Korean J. Food Sci. Ani. Resour.
Vol. 29, No. 2, pp. 245~251(2009)

Effects of Raising Altitude on the Fatty Acid Composition, Aroma Pattern, Color, and Oxidative Stability of *M. Longissimus* from Hanwoo Steers

Panjono, Sun Moon Kang, Ik Sun Lee, and Sung Ki Lee*
Department of Animal Products and Food Science, Kangwon National University, Chuncheon 200-701, Korea

Abstract

This study was carried out to investigate the fatty acid composition, aroma pattern, color, and oxidative stability of *M. longissimus* from 28-mon-old Hanwoo steers with different raising altitude (100, 200, 300, 400, 700, and 800 m above sea level). The samples were stored at 2±0.2°C for 9 d. Meat from 700 and 800 m had lower palmitic acid, saturated fatty acids and higher oleic acid, monounsaturated fatty acids (MUFA) than that from 100 m ($p<0.05$). There was no positive discrimination of the aroma pattern of meat among all groups. There were no significant difference in TBARS values of beef among all groups at 6 and 9 d of storage. At 9 d of storage, meat from 700 m showed the highest MetMb concentration and the lowest a* value among all groups. However, the differences in Mb concentration and color among groups were not linear to the difference in raising altitude. Consequently, the difference in raising altitude at 100-800 m affected the fatty acid composition of meat from Hanwoo steers; the higher the raising altitude, the higher the MUFA concentration. The difference in fatty acid composition among them didn't affect the aroma pattern and oxidative stability.

Key words : raising altitude, fatty acid, aroma pattern, oxidative stability, Hanwoo

Introduction

The houses of cattle in Korean Peninsula area are widely varies in altitude due to nearly 70% of this peninsula is covered by mountains and hills (Asian Info, 2000). There are four primary atmospheric changes associated with altitude: 1) decreasing total atmospheric pressure and partial pressure of all atmospheric gases; 2) reduction of atmospheric temperature, with implications for ambient humidity; 3) increasing radiation under a cloudless sky; and 4) a higher fraction of UV-B radiation at any given total solar radiation (Korner, 2007). The higher altitude, the lower atmospheric pressure, so that the partial pressure of oxygen is also lower (Schmidt-Nielsen, 1990). Hyun *et al.* (2006) stated that lower oxygen saturation in atmosphere at higher altitude improves cardiopulmonary function and oxygen utilization of cattle. In addition, cold environment at high altitude can minimize risks from infectious diseases mediated by insects and stress from environment. It might be hypothesized that raising altitude will affect meat quality of cattle. In case of study on lamb meat quality, Ådnøy *et al.* (2005) found that there were small but significant differences in chemical content and sensory quality of meat from high altitude (sea level above 1000 m) compared to low altitude. However, there is limited information related to the effects of raising altitude on beef quality.

Recent concerns about human well-being have affected the beef production system. Human well-being requires quality foods, which include beef. Among other nutrients, fat content and fatty acid composition are important factors determine the quality of beef. Wood *et al.* (2008) stated that fat and fatty acids, whether in adipose tissue or muscle, contribute importantly to various aspects of meat quality and are central to the nutritional value of meat. Furthermore, Wood *et al.* (2003) stated that interest in meat fatty acid composition stems mainly from the need to find ways to produce healthier meat, i.e. with a higher ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids and a more favorable balance between n-6 and n-3 PUFA. However, Scollan *et al.* (2006) stated that the lacks of meat with higher n-3 PUFA are associated with sensory attributes and color stability. As the content of n-3 PUFA in the meat are increased, sensory attributes such as 'grassy', 'greasy', and 'fishy' score may be increased and color stability may be reduced. In addition, meat with higher PUFA is more susceptible to lipid oxidation.

*Corresponding author : Sung Ki Lee, Department of Animal Products and Food Science, Kangwon National University, Chuncheon 200-701, Korea. Tel: 82-33-250-8646, Fax: 82-33-251-7719, E-mail: skilee@kangwon.ac.kr

Faustman (1994) stated that the double bonds located within PUFA are sites of chemical reactivity. Oxygen may react with these sites to form peroxides and the formation of lipid breakdown products leads to development of undesirable flavors and odors.

