* at the 12-13th thoracic vertebra from each carcass were collected for meat quality analysis.

Proximate and fatty acids compositions analyses

The proximate composition was performed as described by AOAC (1995). Moisture content was determined by drying the samples in the oven at 105°C for 24 h. Crude fat content was determined by ether extraction using Soxhlet system. Nitrogen content was determined using the Kjeltex system (2200 Kjeltex Auto Distillation Unit, Foss Tecator, Sweden) and crude protein was calculated as nitrogen content multiplied by 6.25. Crude ash was determined by burning the samples in the muffle furnace at 550°C for 12 h.

Total lipids were extracted as described by Folch et al. (1957) and converted to fatty acid methyl esters as described by AOAC (1995). Fatty acid methyl esters were measured using the gas chromatography (Agilent 6890N, Agilent Technologies, USA) equipped with a flame ionization detector (FID) and HP-Innowax fused silica capillary column (30 m length \times 0.32 mm id \times 0.25 μm film thickness, J&W Scientific, USA). Injector and FID temperatures were 220 and 275°C, respectively. The carrier gas was helium at the constant flow mode (1 ml/min) and the split ratio was 10:1. The initial oven temperature of 150°C was held for 1 min. After that, the oven temperature was increased to 200°C at 15°C/min, increased to 250°C at 3°C/min and held for 5 min at that temperature.

Physical properties analyses

Ten g of chopped meat was mixed with 10 ml of deionized water. The pH of slurry was measured using the pH meter (F-12, Horiba, Japan).

Water holding capacity (WHC) was performed as described by Honikel and Hamm (1994). A piece of filterpaper (Whatman No. 2) was placed on a plexiglass plate and 0.3 g of chopped meat was placed in its center. A second plexiglass was put on top and pressed tightly for 5 minutes. The filterpaper was then dried in the oven at 37°C

for 24 h. The size of meat and total (meat and fluid) area were measured by a planimeter (Super Planix α , Tamaya Technics Inc., Japan). WHC was calculated as the percentage of meat area to total area.

Drip loss was performed as described by Honikel (1998). Sample was cut into 1.5 cm of thickness, weighed, placed in low density polyethylene zipper bags (Cleanwrap Co., Ltd., Korea) and stored in refrigerator (CAG17DZ, LG Korea) at $4\pm 0.2^{\circ}\text{C}$ for 2 days. The sample was then blotted dry and weighed. The drip loss was expressed as a percentage of the initial weight.

Cooking loss was performed as described by Honikel (1998). Sample was cut into 2.5 cm of thickness, weighed, placed in low density polyethylene zipper bags (Cleanwrap Co., Ltd., Korea) and boiled in the water bath at 85°C until the internal temperature attained 75°C , cooled in ice slurry and held in chilling room for 12 h. The sample was then blotted dry and weighed. The cooking loss was expressed as a percentage of the initial sample weight.

The sample of cooking loss was then used for shear force assessment. Sample was cut with 1 cm^2 cross section with the fiber direction to a long dimension of 1.5 cm. Shear force was measured using a texture analyzer (TA-XT2i, Stable Microsystems Ltd., UK) equipped with a 25 kg load cell, a Warner-Bratzler shear blade, and a test speed setting at 2.0 mm/sec. Only the maximum force (kg) was taken into account.

Sensory properties and aroma pattern analyses

Part of meat samples was cut into pieces of 2 cm in width, 4 cm in length and 0.5 cm in thickness, and roasted in the electronic microwave for home use until internal temperature of 73°C was attained. The cooked meats were served in randomized order on plates for each panelist. Ten trained panelists were used to evaluate the sensory attributes of cooked meat. The taste, aroma, tenderness, juiciness and overall liking were evaluated using 9-point hedonic scales (9 = very good and 1 = very bad). Panelists were given a sufficient time to evaluate samples.

