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The Effects of Dietary Sulfur and Vitamin E Supplementation on the Quality of Beef from the Longissimus Muscle of Hanwoo Bulls

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ABSTRACT : This study was carried out to investigate the effects of dietary sulfur (S) and vitamin E (Vit E) supplementation on the quality of beef from longissimus muscle of Hanwoo bulls. Eleven, 29 months-aged Hanwoo bulls were randomly divided into three feed supplementation groups (S (n = 4), Vit E (n = 4) and S+Vit E (n = 3)). S was given as much as 12 g/head/d and Vit E was given as much as 1,200 IU/head/d; both supplements were given for 3 months prior to slaughter. At 24 h post-slaughter, the carcasses were weighed and evaluated by official grader for carcass traits. At 48 h post-slaughter, the *M. longissimus* from each carcass was collected and stored at 4±0.2°C for 10 days. There were no significant differences in yield and quality grades of carcass and proximate composition, physical properties and aroma pattern of meat among all groups. At 5 days of storage, the TBARS value of meat from cattle with S+Vit E supplementation was significantly lower ($p<0.05$) than other groups; and at 10 days of storage, the TBARS value of meat from cattle with Vit E and S+Vit E supplementations was significantly lower ($p<0.05$) than from cattle with S supplementation. At 5 days of storage, MetMb concentration of meat from cattle with S+Vit E supplementation was significantly lower ($p<0.05$) than from cattle with Vit E supplementation; and at 10 days of storage, MetMb concentration of meat from cattle with S+Vit E supplementation was significantly lower ($p<0.05$) than from other groups. At 10 days of storage, the redness value of meat from cattle with S supplementation was significantly higher ($p<0.05$) than from cattle with Vit E supplementation and the hue-angle value of meat from cattle with S and S+Vit E supplementations was significantly lower ($p<0.05$) than from cattle with Vit E supplementation. Dietary Vit E supplementation had a better effect on lipid stability whereas dietary S supplementation had a better effect on OxyMb stability. The dietary combination of S and Vit E created the highest protection for beef from myoglobin oxidation and thus improved the color stability of meat. (**Key Words :** Beef Quality, Hanwoo Bull, Sulfur, Vitamin E)

INTRODUCTION

Lipid and heme pigment oxidations are the primary causes 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 OxyMb to MetMb is considered undesirable by most consumers (Smith et al., 2000).

Both lipid and heme pigment oxidations imply with free radicals (Renerre, 2000). Free radicals can be inactivated effectively by scavengers capable of donating an electron to the free radicals with the resulting scavenger forming a lower energy radical. Phenolic compounds (such as tocopherols) are the most common and the most effective free radical scavengers (Decker et al., 2000).

Vitamin E (Vit E) functions as a lipid-soluble antioxidant in cell membranes and its biologically important form in animals (α-tocopherol) satiates free radicals and protects meat-color pigments, membrane-bound phospholipids, and cholesterol from oxidation. Farm animals can not synthesize Vit E and normally obtain it by consuming pasture. Grain is relatively low in Vit E and an extended grain-feeding period may deplete tissue α-tocopherol levels. Feeding supplemental Vit E to feedlot cattle increases muscle α-tocopherol, delays MetMb formation, and increases retail caselife of beef. Supplementing diets of feedlot cattle with 500 to 1,000 IU/head/d of Vit E for about 100 days increases shelflife, lengthens retail caselife, and reduces product losses from discounting/discarding unattractively colored beef (Smith et al., 2000). Lee et al. (2003) concluded that the dietary Vit E

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supplementation of 1,000 IU/head/d for 6 months prior to slaughter was effective in delaying discoloration, MetMb accumulation, lipid oxidation and reduction of total reducing ability of *M. longissimus* and *M. semimembranosus* from Hanwoo steer during retail display compared to the control (200 IU/head/d) and 500 IU/head/d. Furthermore, Muramoto et al. (2004) found no differences in body weight gain and feed intake between steers supplemented with 0, 2,000 and 4,000 mg α-tocopherol acetate/head/d for 28 days prior to slaughter and it was not necessary to suplement with over 2,000 mg α-tocopherol to the diet of steers. In addition, Vit E supplementation may improve the fat color (Irie et al., 2006).

