EFFECT OF STORAGE TEMPERATURE ON MEAT QUALITY OF MUSCLE WITH DIFFERENT FIBER TYPE COMPOSITION FROM KOREAN NATIVE CATTLE (HANWOO)

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ABSTRACT

*Three kinds of Hanwoo (Korean native cattle) muscles (Loin, strip loin and inside round) were obtained from a local farm and then divided into two storage temperatures (0 and 5C), respectively. In meat color, redness (*a**) was significantly higher in 5C storage samples compared with 0C storage samples in all muscle samples after 7 days of storage. Loin had significantly lower purge loss than other muscle samples, whereas inside round was significantly higher in purge loss. Strip loin showed lower shear force values compared with those of other muscle samples. 5C storage samples had significantly higher thiobarbituric acid reactive substances value than 0C storage samples in all muscle samples. In sensory evaluation, overall acceptability was significantly higher at 14 or 21 days of storage in all muscle samples, and 5C storage samples showed higher overall acceptability compared with 0C storage samples.*

PRACTICAL APPLICATIONS

This result will obtain information to help understand the meat quality in Hanwoo for the foreign scientists. The results of the present study showed that meat qualities of Hanwoo were much higher in 5C storage sample compared with 0C samples in all muscle samples until 35 days of storage, and loin sample showed higher sensory score than strip loin and inside round samples.

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INTRODUCTION

The native beef cattle in Korea are known as Hanwoo. It is a hybrid of *Bos Taurus* × *Bos zebu* that was transmitted and settled in the Korean Peninsula in 4000 BC (Rhee and Kim 2001). The average 20-month-old Hanwoo bull weighs 500 kg and the average 20-month-old female weights 450 kg (Jeong *et al.* 2004). Earlier studies found that meat qualities are closely related with muscle type and storage conditions such as storage temperature or packaging methods. Bruce and Ball (1990) reported that a high muscle temperature postmortem accelerates the rate of pH decline in muscle, presumably because such physiological temperature conditions permit enzymatic activity to continue. A more rapid decrease in pH at higher temperatures may rupture the lysosomal membrane in which some cathepsins could hydrolyze specific myofibrillar proteins (Whipple *et al.* 1990). Koh *et al.* (1987) also reported that high-temperature conditioning of muscles and carcasses also affected meat tenderness adversely. Higher carcass temperatures early in the postmortem period speed the aging process and result ultimately in increased tenderness (Whipple *et al.* 1990). Kirchofer *et al.* (2002) reported that not only do individual muscles differ in fiber-type composition but muscle fiber type within a specific muscle may be affected by breed, sex, feeding time and maturity. A number of studies have been conducted to investigate the effect of storage conditions on meat qualities. However, the effect of storage conditions on beef quality in different muscle types of Hanwoo during storage is still largely unknown. Thus, the purpose of this study is to investigate the effect of storage temperatures on meat qualities in muscle with different fiber-type composition from Hanwoo.

MATERIALS AND METHODS

Animal and Samples

A total of 48 male Hanwoo (25 months old and averaging 500 kg in weight) were obtained from a local cattle farm. Meat (*longissimus dorsi* muscle at the 13th rib interface) grade were estimated by the Korean carcass grading system (Animal Products Grading Service, 1995). A marbling score of beef marbling standard (BMS, 7 = very abundant; 1 = devoid) No. 7 or 6 is marbling degree for grade 1+; 5 or 4 is requirement for grade 1; BMS No. 3 or 2 comprise grade 2; and 1 is the marbling degree for grade 3. Quality grade 1+ is the highest or most desirable grade whereas grade 3 is the lowest quality degree. Yield grades are determined on the basis of estimated retail cut percentage, which was a function of back-fat thickness, rib eye area and cold carcass weight (A = higher than standard; B = standard; C = lower than standard). After meat is graded, the 1 (quality) and B (yield) grade of loin, strip loin and inside round were removed from the right side of the carcass at 24 h postmortem in commercial slaughter house and then transferred to the laboratory. Three kinds of muscle samples (loin, strip loin and inside round) were cut to 5-cm thick steaks and divided into two storage temperature (0 and 5C). After 48 h postmortem (1 day of storage), a total of six groups (three kinds of muscle samples × two kinds of temperatures) samples were vacuum-packaged and stored for 35 days for subsequent analysis.

pH

pH was measured using a digital pH meter (model 420A, Orion, Boston, MA). Five grams of sample were cut into small pieces to which 45 mL of distilled water was added and slurry was made using a blender and the pH was recorded.

Color

Commission Internationale de l'Eclairage (CIE 1995) L^*(lightness), a^* (redness) and b^* (yellowness) were measured by using a Minolta colorimeter (CR-400, Tokyo, Japan), with measurements standardized with respect to the white calibration plate. Five readings were made from the surface of samples.

Purge Loss

Purge loss (package loss) was calculated at storage period by differences in before and after storage weight of meat. Calculation was: purge loss % = (before storage weight − after storage weight)/(before storage weight) × 100.

Cooking Loss

The samples were placed in a polyethylene bag (4 × 6, 2-mil, Associated Bag Company, Milwaukee, WI) and cooked in a 100C water bath until an internal temperature of 75C was achieved. Cooking loss was calculated from differences in the weight of uncooked and cooked samples, expressed as percentage of initial weight: cooking loss % = (before cooking weight − after cooking weight)/(before cooking weight) × 100.

Shear Force

The samples (1.8 cm in diameter) were placed in polyethylene bags and cooked in 80C water bath until an internal temperature of 75C. Cooked samples were cut along the fiber direction of the muscle and then cut perpendicular to the fiber direction with the Warner Bratzler triangular device and measured for peak shear force in an Instron 3343 (US/MX50, A&D Co., Norwood, MA) equipped with a Warner Bratzler shearing device and cross-head speed set at 100 mm/min.