The aroma pattern was analyzed as described by Hariom et al. (2006). An electronic nose (FOX 3000, Alpha MOS, Toulouse, France) equipped with 12 metal oxide sensors was used. One g of chopped meat was placed into a 10 ml headspace vial, tightly capped with a PTFE/rubber septum and loaded into the automatic sampler tray. The vial was incubated at 40°C and agitation speed 500 rpm for 180 sec to allow the volatilization of flavor components into the headspace. Two and half ml of the sample headspace was extracted by the automatic sampler (HS 100, Alpha MOS, Toulouse, France) syringe at 45°C and flow-injected into the carrier gas flow (synthetic air mixture). The acquisition time was 150 sec.

Lipid oxidation analysis

Part of each sample was individually packaged in low density polyethylene zipper bags (Cleanwrap Co., Ltd., Korea) and stored in refrigerator (CAG17DZ, LG Korea) at $4\pm 0.2^{\circ}\text{C}$ for 7 days. The TBARS (2-thiobarbituric acid reactive substances) values were measured at 0, 2, 5 and 7 days of storage. The TBARS value was performed as a described by Sinnhuber and Yu (1977). Zero point four g of chopped meat was mixed with 3 drops of antioxidant solution, 3 ml of 2-thiobarbituric acid solution and 17 ml of trichloroacetic acid-HCl solution. Zero point four of deionized water was used as the blank. The mixture was then heated in the water bath (OB-25E, Jeio Tech, Korea) at $95\text{--}100^{\circ}\text{C}$ for 30 min and then cooled in the tap water for 10 min. Five ml of the color solution was transferred into test tube, added with 3 ml of chloroform, and centrifuged (GS-6R Centrifuge, Beckman, USA) at 3,000 rpm for 15 min. A part of the aqueous clear color solution was then transferred into cuvet for absorbance measurement at 532 nm using the UV-vis spectrophotometer (UV mini 1240, Shimadzu Co., Japan). The TBARS value was calculated as follows.

$$\text{TBARS value (mg malonaldehyde/kg meat)} = \frac{(\text{As} - \text{Ab}) \times 46}{\text{Sample weight (g)} \times 5}$$

As = Absorbance of sample

Ab = Absorbance of blank

Myoglobin and color stabilities analyses

Part of each sample was cut into 1.5 cm of thickness, wrapped with the low density polyethylene film (oxygen transmission rate = $35,273\text{ cc/m}^2\text{-24 h-atm}$, 0.01 mm of thickness, 3M Co., Korea) and stored in refrigerator (CAG17DZ, LG Korea) at $4\pm 0.2^{\circ}\text{C}$ for 7 days. The relative myoglobin concentration and the CIE (Commission Internationale de l'Eclairage) color values were measured at 0, 2, 5 and 7 days of storage. The relative myoglobin at the surface of meat was measured as described by Krzywicki (1979) using reflectance at 473, 525, 572 and 730 nm. Reflectance at selected wavelengths was measured using a UV-vis spectrophotometer (UV-2401PC, Shimadzu Co., Japan). Reflectance readings were converted to 2-log (% reflectance) and used in the equation as described by Demos et al. (1996).

$$\text{Metmyoglobin (\%)} = \frac{(1.395 - ((R_{572} - R_{730}) / (R_{525} - R_{730})))}{\times 100}$$

$$\text{Deoxymyoglobin (\%)} = \frac{2.375 \times (1 - ((R_{473} - R_{730}) / (R_{525} - R_{730})))}{\times 100}$$

Table 1. Carcass traits¹ of Hanwoo (Korean cattle) bulls with difference housing system²

Items	Tethered	Loose	Significance ³
Yield traits			
Slaughter weight (kg)	652.43±52.71	620.14±52.71	NS
Carcass weight (kg)	375.86±30.43	361.57±47.23	NS
Dressing percentage (%)	57.61±1.72	58.11±2.93	NS
Back fat thickness (mm)	7.71±5.59	4.00±1.00	NS
Ribeye area (cm ²)	83.00±8.21	84.29±6.37	NS
Yield index	68.36±3.51	71.19±0.67	NS
Quality traits			
Marbling	2.14±1.07	1.00±0.00	*
Lean meat color	5.00±0.00	5.57±0.53	*
Fat color	2.86±0.38	3.00±0.00	NS
Firmness	1.86±0.38	2.14±0.38	NS
Maturity	2.14±0.38	2.29±0.49	NS
Carcass quality grade	1.86±0.69	1.00±0.00	**

¹ Carcass traits were conducted by official grader according to the Korean carcass grading standard (NLCF, 2004).