Free radicals in skeletal muscle are generated in both lipid (i.e., breakdown of lipid peroxides) and cytosolic (i.e., breakdown of hydrogen peroxide) environments and tocopherols are lipid-soluble free radical scavengers (Decker et al., 2000). Therefore, antioxidation systems in the meat will be more effective if supplementation of Vit E in diet is accompanied by supplementation of cytosolic skeletal muscle free radicals scavenger compound. Decker et al. (2000) described that some of cytosolic skeletal muscle free radicals scavengers are thiols/sulfhydryls and reduced thiols including cysteine, glutathione, and lipoic acid are capable of donating hydrogen to free radicals. Cysteine is required for the synthesis of glutathione and it is the sulfhydryl group of reduced glutathione which allows the molecule to play its role in the oxidation-reduction processes (Larvor, 1983). Moreover, the supplementation of S and Vit E in the diet may affect the quality of meat.

Kahlon et al. (1975) stated that rumen microorganisms can utilize inorganic as well as organic forms of sulfur to synthesize S-containing amino acids (cystine, cysteine and methionine). Fron et al. (1990) reported that supplementing S as elemental S, sodium sulfate and DL-methionine in the bovine diet appeared to be equally beneficial, despite differences in route and extent of S excretion among the three S sources. Larvor (1983) stated that several forms of S have been used and the most common being elemental S at a level of 1 to 2 g/kg dry matter.

The effects of S supplementation in the diet on cellulolytic rumen micro-organisms and microbial protein synthesis in cattle, on mohair responses of goats, on milk yield and composition of goats and on performance of growing goats have been studied by McSweeney and Denman (2007), Qi et al. (1992a), Qi et al. (1992b) and Qi et al. (1993), respectively. However, there is limited information about the effect of S supplementation on the meat quality, especially in combination with Vit E. This study was carried out to investigate the effects of the dietary S and Vit E supplementation on the quality of beef from longissimus muscle of Hanwoo (Korean cattle) bulls.

MATERIALS AND METHODS

Animals and treatments

Eleven heads of 29 months aged Hanwoo bulls were randomly divided into three groups. The first group (n = 4) was given S supplementation, the second group (n = 4) was given Vit E supplementation, and the third group (n = 3) was given S+Vit E supplementation. The means±standard deviations of initial weight of S, Vit E and S+Vit E groups were 720.50±55.05 kg, 630.00±16.02 kg and 670.00±15.00 kg, respectively. S (S≥95%, Bio Tech Co., Korea) was given 12 g/head/d and Vit E (α-tocopherol 33.3%+α-tocopherol acetate 66.7%, Vixxol Co., Korea) was given as much as 1,200 IU/head/d; both supplements were given for 3 months prior to slaughter.

Carcass traits

At 24 h post-slaughter, the carcasses were weighed and evaluated by official grader for back fat thickness, ribeye area, marbling (1 = devoid and 9 = abundant), lean meat color (1 = brightly cherry red and 7 = extremely dark red), fat color (1 = white and 7 = dark yellow), firmness (1 = soft and 3 = firm), maturity (1 = youthful and 9 = mature), yield index and grade, and carcass quality grade according to the Korean carcass grading standard (NLCF, 2004). Marbling, lean meat color, fat color and maturity scores were based on the exposed longissimus muscle (*M. longissimus*) at the 13th rib interface. Marbling score was about marbling that appear to ribeye area. Firmness was water folding capacity and elasticity of ribeye area in grade decision region. Maturity was about ossification of cartilage in left semiconductor backbone thorn promontory. Dressing percentage was calculated as the percentage of carcass weight to live weight. Yield index was calculated as follows.

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

Yield grade was scored as follows.

3 = A grade (yield index ≥67.50)
2 = B grade (62.00≤yield index<67.50)
1 = C grade (yield index <62.00)

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, the *M. longissimus* at the 12 to 13th thoracic vertebra from each carcass were collected for meat quality analysis.

Proximate composition analysis

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 Kjeltec system (2200 Kjeltec 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.

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±0.2°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 was taken into account.

Aroma pattern analysis

The aroma pattern was analyzed using an electronic nose (FOX 3000, Alpha MOS, Toulouse, France) equipped with 12 metal oxide sensors. 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 for 180 sec (agitation speed: 500 rpm) 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 principal component analysis (Alpha Soft software, version 8.01) was used to explore the data from electronic nose and to assess discrimination performances (Deisingh et al., 2004).