Myofibril Fragmentation Index (MFI)

Two-gram samples were homogenized for 30 s in 20 volumes of MFI buffer (100 mM KCl; 20 mM K-phosphate, pH 7.1; 1 mM ethylene glycol tetraacetic acid; 1 mM $MgCl_2$; 1 mM NaN_3) at 4C. The homogenates were centrifuged for 15 min at 1,000× g at 2C, and the pellet was resuspended in the same volume of MFI buffer as before by using a magnetic stirrer. The centrifugation step was repeated, the pellet was resuspended in five volumes of MFI buffer by vortexing, and the suspension was filtered through a nylon mesh (45 μm diameter). The mesh was rinsed with five volumes of MFI buffer, and the protein concentration of the final suspension was determined by using biuret method. The myofibril suspension was diluted to 0.5 mg myofibrillar protein/mL in a final volume of 8 mL, then the samples were vortexed, and the absorbance of the vortexed suspension was measured at 540 nm with spectrophotometer (Genesys, Spectronic Instruments, Inc., Rochester, NY). The absorbance was multiplied by 200 to give a MFI value.

Thiobarbituric Acid Reactive Substances (TBARS)

TBARS was determined by the modified method of Buege and Aust (1978). Five grams of meat was weighed into a 50-mL test tube and homogenized with 15 mL of deionized distilled water using the Polytron homogenizer (IKA Labortechnik T25-B, Selangor, Malaysia) for 10 s at the highest speed. One milliliter of meat homogenate was transferred to a disposable test tube (3 × 100 mm), and butylated hydroxyanisole (50 μL, 10%) and thiobarbituric acid/trichloroacetic acid (TBA/TCA) (2 mL) were added. The mixture was vortexed and then incubated in a boiling water bath for 15 min to develop color. The sample was cooled in cold water for 10 min, vortexed again and centrifuged for 15 min at 2,000× g. The absorbance of the resulting supernatant solution was determined at 531 nm against a blank containing 1 mL of deionized distilled water (DDW) and 2 mL of TBA/TCA solution. The amounts of TBARS were expressed as milligrams of malondialdehyde per kilogram of meat.

Sensory Evaluation

Sensory evaluation was performed by a panel of 15 semi-trained tasters. Panel development followed the prescreening, screening, training and performance evaluated phases proposed by Cross *et al.* (1978). The panel evaluated each treatment within each replication in quintuplicate, and the evaluation was performed with the samples at room temperature. Quintuplicate responses were taken to monitor the inherent texture variability associated with this sample. The samples were placed in polyethylene bags and cooked in 100C water bath until an internal temperature of 75C. One slice, 1 cm thick and 3 cm in diameter, was cut into rectangle-shaped and presented to each panelist. The panelists chose three of the most characteristic sample in order to avoid a sample containing large pieces of connective tissue. The flavor, color, tenderness and overall acceptability were evaluated using 9-point scale.

Statistical Analysis

The data was analyzed using SAS software (SAS Institute Inc., Cary, NC). The Duncan's multiple range tests was used to compare the differences among means. Significant differences ($P < 0.05$) between mean values of octuple samples were determined for pH, color, purge loss, cooking loss, shear force, MFI, TBARS and sensory evaluation.

RESULTS AND DISCUSSION

pH

pH result is presented in Table 1. pH steadily increased until 21 or 28 days of storage thereafter it significantly decreased in all muscle samples. When pH between temperatures was compared, 5C storage samples were significantly higher than 0C storage samples in all muscle samples. However, pH was not significantly different among the three muscle samples. In general, high pH is closely related to the high water-holding capacity, tenderness and low shear force in meats. Honikel (1987) also reported that pH has a profound effect on the physical properties such as water-holding capacity, tenderness and color in meat. In this study, pH was significantly higher in 5C storage samples than 0C storage samples in all muscle types. Thus, Hanwoo meat quality should be affected by difference in pH observed in this study.

Color

Color result is presented in Table 2. In meat color, lightness (L^*) steadily increased until 14 or 21 days of storage thereafter it decreased with storage periods in all muscle samples. L^* was significantly lower in 0C storage samples than 5C storage samples in all muscle samples after14 days of storage. After 7 days of storage, redness (a^*) in 5C storage samples was

TABLE 1.
CHANGES OF pH IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment	Storage condition	Storage periods (days)					
		1	7	14	21	28	35
Loin	0C	$5.77^{d} \pm 0.03$	$5.95^{Bc} \pm 0.02$	$6.11^{Bb} \pm 0.04$	$6.17^{Ba} \pm 0.02$	$6.20^{Ba} \pm 0.03$	$6.08^{Bb} \pm 0.01$
	5C	$5.77^{d} \pm 0.05$	$6.11^{Ac} \pm 0.05$	$6.18^{Ab} \pm 0.02$	$6.25^{ABa} \pm 0.01$	$6.24^{ABa} \pm 0.04$	$6.17^{Ab} \pm 0.03$
Strip loin	0C	$5.79^{d} \pm 0.01$	$5.98^{Bc} \pm 0.01$	$6.14^{Bb} \pm 0.04$	$6.19^{Ba} \pm 0.02$	$6.21^{Ba} \pm 0.05$	$6.06^{Bbc} \pm 0.04$
	5C	$5.79^{d} \pm 0.05$	$6.14^{Ac} \pm 0.03$	$6.20^{Ab} \pm 0.04$	$6.27^{Aa} \pm 0.01$	$6.26^{Aa} \pm 0.02$	$6.14^{ABc} \pm 0.03$
Inside round	0C	$5.82^{d} \pm 0.02$	$6.01^{Bc} \pm 0.03$	$6.16^{ABb} \pm 0.01$	$6.23^{ABa} \pm 0.04$	$6.22^{Ba} \pm 0.01$	$6.07^{Bc} \pm 0.02$
	5C	$5.82^{c} \pm 0.04$	$6.16^{Ab} \pm 0.04$	$6.23^{Aab} \pm 0.03$	$6.30^{Aa} \pm 0.04$	$6.29^{Aa} \pm 0.04$	$6.14^{ABb} \pm 0.05$

^{A,B} Means with different superscript in the same column significantly differ at $P < 0.05$.
^{a,b,c,d} Means with different superscript in the same row significantly differ at $P < 0.05$.