Lipid and heme pigment oxidations are the primaries cause of quality loss in meat during storage. Lipid oxidation over time has adverse effects on color, odor, flavor, and healthiness of meat products (Monahan, 2000). Myoglobin (Mb) is the primary pigment responsible for the color of meat and the brown color created by changes due to oxidation of the iron in the heme moiety of Mb, and conversion of oxymyoglobin (OxyMb) to metmyoglobin (MetMb) is considered undesirable by most consumers (Smith *et al.*, 2000). There is a significant positive correlation between lipid oxidation and MetMb. Bekhit and Faustman (2005) described that lipid peroxidation increases the percentage of MetMb in meat and, in turn, oxidation of Mb could be generating free radicals that promote lipid oxidation and leads to meat discoloration. Locker (1989) stated that in meat where rancidity is producing peroxides in the fat, the Mb becomes vulnerable to oxidation, even where oxygen is freely available. The surfaces turn brown, and then green brown, as oxidation proceeds further.

Therefore, this study was carried out to investigate the fatty acid composition, aroma pattern, color, and oxidative stability of *M. longissimus* from Hanwoo steers with different raising altitude.

Materials and Methods

Experimental design and meat sample preparation

One hundred and eight heads of 22-mon-old Hanwoo steers were randomly divided into six groups (n=12 heads/group) of raising altitude, i.e. 100, 200, 300, 400, 700, and 800 m above sea level. Cattle were finished for 6 mon prior to slaughter indoor and fed with concentrate at least 10 kg/head/d and rice straw up to 1.5 kg/head/d. The nutrient composition of feedstuffs is presented in Table 1. At 48 h post-slaughter chilling, the *M. longissimus* at the 12-13th thoracic vertebra from each carcass were collected for meat quality analysis. Each sample was cut into 1.5 cm of thickness, individually packaged in a low density polyethylene zipper bag (Cleanwrap Co., Ltd., Korea), and stored at 2±0.2°C for 9 d.

Intramuscular fat content

The intramuscular fat content was determined using a Soxhlet as described by AOAC (1995) method.

Fatty acid composition

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 a gas chromatography (Agilent 6890N, Agilent Technologies, USA) equipped with a flame ionization detector (FID) and HP-Innowax fused silica capillary column (30 m length × 0.32 mm id × 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.

Aroma pattern analysis

The aroma pattern was analyzed as described by Hariom *et al.* (2006). An electronic nose (FOX 3000, Alpha MOS, France) equipped with 12 metal oxide sensors was used. One gram of chopped meat was placed into a 10 mL headspace vial, tightly capped with a PTFE/rubber septum and alumina cap, 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 millimeter of the sample headspace was extracted by the automatic sampler (HS 100, Alpha MOS, France) syringe at 45°C and flow-injected into the carrier gas flow (synthetic air mixture). The acquisition time was 180 s.

Lipid oxidation measurement

The lipid oxidation was measured by 2-thiobarbituric acid reactive substances (TBARS) method as described by Sinnhuber and Yu (1977). Zero point four gram of chopped meat was mixed with 3 drops of antioxidant solution, 3 mL of TBA solution, and 17 mL of trichloroacetic acid-HCl solution. Zero point four millimeter of deionized water was used as the blank. The mixture was then heated in the water bath (OB-25E, Jeio Tech Co., Korea) at 98°C for 30 min and then cooled in the tap water for 10 min. Five millimeter of the color solution was transferred into test tube, added with 3 mL of chloroform, and centrifuged (GS-6R Centrifuge, Beckman Instruments Inc., USA) at 3,000 rpm for 15 min. A part of the aqueous clear color solution was then transferred into a 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.

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

As = absorbance of sample.
Ab = absorbance of blank.

Mb concentration measurement

The relative Mb concentration at the surface of meat was measured as described by Krzywicki (1979) using reflectance at 473, 525, 572, and 730 nm. Reflectance readings were converted to 2-log (% reflectance) and used in the equation as described by Demos *et al.* (1996). Reflectance at selected wavelengths was measured using a UV-vis spectrophotometer (UV-2401PC, Shimadzu Co., Japan). Percent reflectances at 630-580 nm (R630-R580) and 630/580 nm (R630/R580) were used to indicate differences in the redness (Strange *et al.*, 1974).

$$\text{MetMb (\%)} = [1.395-\{(R_{572}-R_{730})/(R_{525}-R_{730})\}]\times 100$$
$$\text{DeoxyMb (\%)} = 2.375\times[1-\{(R_{473}-R_{730})/(R_{525}-R_{730})\}]\times 100$$
$$\text{OxyMb (\%)} = 100-\{\text{MetMb (\%)}+\text{DeoxyMb (\%)}\}$$