² Values represent means±standard deviation of seven cattle.

³ The significance between groups in the same row are * p<0.05, ** p<0.01, and NS = Non significant.

$$\text{Oxymyoglobin (\%)} = 100 - (\text{MetMb (\%)} + \text{DeoxyMb (\%)})$$

The CIE color value was measured using the chroma meter (CR-400, Konica Minolta Sensing Inc., Japan). A light source of illuminant C (2° observer) was standardized to white tile at Y = 93.6, x = 0.3134 and y = 0.3194. The lightness (L*) represented the intensity of color from black (0) to white (100). The redness (a*) value represented the intensity of color from green (-a*) to red (+a*). The yellowness (b*) value represented the intensity of color from blue (-b*) to yellow (+b*). The chroma (C*) value was calculated as $(a^{*2} + b^{*2})^{1/2}$ (Hunter and Harold, 1987). The hue angle (H°) value was calculated as $\tan^{-1}(b^*/a^*)$ (Francis and Clydesdale, 1975).

Statistical analysis

The effects of housing system on carcass traits, proximate and fatty acid compositions, physical and sensory properties, and lipid, myoglobin and color stabilities were analyzed by one-way analysis of variance

using SPSS 12 for windows (SPSS, 2003). The data from electronic nose was explored using the principal component analysis (PCA) (Alpha Soft software, version 8.01) to assess discrimination performances. PCA is based on a linear project of multidimensional data into different coordinates based on maximum variance and minimum correlation. Training pattern of similar samples will be located close to each other after transformation. Hence, the graphical output can be used for determining the difference between groups and comparing this difference to the distribution of pattern within one group (Hernandez-Gomez et al., 2007).

RESULTS AND DISCUSSION

There were no significant differences slaughter and carcass weights, as well as dressing percentage between loose and tethered bulls (Table 1). Similar result was reported by Cheng et al. (2008) that no significant difference in the live and carcass weights, as well as

Table 2. Chemical and physical properties of *M. longissimus* of Hanwoo (Korean cattle) bulls with difference housing system¹

Items	Tethered	Loose	Significance ²
Chemical properties			
Moisture (%)	68.27±1.34	71.95±1.25	***
Crude fat (%)	7.04±1.74	3.41±1.44	**
Crude protein (%)	23.62±0.70	23.46±0.92	NS
Crude ash (%)	1.01±0.03	1.06±0.04	*
Physical properties			
pH	5.51±0.05	5.52±0.04	NS
Water holding capacity (%)	41.39±5.51	38.94±2.28	NS
Drip loss (%)	1.72±0.75	1.69±0.53	NS
Shear force (kg)	3.12±0.41	3.51±0.54	NS

¹ Values represent means±standard deviation of seven cattle.

² The significance between groups in the same row are * p<0.05, ** p<0.01, *** p<0.001, and NS = Non significant.

Table 3. Sensory¹ properties of *M. longissimus* of Hanwoo (Korean cattle) bulls with difference housing system²

Items	Tethered	Loose	Significance ³
Taste	6.78±0.27	6.67±0.54	NS
Aroma	6.67±0.42	6.10±0.57	NS
Tenderness	6.39±0.88	6.48±0.63	NS
Juiciness	6.72±0.57	6.48±0.50	NS
Overall liking	6.44±0.46	6.05±0.62	NS

¹ 9-point hedonic scales: 9 (very good)-1 (very bad). ² Values represent means±standard deviation of seven cattle.

³ The significance between groups in the same row is NS = Non significant.

dressing percentage were observed between the free-range chickens (2.64 m²/bird) and the conventional ones (0.13 m²/bird). In addition, there was no significant difference yield index between loose and tethered bulls. These indicated that loosing bulls didn't affect the carcass yield.