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±0.2°C for 10 days. The TBARS (2-thiobarbituric acid reactive substances) values were measured at 0, 5 and 10 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 95-100°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 stability 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 $cc/m^2 \cdot 24\ h \cdot atm$, 0.01 mm of thickness, 3M Co., Korea) and stored in refrigerator (CAG17DZ, LG, Korea) at 4±0.2°C for 10 days. The

relative Mb (OxyMb and MetMb) concentration and the CIE (Commission Internationale de I'Eclairage) color values were measured at 0, 5 and 10 days of storage. The relative Mb 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).

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

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

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

Reflectance at selected wavelengths was measured using a UV-vis spectrophotometer (UV-2401PC, Shimadzu Co., Japan). 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

Data was analyzed using the General Linear Model procedure of SAS Institute (1999). Differences among means at the 5% level were determined by the Duncan's

Table 1. The carcass traits[1] of Hanwoo (Korean cattle) bulls with different feed supplementation[2]

Items	Feed supplementation		
	S	Vit E	S+Vit E
Yield traits			
Slaughter weight (kg)	773.75±69.85	680.75±9.74	724.67±34.27
Carcass weight (kg)	419.75±39.43	398.00±8.29	423.00±26.21
Dressing percentage (%)	54.62±7.13	58.46±0.79	58.34±0.88
Back fat thickness (mm)	4.75±1.50	4.25±1.50	6.67±2.08
Ribeye area (cm^2)	71.50±11.21	78.50±5.07	83.33±7.57
Yield index	68.96±1.29	69.41±1.42	67.92±2.24
Yield grade	3.00±0.00	3.00±0.00	2.67±0.58
Quality traits			
Marbling score	1.25±0.50	1.50±0.58	1.67±0.58
Lean meat color	6.00±0.00[a]	6.00±0.00[a]	5.00±0.00[b]
Fat color	4.00±0.00	3.75±0.50	3.67±0.58
Firmness	2.00±0.00	2.00±0.00	2.00±0.00
Maturity	4.00±0.82	3.00±0.00	3.33±0.58
Carcass quality grade	1.25±0.50	1.50±0.58	1.33±0.58

[1] Carcass traits were conducted by official grader according to the Korean carcass grading standard (NLCF, 2004).
[2] Values are presented as mean±standard deviation.
[a, b] Means in the same row with different superscripts are significantly different ($p<0.05$).

Table 2. The proximate composition and physical properties of *M. longissimus* from Hanwoo (Korean cattle) bulls with different feed supplementation[1]

Items	Feed supplementation		
	S	Vit E	S+Vit E
Proximate composition (%)			
Moisture	72.81±1.62	71.91±1.97	72.01±2.23
Crude fat	5.76±2.46	6.33±2.80	5.75±1.89
Crude protein	22.98±0.73	23.35±0.65	23.24±0.29
Crude ash	0.96±0.03	0.94±0.03	0.94±0.06
Physical properties			
pH	5.65±0.55	5.61±0.50	5.70±0.45
WHC (%)	47.07±7.20	45.68±5.22	45.73±3.42
Drip loss[2] (%)	1.65±0.35	1.25±0.12	1.31±0.25
Cooking loss (%)	31.88±5.75	32.64±2.20	32.75±5.61
Shear force (kg)	4.05±1.05	3.96±0.89	3.70±0.67

[1] Values are presented as mean±standard deviation. [2] Drip loss of meat after 2 days of refrigerated storage.

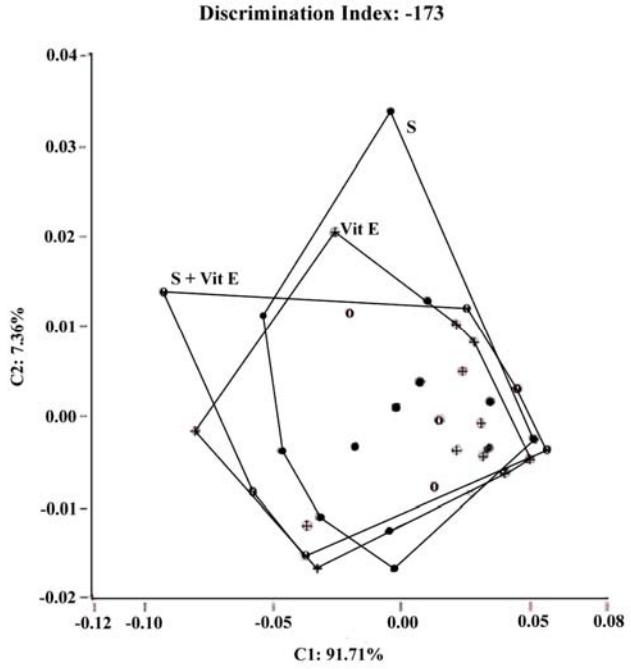

Figure 1. The principal component analysis of aroma pattern of *M. longissimus* from Hanwoo (Korean cattle) with different feed supplementation. C1 and C2 represent the components which are classified depending on the level of information from the electronic nose data. Points represent sensor responses 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.

multiple range tests.