Color measurement

The CIE (Commission Internationale de I'Eclairage) color values were measured using a 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 raising altitude on the fatty acid composition, color, and oxidative stability were investigated by analysis of variance. Differences among means at the 5% level were determined by the Least Significant Differences test. Analyses were performed using the SPSS 12 for windows (SPSS, 2003). The data from electronic nose was explored using a principal component analysis (PCA, Alpha Soft software version 8.01, Alpha MOS, France) 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

Intramuscular fat content

There was no significant difference in intramuscular fat (IMF) content of beef among all groups (Table 2). This indicated that different raising altitude didn't affect IMF content of beef. Conversely, Ådnøy *et al.* (2005) reported that fat content was lower for lamb meat from high altitude compared to low altitude. However, in milk, another study found an increased fat content at high altitude (3600 m above sea level) (Bartl *et al.*, 2009).

Based on the statement of Miller (1994), all groups in this study produced delicious beef. He described that meat with more than 3% fat can be regarded as acceptable for palatability. Meat with higher fat would be expected to produce meat with more desirable palatability (juiciness, tenderness, and flavor). Fat enhances the water-holding capacity of meat, lubricates the muscle fibers during cooking, increases the tenderness of meat and thus the apparent sensation of juiciness, and gives feeling of juice released in the mouth upon stimulating salivary flow during mastication.

Fatty acid composition and aroma pattern

Wood *et al.* (2008) described that a major factor affecting the fatty acid composition of adipose and muscle in cattle is the total amount of fat. Even though there was no significant difference in fat content, there was significant difference in fatty acid composition among groups in this study. The meat from 700 and 800 m raising altitudes had lower saturated fatty acids ($p<0.05$) and higher monounsaturated fatty acids concentrations ($p<0.05$) than that from 100 m altitude (Table 2). This mainly due to their lower palmitic acid (C16:0) ($p<0.05$) and higher oleic acid (C18:1n-9) ($p<0.05$). Bartl *et al.* (2009) reported that glycerol, created from adipose cell tissue (Waldron *et al.*, 2006), increased at high altitude, but corresponding changes were not observed in triglycerides and non-esterified fatty acids. The reason why altitude affect the fatty

Table 1. Nutrient composition of feedstuffs of finishing diet for Hanwoo

Nutrient	Concentrate	Rice straw
Dry matter (DM, % as fed)	83.27	89.55
Crude protein (%DM)	11.23	4.25
Crude fat (%DM)	2.41	1.76
Crude fiber (%DM)	7.20	32.98
Crude ash (%DM)	8.11	12.16
Ca (%DM)	0.74	0.22
P (%DM)	0.37	0.15
Total digestible nutrient (%DM)	71.50	41.29

acid composition of meat should be studied in future research. Kritchevsky (1998) suggested that high rate of saturated fat consumption have been implicated as contributing factors in the cardiovascular disease. In addition, Godber (1994) hypothesized that oleic acid may have a beneficial effect in heart disease and other chronic disorders as well as highly unsaturated fatty acids found in many seafoods.

The α-linolenic acid (ALNA) concentration of meat from 100 m altitude was significantly higher than that from 200 and 300 m altitudes ($p<0.05$) (Table 2). However, the differences in ALNA concentration among groups were not linear to the difference in raising altitude. In addition, there was no positive discrimination of the

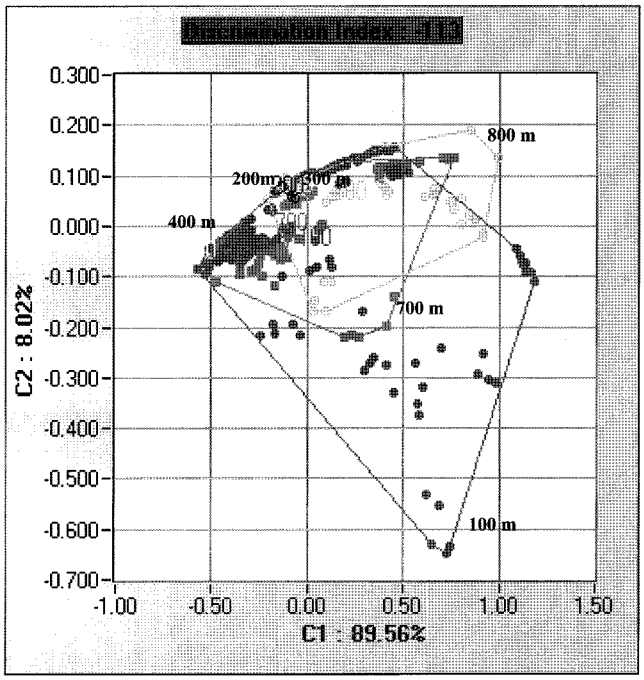

Fig. 1. Aroma pattern of *M. longissimus* from Hanwoo steer with different raising altitude. C1 (X-axis) and C2 (Y-axis) represent the components which are classified depending on the level of information from the electronic nose data. Points represent sensor responses of every sample. Lines connect the outer points of every group. Discrimination index represents the degree of discrimination among groups.