TABLE 2.
CHANGES OF MEAT COLOR IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Items	Treatment	Storage condition	Storage periods (days)					
			1	7	14	21	28	35
L^*	Loin	0C	$32.91^{b} \pm 0.55$	$34.94^{ab} \pm 0.35$	$30.76^{Bc} \pm 0.57$	$36.40^{a} \pm 0.79$	$32.72^{Bb} \pm 0.76$	$33.54^{Bab} \pm 0.33$
		5C	$32.91^{b} \pm 0.55$	$34.99^{ab} \pm 0.16$	$36.95^{Aa} \pm 0.03$	$35.97^{ab} \pm 0.10$	$36.33^{Aa} \pm 0.30$	$35.16^{Aab} \pm 0.26$
	Strip loin	0C	$31.89^{b} \pm 0.62$	$32.30^{b} \pm 0.39$	$28.45^{Bc} \pm 0.23$	$35.79^{a} \pm 0.44$	$31.67^{Bb} \pm 0.43$	$32.25^{Bb} \pm 0.64$
		5C	31.89 ± 0.62	33.58 ± 1.27	$36.31^{A} \pm 0.42$	36.01 ± 1.08	$36.52^{A} \pm 0.32$	$35.64^{A} \pm 0.58$
	Inside round	0C	$30.79^{d} \pm 0.40$	$33.25^{b} \pm 0.27$	$27.50^{Be} \pm 0.39$	$35.83^{a} \pm 0.47$	$30.80^{Bd} \pm 0.07$	$31.81^{Bc} \pm 0.07$
		5C	$30.79^{c} \pm 0.40$	$33.36^{b} \pm 0.64$	$35.71^{ABa} \pm 0.48$	$34.48^{ab} \pm 0.48$	$34.98^{ABab} \pm 0.19$	$34.04^{ABb} \pm 0.48$
a^*	Loin	0C	$18.48^{a} \pm 0.03$	$18.92^{Ca} \pm 0.55$	$16.65^{Cab} \pm 0.38$	$17.67^{Cab} \pm 0.75$	$15.93^{Eb} \pm 0.70$	$15.89^{Cb} \pm 0.46$
		5C	$18.48^{b} \pm 0.03$	$20.41^{Ba} \pm 0.61$	$21.04^{ABa} \pm 0.29$	$20.21^{Ba} \pm 0.40$	$20.04^{Ca} \pm 0.24$	$20.69^{Aa} \pm 0.55$
	Strip loin	0C	$20.24^{a} \pm 0.42$	$20.69^{Ba} \pm 0.44$	$19.35^{Bab} \pm 0.58$	$19.80^{Bab} \pm 0.11$	$18.46^{Db} \pm 0.67$	$19.67^{Bab} \pm 0.18$
		5C	$20.24^{c} \pm 0.42$	$23.02^{Aa} \pm 0.18$	$23.29^{Aa} \pm 0.31$	$21.75^{ABb} \pm 0.66$	$22.19^{Aab} \pm 0.27$	$21.43^{Ab} \pm 0.79$
	Inside round	0C	$19.46^{a} \pm 0.24$	$19.74^{Ba} \pm 0.67$	$18.04^{Bc} \pm 0.55$	$18.21^{BCbc} \pm 0.63$	$16.85^{Ed} \pm 0.61$	$18.84^{Bb} \pm 0.50$
		5C	$19.46^{c} \pm 0.24$	$21.66^{Bab} \pm 0.42$	$22.72^{ABa} \pm 0.84$	$22.11^{Aa} \pm 0.29$	$21.19^{Bab} \pm 0.40$	$20.38^{Ab} \pm 0.15$
b^*	Loin	0C	$8.27^{B} \pm 0.74$	$7.05^{AB} \pm 0.65$	$7.10^{B} \pm 0.16$	$7.96^{B} \pm 0.64$	$7.85^{B} \pm 0.39$	$7.28^{B} \pm 0.58$
		5C	$8.27^{B} \pm 0.74$	$8.24^{A} \pm 0.53$	$8.01^{A} \pm 0.76$	$9.04^{A} \pm 0.27$	$9.69^{A} \pm 0.66$	$9.24^{A} \pm 0.34$
	Strip loin	0C	$18.27^{ABa} \pm 0.32$	$5.23^{Cb} \pm 0.76$	$5.32^{Cb} \pm 0.73$	$5.48^{Db} \pm 0.46$	$4.94^{Db} \pm 0.29$	$5.62^{Cb} \pm 0.44$
		5C	$18.27^{ABa} \pm 0.32$	$7.10^{ABd} \pm 0.31$	$6.90^{Bd} \pm 0.51$	$8.27^{ABc} \pm 0.73$	$9.27^{Ab} \pm 0.52$	$9.13^{Ab} \pm 0.37$
	Inside round	0C	$19.02^{Aa} \pm 0.16$	$6.31^{Bb} \pm 0.17$	$5.48^{Cc} \pm 0.59$	$6.41^{Cb} \pm 0.56$	$5.82^{Cc} \pm 0.40$	$5.88^{Cc} \pm 0.60$
		5C	$19.02^{Aa} \pm 0.16$	$7.56^{ABc} \pm 0.58$	$7.10^{Bc} \pm 0.69$	$8.63^{ABb} \pm 0.26$	$9.25^{Ab} \pm 0.27$	$9.07^{Ab} \pm 0.42$

[A,B,C,D,E] Means with different superscript in the same column significantly differ at $P < 0.05$.
[a,b,c,d] Means with different superscript in the same row significantly differ at $P < 0.05$.

significantly higher compared with 0C storage samples in all muscle samples. Yellowness (b^*) was significantly lower in loin but it did not significantly change during storage periods. However, strip loin and inside round steadily decreased yellowness with storage periods in both 0 and 5C storage samples. When yellowness was compared between 0C and 5C storage temperature, 0C storage samples were significantly lower compared with 5C storage samples in all muscle samples. The consumer associates the bright red color caused by oxygenation from the myoglobin pigment (oxymyoglobin) with freshness and good quality (Taylor *et al.* 1990). The decreases in a^* and the increase in b^* values have frequently been associated with the gradual formation of metmyoglobin and consequently with a meat discoloration result. In this study, meat color not only had higher a^* value but also higher b^* value in all muscle samples when stored at 5C compared with 0C during storage periods. Thus, Hanwoo meat color may be less different among the samples, which was not much significantly different in color score between 0 and 5C storage samples in all muscle samples, agreed with sensory evaluation, although mechanical color was different between temperatures.