The marbling score and fat content of meat from loose bulls was significantly lower ($p<0.05$ and $p<0.01$, respectively) than those of tethered bulls (Tables 1 and 2), indicated that loosing bulls decreased the fat deposition. This might due to their higher exercise opportunity. Similar results had been reported by previous studies. Jurie et al. (1998) reported that loose bulls (6.5 m²/head) had less visceral and carcass adipose deposits than tethered bulls

(1.8 m²/head). Moloney et al. (2004) reported that pastured animals have a lower amount of fatness compared to housed animals due to their greater energy expenditure on exercise and/or partitioning of absorbed energy towards muscle as a result of exercise.

On the other hand, the higher exercise opportunity might increase lean meat color score. Miller (1994) described that myoglobin content is directly related to final muscle color and high-use muscles have a higher myoglobin content due to the need for myoglobin to store and deliver oxygen in the muscle. Table 1 shows the lean meat color score from loose bulls was significantly higher ($p<0.05$) than that from tethered bulls. However, there were no difference CIE color (lightness, redness, yellowness, chroma and hue-angle) values between both groups at 0 days of storage (data was not shown).

Carcass quality grade of carcass from loose bulls were significantly lower ($p<0.01$) than that from tethered bulls (Table 1). This might due to their lower marbling score. Miller (1994) stated that beef carcasses containing a higher level of evenly distributed intramuscular fat are eligible for a higher-quality grade.

Meat fat content has been highly related to quality as fat has been shown to affect flavor, juiciness, and tenderness of meat. When fat content is less than 3%, palatability declines below an acceptable level. However, high fat content also can be associated with a negative perception of quality. As fat content exceeds 7.3%, issues related to increased consumption of fat and the relation of fat intake to coronary heart disease, obesity, or some forms of cancer affect consumers' perception of acceptability (Miller, 1994). Fat content in both meat from loose and tethered bulls were still in the range of acceptable level (Table 2). In addition, there were no significant differences physical properties (Table 2), sensory properties (Table 3) and aroma pattern (Figure 1) of meat from both loose and tethered bulls. These indicated that the difference fatness hadn't altered physical properties and acceptability among them.

Moisture and ash content of meat from loose bulls was significantly higher ($p<0.001$ and $p<0.05$, respectively) than those of tethered bulls. These might due to their lower fat content. Jurgens (1982) stated that in the animal tissue, percentage of body water has an inverse relationship with body fat. Minerals in meat are associated with lean tissue

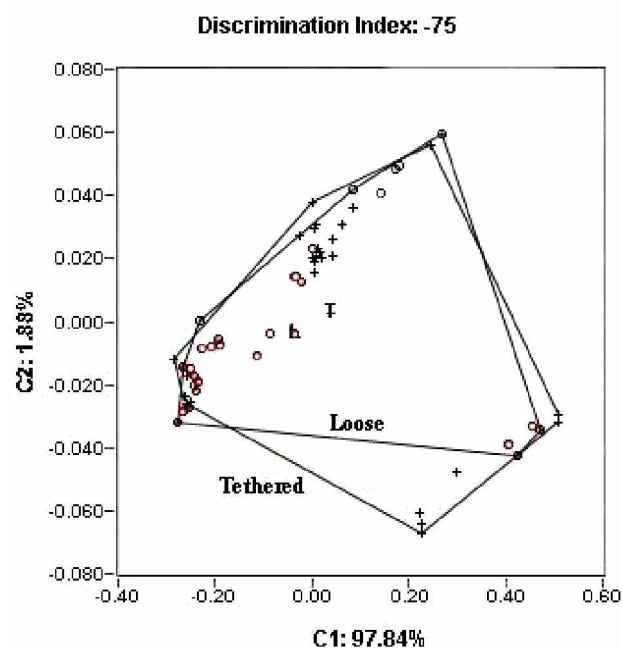


Figure 1. The aroma pattern of raw meat *M. longissimus* from Hanwoo (Korean cattle) bull with difference housing system. C1 and C2 represent the components which are classified depending on the level of information from the electronic nose data. Points represent sensor responses of every sample. Lines connect the outer points of every group. Discrimination Index represents the degree of discrimination among groups. Higher is the Discrimination Index, better is the discrimination. When the groups are easily discriminated, the Discrimination Index is positive; the maximum positive figure is 100. When the groups start to overlap, the Discrimination Index is negative.