Table 2. Intramuscular fat (IMF) content and fatty acid composition of *M. longissimus* from Hanwoo steers with different raising altitude

Items	Raising altitude (m)					
	100	200	300	400	700	800
IMF (%)	14.16±3.75	14.74±3.49	12.76±4.70	12.41±1.96	14.43±4.44	15.00±4.49
Fatty acid (%)						
C14:0	3.80±0.55	3.82±0.39	3.72±0.83	3.67±0.66	3.71±0.55	3.75±0.57
C16:0	31.31±2.04^{a}	28.99±1.55^{b}	29.13±2.26^{b}	29.21±1.96^{b}	28.82±1.32^{b}	28.61±1.69^{b}
C16:1n-7	0.65±0.08^{a}	0.55±0.07^{b}	0.57±0.15^{b}	0.55±1.45^{b}	0.55±0.09^{b}	0.54±0.09^{b}
C18:0	23.89±1.90	23.95±1.50	23.83±1.61	23.87±1.45	23.58±2.14	23.81±1.50
C18:1n-9	36.79±2.23^{b}	38.93±1.49^{ab}	38.89±2.48^{ab}	38.97±2.23^{ab}	39.92±2.09^{a}	39.86±1.57^{a}
C18:2n-6	2.40±0.50^{ab}	2.67±0.93^{a}	2.68±0.82^{a}	2.62±0.53^{a}	2.22±0.60^{b}	2.25±0.71^{b}
C18:3n-3	0.24±0.05^{a}	0.18±0.03^{b}	0.19±0.06^{b}	0.18±0.05^{b}	0.21±0.05^{ab}	0.22±0.06^{ab}
C20:1n-9	0.40±0.07	0.39±0.08	0.42±0.12	0.41±0.08	0.41±0.08	0.40±0.05
C20:4n-6	0.44±0.15	0.44±0.07	0.47±0.29	0.43±0.11	0.46±0.17	0.45±0.17
C22:4n-6	0.11±0.10	0.08±0.01	0.10±0.06	0.09±0.02	0.12±0.15	0.11±0.02
SFA[1)]	59.00±2.20^{a}	56.76±1.29^{b}	56.68±2.12^{b}	56.75±2.75^{b}	56.11±2.45^{b}	56.17±2.09^{b}
MUFA[2)]	37.84±2.40^{b}	39.87±1.46^{ab}	39.88±2.59^{ab}	39.93±2.30^{ab}	40.88±2.18^{a}	40.80±1.58^{a}
PUFA[3)]	3.19±0.57	3.37±0.92	3.44±1.13	3.32±0.55	3.01±0.79	3.03±0.81
n-6/n-3 PUFA	12.29±8.11	17.72±4.97	17.11±5.29	17.44±3.12	13.33±9.09	12.77±5.75

$^{a-d}$ Means±SD in the same row with different superscripts are significantly different ($p<0.05$).

[1)] Saturated fatty acids.

[2)] Monounsaturated fatty acids.

[3)] Polyunsaturated fatty acids.

aroma pattern of raw beef among all groups (Fig. 1). This indicated that the difference in fatty acid composition among groups didn't affect their aroma. The difference in aroma due to the difference in n-3 PUFA concentration as described by Scollan *et al.* (2006) was not detected in this study. This might due to the ALNA content in the meat was too small to affect the aroma.