Purge Loss

Purge loss result is presented in Table 3. Purge loss was significantly higher in 0C storage samples than 5C storage samples after 14 days of storage in all muscle samples. Purge loss was significantly higher in 0C storage inside round sample than those of other muscle samples. Loin significantly increased purge loss until 28 days of storage thereafter it significantly decreased in both 0C and 5C storage samples. However, strip loin did not have a significantly different purge loss during the storage periods in 5C storage samples. To the meat industry, low water-holding capacity implies increased economical losses, and consequently there is a strong interest in optimizing this parameter (Schafer *et al.* 2002). In the present study, we found that water-holding capacity was higher in 5C storage samples than 0C storage samples in all muscle samples. This difference of water-holding capacity may be influenced by pH. Schafer *et al.* (2002) reported that physical factors of importance to water-holding capacity are mainly thought to be temperature postmortem, shrinkage of the myofilament lattice postmortem because of pH fall and actomyosin cross-bridges, myosin denaturation, structural changes at the fiber and fiber bundle level that lead to an increase of the extracellular space. In this study, high final pH in 5C storage samples should increase the water-holding capacity. In general, meat with a high purge loss has an unattractive appearance and therefore has a low consumer acceptance, which leads to loss of sales (Otto *et al.* 2004). Thus, 5C storage samples and loin samples would be better from the point of view of water-holding capacity in Hanwoo.

TABLE 3.
CHANGES OF PURGE LOSS IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment	Storage condition	Storage periods (days)					
		1	7	14	21	28	35
					%		
Loin	0C	–	$3.86^{b} \pm 0.38$	$4.03^{BCab} \pm 0.17$	$4.21^{Ba} \pm 0.20$	$4.34^{Ca} \pm 0.18$	$4.23^{Ca} \pm 0.11$
	5C	–	$3.41^{b} \pm 0.51$	$3.85^{Cab} \pm 0.21$	$3.88^{Cab} \pm 0.35$	$4.40^{Ca} \pm 0.40$	$4.02^{Cab} \pm 0.36$
Strip loin	0C	–	$3.88^{c} \pm 0.13$	$4.35^{Bc} \pm 0.33$	$5.24^{Ab} \pm 0.34$	$6.12^{Ba} \pm 0.23$	$5.30^{Bb} \pm 0.38$
	5C	–	3.75 ± 0.76	$3.71^{C} \pm 0.50$	$3.83^{C} \pm 0.41$	$4.20^{C} \pm 0.41$	$4.15^{C} \pm 0.45$
Inside round	0C	–	$4.08^{d} \pm 0.50$	$5.12^{Ac} \pm 0.30$	$5.76^{Ac} \pm 0.37$	$8.12^{Aa} \pm 0.27$	$7.14^{Ab} \pm 0.31$
	5C	–	$3.40^{b} \pm 0.35$	$3.70^{Cab} \pm 0.42$	$4.38^{Ba} \pm 0.49$	$4.49^{Ca} \pm 0.40$	$4.58^{Ca} \pm 0.51$

^{A,B,C} Means with different superscript in the same column significantly differ at $P < 0.05$.
^{a,b,c,d} Means with different superscript in the same row significantly differ at $P < 0.05$.

Cooking Loss

Cooking loss result is presented in Table 4. Cooking loss significantly decreased with storage periods in all muscle samples. This decrease may be caused by the increase of water-holding capacity. Paradoxically, increase of purge loss with storage periods can reduce cooking loss because free water in meat is already exuded with storage periods when meat conditions are same. Thus, cooking loss should be decreased with storage periods in all muscle samples. In the present study, cooking loss was significantly lower in loin sample than other muscle samples both 0 and 5C storage samples during storage periods. This result may be influenced by fat content in muscle because fat content was higher in loin than other muscle samples in this study (data are not shown). In general, intramuscular fat content is closely related to the water-holding capacity because water content should be lower in meat containing higher intramuscular fat than lean meat (Joo *et al.* 2000). Thus, cooking loss of Hanwoo should be lower in loin sample than other muscle samples.

Shear Force

Shear force result is presented in Table 5. Shear force value steadily decreased with storage periods in all muscle samples. Shear force of 5C storage samples was significantly lower compared with 0C storage samples in all muscle samples. Shear force of strip loin sample was significantly lower than other muscle samples, whereas inside round was significantly higher in shear force during storage periods. Bruce and Ball (1990) reported that aging muscles at a high temperature had the most dramatic effect on muscle characteristics by decreasing pH, sarcomere length and protein solubility, and increasing fragmentation index, shear force and color reflectance compared with the low temperature. Koohmaraie *et al.* (1987) also reported that high temperature promotes would lower pH below the realm of calcium dependent protease activity, reducing the substantial contribution of these proteases to the progression of tenderness. In the present study, shear force was significantly lower in 5C storage samples than 0C sample in all muscle samples, and strip loin had lower shear force compared with other muscle samples. The significant interaction between extension and temperature for shear force indicated that muscle extension for a short period of time early postmortem affected meat tenderness. Extended muscles had lower shear forces when aged at the low temperature than when aged at the high temperature (Bruce and Ball 1990). Thus, meat tenderness of Hanwoo should be higher in 5C storage samples than 0C storage samples.