Table 4. Fatty acids composition (%) of *M. longissimus* of Hanwoo (Korean cattle) bulls with difference housing system¹

Items	Tethered	Loose	Significance ²
C10:0	0.05±0.02	0.05±0.02	NS
C12:0	0.10±0.02	0.11±0.03	NS
C14:0	3.65±0.65	3.50±0.60	NS
C15:0	0.24±0.05	0.25±0.05	NS
C16:0	27.66±1.66	27.68±1.01	NS
C16:1 n-7	0.55±0.11	0.60±0.12	NS
C17:0	0.63±0.09	0.70±0.10	NS
C17:1 n-6	0.64±0.12	0.56±0.15	NS
C18:0	34.14±4.37	31.77±5.02	NS
C18:1 n-9	27.69±3.49	28.79±4.17	NS
C18:1 n-7	3.31±1.49	3.81±0.58	NS
C18:2 n-6	0.11±0.02	0.12±0.06	NS
C18:3 n-6	0.06±0.02	0.05±0.02	NS
C18:3 n-3	0.16±0.05	0.22±0.08	NS
C20:1 n-9	0.39±0.07	0.39±0.10	NS
C20:4 n-6	0.49±0.16	1.11±0.37	**
C22:4 n-6	0.09±0.03	0.17±0.07	*
C22:6 n-3	0.04±0.01	0.09±0.03	**
SFA ³	66.47±4.58	64.06±4.37	NS
MUFA ⁴	32.58±4.43	34.16±4.36	NS
PUFA ⁵	0.95±0.22	1.78±0.40	***
MUFA/SFA	0.50±0.10	0.54±0.10	NS
PUFA/SFA	0.01±0.00	0.03±0.01	***
PUFA n-6/n-3	3.99±1.00	4.85±1.45	NS

¹ Values represent means±standard deviation of seven cattle.

² The significance between groups in the same row are * p<0.05, ** p<0.01, *** p<0.001, and NS = Non significant.

³ Saturated fatty acid. ⁴ Monounsaturated fatty acid.

⁵ Polyunsaturated fatty acid.

(Judge et al., 1989) so the lower fat content, the higher ash content.

The polyunsaturated fatty acid (PUFA) concentration of meat from loose bulls were significantly higher (p<0.001) than those from tethered bulls (Table 4). Meat from loose bulls has higher arachidonic acid (C20:4 n-6) (p<0.01), docosatetraenoic acid (C22:4 n-6) (p<0.05) and docosahexaenoic acid (DHA, C22:6 n-3) (p<0.01) than those from tethered bulls. These might due to the lower fat content of meat from loose bulls. Wood et al. (2008) described that cattle 'conserve' long chain PUFA in muscle phospholipid which is an essential component of cell membranes and its amount remains fairly constant, or increases little, as the animal increases in fatness. Scollan et al. (2006) stated that as the content of saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA) increases faster with increasing fatness than does the content of PUFA, the relative proportion of PUFA and the PUFA/SFA ratio decrease with increasing fatness.

Epidemiological comparisons of various populations have shown that the amount of SFA in the diet can have a positive relationship with serum cholesterol levels and with

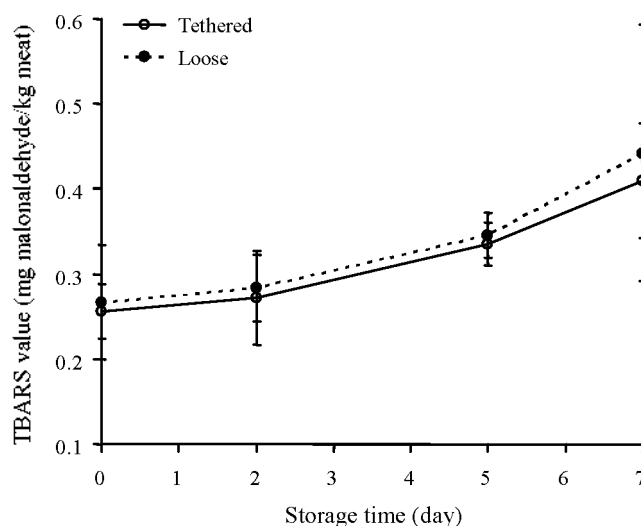


Figure 2. The TBARS value of *M. longissimus* from Hanwoo (Korean cattle) bulls with difference housing system during refrigerated storage. Points represent means and standard deviation of seven cattle.