Lipid oxidation, Mb concentration, and color

There were no significant differences in TBARS values of beef among all groups at 6 and 9 d of storage (Table 3). This indicated that difference in fatty acid composition among groups didn't affect their lipid stability during storage. At 9 d of storage, meat from 700 m altitude showed the lowest OxyMb and highest MetMb concentration than other groups (Table 4). This indicated that beef from those raising altitude was more susceptible to Mb oxidation than others. In accordance to the MetMb concentration, the a* value of meat from 700 m altitude was the lowest compared to others groups at 9 d of storage (Table 5). This is in agreement with earlier finding, lamb meat from high altitude showed higher a* value than that from low altitude (Ådnøy *et al.*, 2005). Renerre (2000) stated that it is possible to follow the decrease of a* value by following the accumulation of MetMb during oxidation. Furthermore, Kim *et al.* (2006) stated that the

Table 3. TBARS values (mg malonaldehyde/kg meat) of *M. longissimus* from Hanwoo steers with different raising altitude during refrigerated storage

Storage time (d)	Raising altitude (m)					
	100	200	300	400	700	800
0	0.31±0.08^{aC}	0.31±0.01^{abD}	0.23±0.07^{cC}	0.27±0.01^{abcD}	0.27±0.05^{bcC}	0.31±0.01^{abD}
3	0.35±0.07^{aB}	0.33±0.02^{abC}	0.31±0.08^{abB}	0.29±0.01^{bC}	0.33±0.10^{abB}	0.33±0.01^{abC}
6	0.36±0.07^{AB}	0.36±0.02^{B}	0.37±0.07^{A}	0.33±0.02^{B}	0.35±0.07^{AB}	0.36±0.01^{B}
9	0.38±0.06^{A}	0.41±0.03^{A}	0.41±0.08^{A}	0.39±0.04^{A}	0.39±0.07^{A}	0.40±0.03^{A}

$^{a-c}$ Means±SD in the same row with different superscripts are significantly different ($p<0.05$).
$^{A-D}$ Means±SD in the same column with different superscripts are significantly different ($p<0.05$).

Table 4. Mb concentration at the surface of *M. longissimus* from Hanwoo steers with different raising altitude during refrigerated storage

Items	Storage time (d)	Raising altitude (m)					
		100	200	300	400	700	800
OxyMb (%)	0	70.30±4.02^{aA}	71.01±1.82^{aA}	68.50±3.47^{abA}	68.52±1.96^{abA}	68.17±4.64^{bA}	70.93±1.67^{aA}
	3	69.33±4.49^{aA}	68.65±0.99^{aB}	67.33±2.98^{abAB}	63.63±1.85^{bB}	67.82±4.25^{aA}	68.40±1.68^{aB}
	6	68.50±4.75^{aA}	66.71±1.43^{abC}	66.01±3.70^{abAB}	60.76±1.71^{cB}	65.40±5.18^{bA}	65.59±2.51^{abBC}
	9	65.34±9.31^{aB}	65.32±2.33^{aC}	65.45±3.70^{aB}	60.39±2.06^{abB}	55.761±2.55^{bB}	65.69±3.34^{aC}
DeoxyMb (%)	0	9.39±3.16^{bA}	9.91±2.73^{abA}	11.15±2.31^{ab}	10.49±0.66^{ab}	11.75±3.64^{aB}	10.79±1.46^{abA}
	3	8.17±1.93^{cB}	8.58±0.84^{bcAB}	9.86±1.81^{ab}	11.38±1.20^{a}	9.29±2.47^{bC}	8.91±1.23^{bcB}
	6	8.57±1.96^{cAB}	8.21±0.44^{cB}	10.53±1.96^{a}	11.46±1.09^{a}	9.74±2.38^{abBC}	8.39±1.65^{bcB}
	9	9.62±3.04^{bA}	9.02±0.93^{bAB}	10.91±1.64^{b}	10.53±1.28^{ab}	14.12±6.02^{aA}	9.57±1.85^{bAB}
MetMb (%)	0	20.31±2.66^{aC}	19.08±1.11^{abC}	20.35±1.66^{aB}	20.99±1.71^{aC}	20.10±2.56^{aC}	18.29±1.58^{bC}
	3	22.50±3.43^{BC}	22.77±0.80^{B}	22.81±1.71^{A}	24.98±0.77^{B}	22.90±3.63^{BC}	22.69±2.19^{B}
	6	22.90±4.05^{cAB}	25.08±1.48^{abcA}	23.46±2.33^{bcA}	27.78±0.96^{aA}	24.87±4.18^{abB}	25.02±2.95^{abcA}
	9	25.04±7.39^{bA}	25.66±1.71^{abA}	23.65±2.79^{bA}	29.08±1.83^{abA}	30.12±8.68^{aA}	24.75±2.89^{bAB}
R_{630}-R_{580} (%)	0	23.39±3.50^{aA}	22.68±3.49^{aA}	19.15±6.97^{bB}	20.54±2.04^{abA}	22.31±3.58^{aA}	22.72±1.97^{aA}
	3	23.40±4.07^{aA}	21.56±2.22^{abcAB}	23.24±3.45^{abA}	17.29±1.67^{cB}	21.06±5.02^{bcAB}	19.97±2.61^{cB}
	6	22.09±4.65^{aA}	20.26±1.99^{abBC}	22.30±3.74^{aAB}	15.47±1.68^{cB}	19.03±5.11^{bcB}	18.36±3.03^{bcB}
	9	19.70±5.59^{abB}	18.73±1.94^{abC}	21.32±3.55^{aAB}	15.45±2.07^{bcB}	14.64±6.03^{cC}	18.16±3.07^{abcB}
R_{630}/R_{580} (%)	0	4.46±0.46^{aA}	4.22±0.39^{abA}	3.90±1.13^{bB}	3.94±0.21^{abA}	4.33±0.47^{aA}	4.26±0.22^{abA}
	3	4.40±0.61^{aA}	3.68±0.31^{bcB}	4.49±0.52^{aA}	3.36±0.23^{cB}	4.07±0.70^{bA}	3.69±0.36^{bcB}
	6	4.01±0.63^{aB}	3.38±0.34^{bcB}	4.15±0.55^{aAB}	2.97±0.29^{cB}	3.61±0.67^{bB}	3.37±0.44^{bcBC}
	9	3.60±0.74^{abC}	3.36±0.45^{abcB}	3.89±0.52^{aB}	2.82±0.37^{ceB}	2.87±0.79^{deC}	3.34±0.44^{bcdC}