TABLE 4.
CHANGES OF COOKING LOSS IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment	Storage condition	Storage periods (days)					
		1	7	14	21	28	35
					%		
Loin	0C	$35.74^{Ba} \pm 0.23$	$36.01^{Ca} \pm 0.73$	$31.68^{Dc} \pm 0.39$	$34.96^{Bb} \pm 0.31$	$31.31^{Cc} \pm 0.56$	$31.33^{Bc} \pm 0.49$
	5C	$35.74^{Ba} \pm 0.23$	$35.26^{Da} \pm 0.26$	$33.22^{Cb} \pm 0.19$	$33.39^{Bb} \pm 0.40$	$32.19^{Cc} \pm 0.68$	$30.72^{Cd} \pm 0.45$
Strip loin	0C	$41.55^{Aa} \pm 0.58$	$37.01^{Bb} \pm 0.80$	$35.71^{Bc} \pm 0.51$	$32.71^{Cd} \pm 0.58$	$31.95^{Cd} \pm 0.43$	$30.81^{Ce} \pm 0.61$
	5C	$41.55^{Aa} \pm 0.58$	$40.78^{Aa} \pm 0.37$	$38.35^{Ab} \pm 0.55$	$34.28^{Bc} \pm 0.49$	$33.76^{Bc} \pm 0.51$	$31.79^{Bd} \pm 0.65$
Inside round	0C	$40.95^{Aa} \pm 0.34$	$38.18^{ABb} \pm 0.93$	$36.69^{Bc} \pm 1.11$	$36.46^{ABc} \pm 0.84$	$34.22^{Be} \pm 0.48$	$35.25^{Ad} \pm 0.72$
	5C	$40.95^{Aa} \pm 0.34$	$39.41^{Aa} \pm 0.58$	$38.06^{Ab} \pm 0.20$	$37.37^{Ab} \pm 0.71$	$35.36^{Ac} \pm 0.55$	$35.71^{Ac} \pm 0.44$

^{A,B,C,D} Means with different superscript in the same column significantly differ at $P < 0.05$.
^{a,b,c,d,e} Means with different superscript in the same row significantly differ at $P < 0.05$.

TABLE 5.
CHANGES OF SHEAR FORCE IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment	Storage condition	Storage periods (days)					
		1	7	14	21	28	35
					kg		
Loin	0C	$5.17^{a} \pm 0.23$	$4.93^{ab} \pm 0.22$	$4.18^{Ab} \pm 0.19$	$3.80^{ABc} \pm 0.07$	$3.57^{Ad} \pm 0.17$	$3.45^{Bd} \pm 0.28$
	5C	$5.17^{a} \pm 0.23$	$4.60^{b} \pm 0.13$	$3.70^{Bc} \pm 0.24$	$3.15^{Cd} \pm 0.02$	$2.85^{Cde} \pm 0.24$	$2.31^{De} \pm 0.13$
Strip loin	0C	$5.25^{a} \pm 0.18$	$4.53^{b} \pm 0.33$	$3.68^{Bc} \pm 0.35$	$3.64^{Bc} \pm 0.30$	$3.31^{Bcd} \pm 0.32$	$3.04^{Cd} \pm 0.19$
	5C	$5.25^{a} \pm 0.18$	$4.12^{b} \pm 0.22$	$3.20^{Cc} \pm 0.18$	$3.22^{Cc} \pm 0.08$	$2.95^{Ccd} \pm 0.24$	$2.30^{Dd} \pm 0.24$
Inside round	0C	$5.31^{a} \pm 0.20$	$5.08^{b} \pm 0.13$	$4.33^{Ac} \pm 0.24$	$4.09^{Acd} \pm 0.30$	$3.67^{Ad} \pm 0.31$	$3.79^{Ad} \pm 0.18$
	5C	$5.31^{a} \pm 0.20$	$4.76^{b} \pm 0.20$	$3.76^{Bc} \pm 0.07$	$3.68^{Bc} \pm 0.15$	$3.51^{Ad} \pm 0.28$	$3.57^{ABd} \pm 0.23$

^{A,B,C,D} Means with different superscript in the same column significantly differ at $P < 0.05$.
^{a,b,c,d,e} Means with different superscript in the same row significantly differ at $P < 0.05$.

MFI

MFI result is presented in Table 6. MFI significantly increased with storage periods in all muscle samples, and approximately seven- to 10-folds higher MFI showed in all muscle samples after 35 days of storage. MFI was significantly higher in 5C storage sample compared with 0C storage sample in all muscle samples. Especially, MFI was higher in strip loin sample when stored at 5C. Higher storage temperatures accelerated myofibril fragmentation (Olson *et al.* 1976). Moeller *et al.* (1976) also suggested that higher temperature and lower pH may disrupt the lysosome, thus releasing cathepsins. Thus, high temperature condition marginally improved tenderness of meat (Whipple *et al.* 1990). Koohmaraie *et al.* (1987) reported that tenderness often is related to the amount of muscle fiber fragmentation, as indicated by MFI values. As a result of this study, MFI value was higher in 5C storage samples compared with 0C in all muscle samples. Thus, tenderness of Hanwoo should be higher in 5C storage samples in all muscle samples. MFI value was also a good matched with shear force value.

TBARS

TBARS result is presented in Table 7. TBARS value steadily increased with storage periods in all muscle samples. Storage samples at 5C were significantly higher TBARS value than 0C storage samples in all muscle samples. Inside round was significantly lower TBARS compared with loin and strip loin samples. Lipid oxidation is a leading cause of quality deterioration in meat and meat products. Because the oxidation greatly reduces consumer acceptability because of associated rancid flavors (Cross *et al.* 1987). In this study, lower TBARS values were found in 0C storage samples in all muscle samples. Thus, lower temperature would be better from the point of view of meat deterioration because lower temperature can reduce lipid oxidation during storage. The relationship between oxidation of lipids and myoglobin is of considerable interest in fresh meat because it relates development of rancidity to meat discoloration during storage. Berruga *et al.* (2005) suggested that lipid oxidation promotes oxymyoglobin oxidation, it is indicated that myoglobins are able to initiate lipid oxidation. In this study, redness (a^*) was significantly higher in 5C storage samples than 0C storage samples in all muscle samples. This finding indicates that lipid oxidation levels are less influenced redness because TBARS value was higher in 5C storage samples in this study. It may be, because all muscle samples were fresh until 35 days of storage, and vacuum condition also influenced meat color and TBARS.