deaths arising from coronary heart disease. However, the intake of total dietary fat and the PUFA/SFA ratios in the diet seem to have a greater effect on blood cholesterol levels than does cholesterol itself (Seman and McKenzie-Parnell, 1989). It is recommended to reduce the fat intake to 30% of total energy intake and to increase the PUFA/SFA to above 0.4 (Wood et al., 2003). Based on their fat content and fatty acids composition, meat from loose bulls can be regarded as healthier meat than that from tethered (Table 4).

The double bonds located within PUFA are sites of chemical reactivity. Oxygen is a necessary ingredient for lipid oxidation and may react with these sites to form peroxides, which lead to rancidity. PUFAs are especially susceptible to oxidative rancidity because of their high number of reactive double bonds. The formation of lipid breakdown products leads to development of undesirable flavors and odors. Those muscle foods with high concentrations of PUFA typically develop rancid flavors and odors faster than foods with less PUFA (Faustman, 1994). The TBARS value of meat from both loose and tethered bulls was gradually increase during refrigerated storage (Figure 2). However, there were no differences TBARS values between loose and tethered bulls at 0, 2, 5 and 7 days of storage. This indicated that the higher PUFA concentration in the meat from loose bulls had not altered lipid stability during storage.

The deep portion of a fresh piece of meat is anoxic, and when sliced will reveal an interior that is purplish-red in color (deoxymyoglobin). Following exposure to air for 20 to 30 min, the deoxymyoglobin will oxygenate to form cherry-red oxymyoglobin. As display time increases, oxymyoglobin will oxidize to metmyoglobin which is

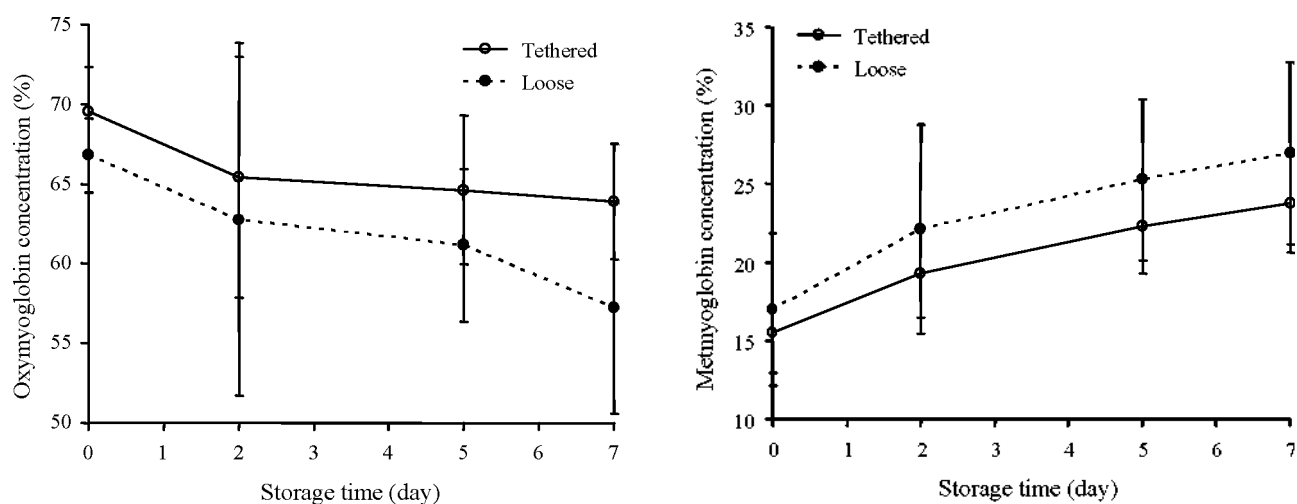


Figure 3. The oxy-myoglobin and metmyoglobin concentration at the surface of *M. longissimus* from Hanwoo (Korean cattle) bulls with difference housing system during refrigerated storage. Points represent means and standard deviation of seven cattle.