$^{a-e}$ Means±SD in the same row with different superscripts are significantly different ($p<0.05$).
$^{A-C}$ Means±SD in the same column with different superscripts are significantly different ($p<0.05$).

Table 5. CIE color values of *M. longissimus* from Hanwoo steers with different raising altitude during refrigerated storage

Items	Storage time (d)	Raising altitude (m)					
		100	200	300	400	700	800
Lightness (L*)	0	41.23±1.74	41.08±1.62	40.59±1.74	40.64±2.06	41.72±1.87	41.80±1.38
	3	41.29±1.72^{ab}	41.29±1.71^{ab}	40.60±1.72^{b}	40.48±1.56^{b}	41.29±2.41^{ab}	42.28±1.77^{a}
	6	41.55±2.04	41.33±1.79	41.18±1.52	40.79±1.55	41.37±2.53	42.51±1.84
	9	41.43±2.04	41.14±1.92	41.58±1.66	41.69±1.99	41.56±2.55	42.43±1.53
Redness (a*)	0	21.05±2.44^{BC}	21.27±1.33^{A}	21.15±2.20^{C}	19.85±2.11	20.45±1.74^{C}	20.94±1.10
	3	22.94±2.13^{abA}	20.83±1.13^{dA}	23.95±1.49^{aA}	20.75±1.23^{d}	22.34±1.76^{bcA}	21.21±1.20^{cd}
	6	22.22±2.47^{abAB}	20.15±1.66^{cAB}	23.02±1.74^{aAB}	20.65±1.29^{c}	21.09±2.18^{cAB}	21.06±1.27^{bc}
	9	20.35±3.50^{bC}	19.15±1.41^{bcB}	22.46±2.02^{aBC}	19.30±2.11^{bc}	18.46±3.33^{cB}	20.38±1.16^{abc}
Yellowness (b*)	0	10.42±1.49^{abB}	10.86±1.00^{a}	10.34±1.32^{abB}	9.67±1.60^{b}	10.04±1.05^{abB}	10.58±0.57^{abB}
	3	11.55±1.29^{abA}	11.00±0.81^{bc}	12.12±0.93^{aA}	10.41±0.90^{c}	11.27±1.11^{bA}	11.26±0.58^{abcA}
	6	11.35±1.43^{abA}	10.87±0.98^{ab}	11.61±1.07^{aA}	10.56±0.96^{b}	10.77±1.36^{bA}	11.52±0.57^{abA}
	9	10.56±1.44^{abB}	10.39±0.89^{abc}	11.35±1.23^{aA}	9.98±1.75^{bc}	9.71±1.57^{cB}	11.26±0.55^{aA}
Chroma (C)	0	23.50±2.84^{B}	23.89±1.62^{A}	23.55±2.55^{C}	22.09±2.59	22.79±2.01^{B}	23.47±1.22
	3	25.69±2.45^{abA}	23.57±1.33^{cdA}	26.85±1.73^{aA}	23.22±1.50^{d}	25.03±2.04^{bcA}	24.03±1.27^{cd}
	6	24.96±2.82^{abA}	22.90±1.89^{cAB}	25.79±2.02^{aAB}	23.20±1.58^{bc}	23.69±2.54^{cAB}	24.02±1.30^{abc}
	9	22.95±3.68^{bB}	21.79±1.62^{bcB}	25.17±2.35^{aBC}	21.74±2.67^{bc}	20.89±3.51^{cC}	23.30±1.19^{ab}
Hue-angle (H)	0	26.23±0.98^{bcB}	27.00±0.92^{aB}	25.98±0.70^{cB}	25.84±1.42^{cB}	26.07±0.76^{cB}	26.76±0.59^{abC}
	3	26.65±1.02^{bB}	27.82±0.99^{aAB}	26.80±0.56^{bA}	26.57±0.70^{bAB}	26.72±0.86^{bB}	27.96±1.00^{aB}
	6	27.00±1.05^{bAB}	28.34±0.96^{aA}	26.72±0.74^{bA}	27.04±0.74^{bA}	26.99±0.97^{bAB}	28.73±1.21^{aAB}
	9	27.70±2.88^{abA}	28.46±1.07^{abA}	26.75±0.74^{bA}	27.17±1.63^{abA}	28.01±3.67^{abA}	28.98±1.23^{aA}