TABLE 6.
CHANGES OF MYOFIBRIL FRAGMENTATION INDEX* IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment	Storage condition	Storage periods (days)					
		1	7	14	21	28	35
Loin	0C	$25.20^{f} \pm 2.08$	$50.32^{e} \pm 3.92$	$80.48^{Ed} \pm 1.76$	$132.68^{Dc} \pm 2.46$	$156.08^{Db} \pm 6.38$	$180.96^{Ea} \pm 3.38$
	5C	$25.20^{f} \pm 2.08$	$56.92^{e} \pm 6.60$	$123.04^{Bd} \pm 2.47$	$188.76^{Ac} \pm 5.43$	$209.88^{Bb} \pm 4.78$	$236.72^{Ba} \pm 5.41$
Strip loin	0C	$23.20^{e} \pm 1.98$	$52.72^{d} \pm 2.52$	$86.64^{Dc} \pm 6.12$	$150.60^{Bb} \pm 3.54$	$150.52^{Eb} \pm 3.79$	$189.24^{Da} \pm 2.76$
	5C	$23.20^{f} \pm 1.98$	$58.60^{e} \pm 4.56$	$130.88^{Ad} \pm 4.48$	$186.88^{Ac} \pm 4.53$	$224.48^{Ab} \pm 5.31$	$267.48^{Aa} \pm 8.52$
Inside round	0C	$26.92^{f} \pm 3.65$	$48.60^{e} \pm 2.31$	$75.48^{Fd} \pm 1.11$	$121.88^{Ec} \pm 1.90$	$145.80^{Fb} \pm 3.63$	$159.00^{Fa} \pm 7.74$
	5C	$26.92^{e} \pm 3.65$	$54.44^{d} \pm 5.55$	$94.00^{Cc} \pm 2.49$	$146.80^{Cb} \pm 4.59$	$198.28^{Ca} \pm 1.72$	$196.36^{Ca} \pm 2.66$

* Myofibril fragmentation index was described according to the prodedures of Culler *et al.* (1978).
^{A,B,C,D} Means with different superscript in the same column significantly differ at $P < 0.05$.
^{a,b,c,d,e,f} Means with different superscript in the same row significantly differ at $P < 0.05$.

TABLE 7.
CHANGES OF TBARS IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment	Storage condition	Storage periods (days)					
		1	7	14	21	28	35
		mgMA*/kg meat					
Loin	0C	$0.19^{f} \pm 0.02$	$0.24^{Ce} \pm 0.01$	$0.33^{Cd} \pm 0.02$	$0.38^{Cc} \pm 0.03$	$0.46^{Bb} \pm 0.02$	$0.50^{Ca} \pm 0.03$
	5C	$0.19^{f} \pm 0.02$	$0.30^{Be} \pm 0.02$	$0.40^{Bd} \pm 0.02$	$0.47^{Bc} \pm 0.02$	$0.53^{Ab} \pm 0.02$	$0.56^{Ba} \pm 0.02$
Strip loin	0C	$0.17^{f} \pm 0.03$	$0.25^{Ce} \pm 0.01$	$0.34^{Cd} \pm 0.02$	$0.41^{Cc} \pm 0.01$	$0.48^{Bb} \pm 0.01$	$0.52^{Ca} \pm 0.03$
	5C	$0.17^{f} \pm 0.03$	$0.33^{Ae} \pm 0.01$	$0.44^{Ad} \pm 0.03$	$0.53^{Ac} \pm 0.01$	$0.56^{Ab} \pm 0.02$	$0.59^{Aa} \pm 0.01$
Inside round	0C	$0.18^{e} \pm 0.01$	$0.21^{Dd} \pm 0.02$	$0.22^{Dd} \pm 0.01$	$0.34^{Dc} \pm 0.03$	$0.38^{Db} \pm 0.03$	$0.44^{Da} \pm 0.03$
	5C	$0.18^{f} \pm 0.01$	$0.24^{Ce} \pm 0.03$	$0.32^{Cd} \pm 0.03$	$0.39^{Cc} \pm 0.02$	$0.42^{Cb} \pm 0.02$	$0.51^{Ca} \pm 0.02$

* Malondealdehyde.
A,B,C,D Means with different superscript in the same column significantly differ at $P < 0.05$.
a,b.c.d,e,f Means with different superscript in the same row significantly differ at $P < 0.05$.