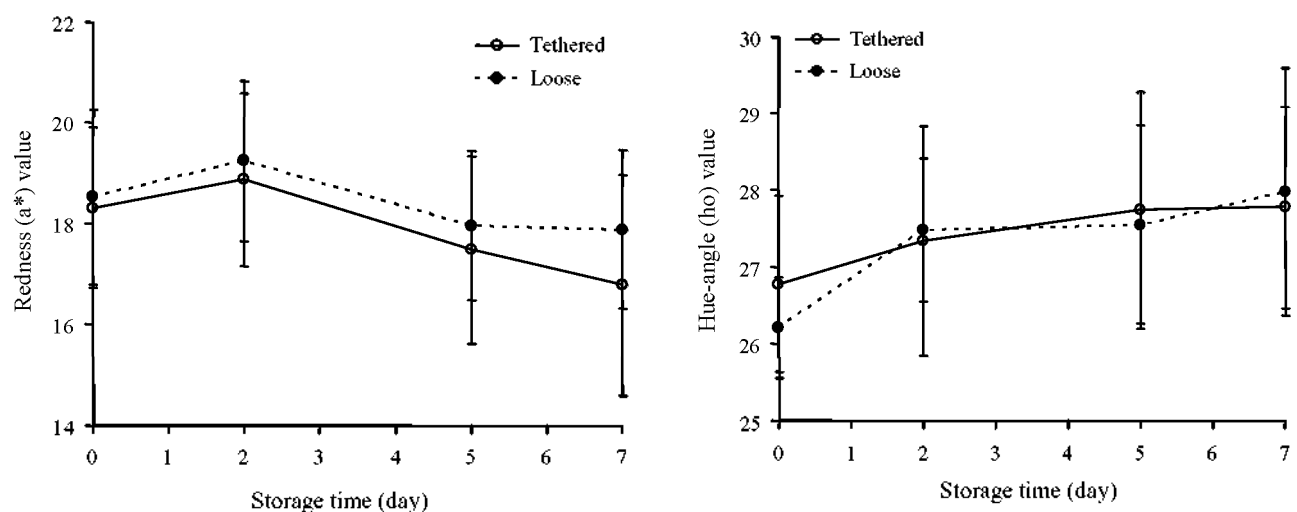


Figure 4. The redness (a^*) and hue angle (h°) values of *M. longissimus* from Hanwoo (Korean cattle) bulls with difference housing system during refrigerated storage. Points represent means and standard deviation of seven cattle.

brownish-red in color (Faustman, 1994). It is possible to follow the decrease redness value to follow the accumulation of metmyoglobin during oxidation and the increase in hue-angle indicates the degree of change from redness to yellowness during storage of meat (Renner, 2000). During storage, the oxy-myoglobin concentration gradually decreased and metmyoglobin concentration gradually increased (Figure 3). There were no significant differences oxy-myoglobin concentration at 0, 2 and 5 days of storage but, at 7 days of storage, the oxy-myoglobin concentration of meat from loose bulls was significantly lower than that from tethered bulls. However, there were no significant differences metmyoglobin concentration and redness and hue-angle values of meat from both loose and tethered bulls at 0, 2, 5 and 7 days of storage (Figures 3 and 4). This indicated that the higher PUFA concentration in the

meat from loose bulls had not altered color stability during storage. Mitumoto (2000) stated that pigment and lipid oxidation can be closely related; activated metmyoglobin initiates lipid oxidation and lipid hydroperoxide causes pigment oxidation.

Compared with tethering, loose housing at $7 \times 8 \text{ m}^2$ for 7 head of bulls ($8 \text{ m}^2/\text{head}$) didn't affect the carcass yield but did decreased fat deposition and carcass quality grade. On the other hand, loosening bulls produced healthier meat with lower fat content and higher PUFA/SFA without altering physical properties and acceptability. It also didn't affect lipid and color stabilities during refrigerated storage.

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