$^{a-d}$ Means±SD in the same row with different superscripts are significantly different ($p<0.05$).
$^{A-C}$ Means±SD in the same column with different superscripts are significantly different ($p<0.05$).

larger H value, the less red color of meat. In addition, Renerre (2000) stated that during storage of meat, the increase in H value indicates the degree of change from a* value to b* value. At the same time, the H value of meat from 700 m altitude was high even it was not the highest among other groups (Table 5). However, the differences in Mb concentrations and CIE color values among groups were not linear to the difference in raising altitude.

Acknowledgement

This study was supported by the Institute of Animal Resources, Kangwon National University, Republic of Korea.

References

1. Ådnøy, T. Haug, A., Sørheim, O., Thomassen, M. S., Varszegi, Z., and Eik, L. O. (2005) Grazing on mountain pastures-does it affect meat quality in lambs? *Livest. Prod. Sci.* **94**, 25-31.
2. AOAC (1995) Official Methods of Analysis. 16th ed, Association of Official Analytical Chemists, Washington, DC.
3. Asian Info (2000) Korea's Geography. http://www.asian-info.org. Accessed on July 1, 2007.
4. Bartl, K., Gómez, C. A., Aufdermauer, T., Garcia, M., Kreuzer, M., Hess, H. D., and Wettstein, H. -R. (2009) Effect of diet type on performance and metabolic traits of Peruvian local and introduced cow types kept at 200 and 3600 m of altitude. *Livest. Sci.* **122**, 30-38.
5. Bekhit, A. E. D. and Faustman, C. (2005) Metmyoglobin reduction activity. *Meat Sci.* **71**, 407-439.
6. Demos, B. P., Gerrad, D. E., Mandigo, R. W., Gao, X., and Tan, J. (1996) Mechanically recovered neck bone lean and ascorbic acid improve color stability of ground beef patties. *J. Food Sci.* **61**, 655-659.
7. Faustman, C. (1994) Postmortem changes in muscle foods. In: Muscle foods: meat, poultry and seafood technology. Kinsman. D. M., Kotula, A. W., and Breidenstein, B. C. (eds), Chapman & Hall Inc., NY, pp. 63-78.
8. Folch, J., Lees, M., and Stanley, G. H. S. (1957) A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* **226**, 497-509.
9. Francis, F. J. and Clydesdale, F. M. (1975) The measurement of meat color. In: Food colorimetry: theory and application. The AVI Publishing Company, Westport, CT, pp. 73-111.
10. Godber, J. S. (1994) Nutritional value of muscle foods. In: Muscle foods: meat, poultry and seafood technology. Kinsman. D. M., Kotula, A. W., and Breidenstein, B. C. (eds), Chapman & Hall, NY, pp. 430-455.
11. Hariom, B. N. S., Prakash, M., and Bhat, K. K. (2006) Vanilla flavor evaluation by sensory and electronic nose