TABLE 8.
CHANGES OF SENSORY EVALUATION IN DIFFERENT MUSCLE TYPES OF HANWOO (KOREAN NATIVE CATTLE) DURING STORAGE

Treatment		Storage condition	Storage periods (days)					
			1	7	14	21	28	35
Flavor	Loin	0C	$6.00^{A} \pm 0.26$	5.25 ± 1.49	5.86 ± 0.69	6.14 ± 1.42	$5.60^{B} \pm 0.89$	4.83 ± 0.98
		5C	$6.00^{Ab} \pm 0.26$	$6.75^{ab} \pm 0.89$	$6.29^{b} \pm 0.50$	$6.86^{ab} \pm 0.69$	$7.60^{Aa} \pm 0.55$	$4.50^{c} \pm 0.55$
	Strip loin	0C	$4.42^{Bc} \pm 0.32$	$5.13^{b} \pm 0.64$	$5.86^{ab} \pm 0.69$	$6.43^{a} \pm 0.53$	$4.40^{Bc} \pm 0.89$	$4.50^{c} \pm 0.58$
		5C	$4.42^{Bc} \pm 0.32$	$4.75^{bc} \pm 0.71$	$5.29^{b} \pm 0.76$	$6.57^{ab} \pm 0.61$	$7.20^{Aa} \pm 1.30$	$4.33^{c} \pm 0.23$
	Inside round	0C	$4.38^{Bb} \pm 0.43$	$4.89^{b} \pm 0.64$	$5.86^{a} \pm 0.69$	$5.86^{a} \pm 0.69$	$4.90^{Bb} \pm 0.71$	$4.33^{b} \pm 0.62$
		5C	$4.38^{Bd} \pm 0.43$	$4.75^{cd} \pm 0.46$	$5.43^{c} \pm 0.79$	$6.29^{b} \pm 0.76$	$7.20^{Aa} \pm 0.45$	$4.91^{cd} \pm 0.89$
Color	Loin	0C	$6.13^{A} \pm 0.12$	5.38 ± 1.41	5.43 ± 0.53	$5.43^{B} \pm 0.13$	5.81 ± 0.24	$6.00^{A} \pm 0.10$
		5C	$6.13^{Aa} \pm 0.12$	$5.50^{b} \pm 0.53$	$5.57^{b} \pm 0.98$	$5.71^{Bb} \pm 0.76$	$5.66^{b} \pm 0.55$	$4.50^{Bc} \pm 0.45$
	Strip loin	0C	$5.38^{ABab} \pm 0.51$	$5.63^{a} \pm 0.52$	$5.71^{a} \pm 0.76$	$5.43^{Bab} \pm 0.53$	$5.80^{a} \pm 0.45$	$4.50^{Bb} \pm 0.56$
		5C	$5.38^{ABb} \pm 0.51$	$5.50^{b} \pm 0.76$	$5.86^{ab} \pm 0.69$	$6.57^{Aa} \pm 0.98$	$5.49^{Ab} \pm 0.55$	$4.33^{Bc} \pm 0.72$
	Inside round	0C	$4.38^{Bc} \pm 0.59$	$5.00^{b} \pm 0.53$	$5.29^{ab} \pm 0.54$	$5.57^{Ba} \pm 0.53$	$5.78^{a} \pm 0.45$	$4.67^{Bbc} \pm 0.32$
		5C	$4.38^{Bb} \pm 0.59$	$4.83^{b} \pm 0.75$	$5.57^{ab} \pm 0.53$	$5.86^{Ba} \pm 0.69$	$6.00^{a} \pm 0.59$	$4.83^{Bb} \pm 0.75$
Tenderness	Loin	0C	$5.13^{A} \pm 0.64$	4.75 ± 0.89	$5.14^{B} \pm 0.90$	$5.43^{B} \pm 0.98$	$5.60^{C} \pm 0.44$	$5.67^{B} \pm 1.03$
		5C	$5.13^{Ac} \pm 0.64$	$5.25^{c} \pm 0.71$	$6.00^{Ab} \pm 0.82$	$6.43^{ABb} \pm 0.53$	$7.20^{Aa} \pm 0.84$	$6.33^{Ab} \pm 0.52$
	Strip loin	0C	$3.38^{Bd} \pm 0.44$	$4.63^{c} \pm 0.52$	$5.29^{Bb} \pm 0.49$	$6.43^{ABa} \pm 0.79$	$6.40^{Ba} \pm 0.55$	$6.83^{Aa} \pm 0.41$
		5C	$3.38^{Be} \pm 0.44$	$4.50^{d} \pm 0.53$	$5.57^{Bc} \pm 0.53$	$7.00^{Aa} \pm 0.58$	$7.20^{Aa} \pm 0.84$	$6.50^{Ab} \pm 0.10$
	Inside round	0C	$2.50^{Cd} \pm 0.53$	$3.50^{c} \pm 0.12$	$4.14^{Cb} \pm 0.69$	$5.14^{Ba} \pm 0.69$	$5.40^{Ca} \pm 0.55$	$5.33^{Ba} \pm 0.52$
		5C	$2.50^{Cc} \pm 0.53$	$5.50^{a} \pm 0.84$	$4.57^{Cb} \pm 0.53$	$5.57^{Ba} \pm 0.53$	$5.60^{Ca} \pm 0.29$	$5.50^{Ba} \pm 0.84$
Overall acceptability	Loin	0C	$6.23^{A} \pm 0.26$	$6.30^{A} \pm 0.17$	$6.43^{AB} \pm 0.42$	$6.42^{B} \pm 0.54$	$6.70^{B} \pm 0.52$	$6.68^{B} \pm 0.10$
		5C	$6.13^{Abc} \pm 0.36$	$5.36^{Bc} \pm 0.24$	$6.71^{Ab} \pm 0.66$	$7.29^{Aab} \pm 0.43$	$7.88^{Aa} \pm 0.34$	$7.23^{Aab} \pm 0.25$
	Strip loin	0C	$3.50^{Bd} \pm 0.61$	$4.63^{Cc} \pm 0.52$	$6.23^{Ba} \pm 0.53$	$6.29^{Ba} \pm 0.64$	$6.32^{Ba} \pm 0.55$	$5.17^{Cb} \pm 0.18$
		5C	$3.50^{Bd} \pm 0.45$	$4.75^{Cc} \pm 0.41$	$5.29^{Cb} \pm 0.26$	$6.57^{Ba} \pm 0.56$	$6.39^{Ba} \pm 0.89$	$5.00^{Cb} \pm 0.63$
	Inside round	0C	$3.38^{Be} \pm 0.50$	$4.13^{Cd} \pm 0.44$	$4.71^{Dc} \pm 0.49$	$5.57^{Cb} \pm 0.50$	$6.40^{Ba} \pm 0.55$	$4.17^{Dd} \pm 0.56$
		5C	$3.38^{Bd} \pm 0.39$	$4.17^{Cc} \pm 0.25$	$5.57^{Cb} \pm 0.53$	$5.43^{Cb} \pm 0.39$	$6.58^{Ba} \pm 0.84$	$4.17^{Dc} \pm 0.53$

^{A,B,C,D} Means with different superscript in the same column significantly differ at $P < 0.05$.
^{a,b,c,d,e} Means with different superscript in the same row significantly differ at $P < 0.05$.

Sensory Evaluation

Sensory evaluation result is presented in Table 8. Most sensory evaluation items were higher at 21 and 28 days of storage in the strip loin and inside round samples regardless of storage temperature. However, sensory scores of loin samples did not much change during the storage periods when storage was at 0C. Color was not much different between 0C and 5C storage samples in all muscle samples although instrumental meat color was significantly different among the samples. In sensory evaluation, we found that meat color may not be influenced much with storage periods and storage temperature in all Hanwoo muscles until 35 days of storage periods. It may be, because muscle samples should be fresh until 35 days of storage under the vacuum condition. Overall acceptability was significantly higher at 14 or 21 days of storage in all muscle samples, and 5C storage samples showed higher overall acceptability compared with 0C storage samples in all muscle samples. Thus, optimal days of consumption of Hanwoo may be at 14 to 21 days of storage in 5C storage samples regardless of muscle samples. Different muscles in different part of an animal have different ratio of muscle fibers, connective tissues and fats. Therefore, sensory scores also differed between muscle samples. In the present study, significantly higher overall acceptability was seen in loins compared with strip loin and inside round sample. Thus, Hanwoo meat quality should be higher in loin sample than strip loin and inside round samples.

CONCLUSION

As result of this study, we assume that the meat qualities of Hanwoo were much higher in 5C storage sample compared with 0C samples in all muscle samples until 35 days of storage regardless of spoil. When sensory score among the muscle samples were compared, loin sample showed higher sensory score than strip loin and inside round samples. However, it does not mean that these results may be a good match in all Hanwoo muscles and meat grades. Thus, more research is needed to determine the effects of storage condition on quality of different muscle types of Hanwoo.

REFERENCES

ANIMAL PRODUCTS GRADING SERVICE. 1995. Report of business for animal products grading. APGS, Korea.

BERRUGA, M.I., VERGARA, H. and GALLEGO, L. 2005. Influence of packaging condition on microbial and lipid oxidation in lamb meat. Meat Sci. *57*, 257–264.

BRUCE, H.L. and BALL, R.O. 1990. Postmortem interaction of muscle temperature, pH and extension on beef quality. J. Anim. Sci. *68*, 4167–4175.

BUEGE, A.J. and AUST, S.D. 1978. Microsomal lipid peroxidation. Methods Enzymol. *52*, 302–310.

CIE. 1995. Industrial colour – difference evaluation, CIE Publication 116, Commission International de L'Éclairage, Vienna, Austria.

CROSS, H.R., LEU, R. and MILLER, M.F. 1987. Scope of warmed-over flavor and its importance to the meat industry. In *Warmed-Over Flavor of Meat* (A.J. St. Angelo and M.E. Bailey, eds.) pp. 1–18, Academic Press, Inc., Orlando, FL.

CROSS, H.R., WEST, R.L. and DUTSON, T.R. 1978. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. *5*, 261–266.

CULLER, R.D., PARRISH, F.C., SMITH, G.C. and CROSS, H.R. 1978. Relationship of myofibril fragmentation index to certain chemical, physical and sensory characteristics of bovine longissimus muscle. J. Food Sci. *43*, 1177–1180.

HONIKEL, K.O. 1987. The water binding of meat. Fleischwirtschaft *67*(9), 1098–1102.

JEONG, M.K., SHEALES, T., GLEESON, T. and MCDONLD, D. 2004. Korean and Australian beef: Markets and prospects for trade. ABARE eReport. Prepared in conjunction with the Korea Rural Economic Institute, Canberra, December, pp. 1–67.

JOO, S.T., KAUFFMAN, R.G., BORGGAARD, C., STEVENSON-BARRY, J.M., PARK, G.B. and KIM, B.C. 2000. Objectively predicting quality of post-rigor pork musculature: I. Initial comparison of techniques. Asian-Australas. J. Anim. Sci. *13*, 68–76.

KIRCHOFER, K.S., CALKINS, C.R. and GWARTNEY, B.L. 2002. Fiber-type composition of muscles of the beef chuck and round. J. Anim. Sci. *80*, 2872–2878.

KOH, K.C., BINDER, T.D., MCMILLIN, K.W. and HILL, G.M. 1987. Effects of electrical stimulation and temperature on beef quality and tenderness. Meat Sci. *21*, 189–201.

KOOHMARAIE, M., SDIDEMAN, S.C., SCHOLLMEYER, J.E., DUTSON, T.R. and CROUSE, J.D. 1987. Effect of postmortem storage on calcium-dependent proteases, their inhibitor and myofibril fragmentation. Meat Sci. *19*, 187–196.

MOELLER, P.W., FIELDS, P.A., DUTSON, T.R., LANDMANN, W.A. and CARPENTER, Z.L. 1976. Effect of high temperature conditioning on subcellular distribution and levels of lysosomal enzymes. J. Food Sci. *41*, 216–217.

OLSON, D.G., PARRISH, F.C., JR and STROMER, M.H. 1976. Myofibril fragmentation and shear resistance of three bovine muscles during postmortem storage. J. Food Sci. *41*, 1036–1041.

OTTO, G., ROEHE, R., LOOFT, H., THOELKING, L. and KALM, E. 2004. Comparison of different methods for determination of drip loss and their relationships to meat quality and carcass characteristics in pigs. Meat Sci. *68*, 401–409.

RHEE, M.S. and KIM, B.C. 2001. Effect of low voltage electrical stimulation and temperature conditioning on postmortem changes in glycolysis and calpains activities of Korean native cattle (Hanwoo). Meat Sci. *58*, 231–237.

SAS. 1996. SAS/STAT software for PC. Release 6.11, SAS Institute, Cary, NC.

SCHAFER, A., ROSENVOLD, K., PURSLOW, P.P., ANDERSEN, H.J. and HENCKEL, P. 2002. Physiological and structural events post mortem of importance for drip loss in pork. Meat Sci. *61*, 355–366.

TAYLOR, A.A., DOWN, N.F. and SHAW, B.G. 1990. A comparison of modified atmosphere and vacuum skin packing for the storage of red meats. Int. J. Food Sci. Technol. *25*, 98–109.

WHIPPLE, G., KOOHMARAIE, M., DIKEMAN, M.E. and CROUSE, J.D. 1990. Effects of high-temperature conditioning on enzymatic activity and tenderness of *Bos Indicus* longissimus muscle. J. Anim. Sci. *68*, 3654–3662.