techniques. *J. Sens. Stud.* **21**, 228-239.
12. Hernandez-Gomez, A., Wang, J., Hu, G., and Pereira, A. G. (2007) Discrimination of storage shelf-life for mandarin by electronic nose technique. *LWT Food Sci. Technol.* **40**, 681-689.
13. Hunter, R. S. and Harold, R. W. (1987) Uniform color scales: Munsell-based scales. In: The measurement of appearance. 2nd ed, Hunter Associates Laboratory, Reston, VA, pp. 135-148.
14. Hyun, C., Rhee, Y. J., Lee, S. A., Lee, S.G., Lee, S. K., Kim, J. T., and Song, Y. H. (2007) Hematological, blood chemical and hormonal changes in Hanwoo (Korean native cattle) raised at different altitudes. *J. Vet. Clin.* **24**, 1-4.
15. Kim, Y. S., Liang, C. Y., Song, Y. H., and Lee, S. K. (2006) Effects of dietary Rhus verniciflua stokes supplementation on meat quality characteristics of Hanwoo (Korean cattle) beef during refrigerated storage. *Asian-Aust. J. Anim. Sci.* **19**, 113-118.
16. Korner, C. (2007) The use of 'altitude' in ecological research. *Trends Ecol. Evol.* **22,** 569-574.
17. Kritchevsky, D. (1998) History of recommendations to the public about dietary fat. *J. Nutr.* **128**, 449-452.
18. Krzywicki, K. (1979) Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of the beef. *Meat Sci.* **3**, 1-10.
19. Locker, R. H. (1989) Muscle into meat. In: Meat production and processing. Purchas. R. W., Butler-Hogg, B. W., and Davies, A. S. (eds), Occasional Publication No. 11, New Zealand Society of Animal Production Inc., NZ, pp. 173-183.
20. Monahan, F. J. (2000) Oxidation of lipid in muscle foods: fundamental and applied concerns. In: Antioxidants in muscle foods: nutritional strategies to improve quality. Decker. E. A., Faustman, C., and Lopez-Bote, C. J. (eds), John Wiley & Sons, Inc., Toronto, pp. 3-23.
21. Miller, R. K. (1994) Quality characteristics. In: Muscle foods: meat, poultry and seafood technology. Kinsman. D. M., Kotula, A. W., and Breidenstein, B. C. (eds), Chapman & Hall, NY, pp. 296-332.
22. Renerre, M. (2000) Oxidative processes and Myoglobin. In: Antioxidants in muscle foods: nutritional strategies to improve quality. Decker. E. A., Faustman, C., and Lopez-Bote, C. J. (eds), John Wiley & Sons, Inc., Toronto, pp. 113-133.
23. Scollan, N., Hocquette, J. F., Nuernberg, K., Dannenberger, D., Richardson, I., and Moloney, A. (2006) Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Sci.* **74,** 17-33.
24. Schmidt-Nielsen, K. (1990) Animal physiology: adaptation and environment. 4th ed, Cambridge University Press, NY.
25. Smith, G. C., Belk, K. E., Sofos, J. N., Tatum, J. D., and Williams, S. N. (2000) Economic implications of improved color stability in beef. In: Antioxidants in muscle foods: nutritional strategies to improve quality. Decker. E. A., Faustman, C., and Lopez-Bote, C. J. (eds), John Wiley & Sons, Inc. Toronto. pp. 397-426.
26. Sinnhuber, R. O. and Yu, T. C. (1977) The 2-thiobarbituric acid reaction, an objective measure of the oxidative deterioration occurring in fats and oils. *J. Jap. Soc. Fish. Sci.* **26,** 259-267.
27. SPSS (2003) SPSS Software for Windows. Release 12.0, SPSS Inc., Chicago, USA.
28. Strange, E. E., Benedicts, R. C., Gugger, R. E., Metzger, V. G., and Swift, C. E. (1974) Simplified methodology for measuring meat color. *J. Food Sci.* **39,** 988-992.
29. Waldron, M. R., Kulick, A. E., Bell, A. W., and Overton, T. R. (2006) Acute experimental mastitis is not causal toward the development of energy-related metabolic disorders in early postpartum dairy cows. *J. Dairy Sci.* **89,** 596-610.
30. Wood, J. D., Enser, M., Fisher, A.V., Nute, G. R., Sheard, P. R., Richardson, R. I., Hughes, S. I., and Whittington, F. M. (2008) Fat deposition, fatty acid composition and meat quality: a review. *Meat Sci.* **78,** 343-358.

(Received 2009.1.9/Revised 2009.4.2/Accepted 2009.4.5)