RESULTS AND DISCUSSION

The results of carcass traits are shown in Table 1. There were no significant differences of the carcass traits among all groups except lean meat color. In the carcass traits which was conducted by official grader, lean meat color score of meat from cattle with S supplementation and Vit E supplementation was significantly higher ($p<0.05$) than that from cattle with S+Vit E supplementation. However, the lean meat color scores of all groups were still in the range of normal color according to the Korean carcass grading standard (NLCF, 2004). In addition, there were no significant differences of the lightness, redness, yellowness, chroma and hue-angle values among all groups at 0 days of storage (Table 5). Liu et al. (1995) stated that, generally, Vit E supplementation has not affected feedlot performance, carcass characteristics, or quality and yield grades of beef cattle. Zinn et al. (1997) reported that dietary S at 0.15, 0.20 and 0.25% (DM basis) level in feedlot cattle did not influence dressing percentage, fat thickness, marbling score or retail yield; however, increasing dietary S level decreased longissimus muscle (ribeye) area. Decreasing ribeye area was not found in this study since there was no significant difference ribeye area among all groups (Table 1).

Irie et al. (2006) guessed Vit E supplementation may improve the fat color, meaning in more white fat will be produced. The score of fat color from cattle with Vit E and S+Vit E supplementations tended to lower than that from S supplementation. However, there was no significant difference fat color score among them.

There was no significant difference proximate composition and physical properties of meat among all groups (Table 2) and there was no positive discrimination of the aroma pattern of raw meat among all groups (Figure 1). These indicated that the dietary S and Vit E

Table 3. The TBARS values (mg malonaldehyde/kg meat) of *M. longissimus* from Hanwoo (Korean cattle) with different feed supplementation during refrigerated storage[1]

Storage time (day)	Feed supplementation		
	S	Vit E	S+Vit E
0	0.24±0.04	0.24±0.05	0.23±0.03
5	0.33±0.03[a]	0.33±0.04[a]	0.29±0.02[b]
10	0.42±0.04[a]	0.38±0.05[b]	0.36±0.05[b]

[1] Values are presented as mean±standard deviation.
[a, b] Means in the same row with different superscripts are significantly different ($p<0.05$).

Table 4. The relative myoglobin concentration (%) at the surface of *M. longissimus* from Hanwoo (Korean cattle) with different feed supplementation during refrigerated storage[1]

Items	Storage time (day)	Feed supplementation		
		S	Vit E	S+Vit E
MetMb	0	19.36±3.33[a]	19.70±3.51[a]	18.19±4.62[b]
	5	27.17±3.90[ab]	27.69±3.41[a]	26.41±3.88[b]
	10	34.75±7.91[b]	38.50±11.10[a]	32.36±6.53[c]
DeoxyMb	0	23.58±11.18	22.68±14.30	21.98±13.88
	5	13.32±6.07[a]	12.56±5.22[ab]	11.60±4.21[b]
	10	24.49±14.57	26.43±14.55	21.93± 15.96
OxyMb	0	57.05±12.55	57.62±15.68	59.83±15.07
	5	59.50±7.04[b]	59.75±6.06[b]	61.99±5.51[a]
	10	40.76±15.60[b]	35.07±12.16[c]	45.71±16.11[a]

[1] Values are presented as mean±standard deviation.
[a, b, c] Means in the same row with different superscripts are significantly different ($p<0.05$).

supplementations had no effect on the proximate composition, physical properties and aroma of meat.

The TBARS value and the relative Mb concentration of meat during refrigerated storage are shown in Table 3 and 4, respectively. At 5 days of storage, the TBARS value of meat from cattle with S+Vit E supplementation was significantly lower ($p<0.05$) than those from other groups; and at 10 days of storage, the TBARS value of meat from cattle with Vit E supplementation and S+Vit E supplementation was significantly lower ($p<0.05$) than that from cattle with S supplementation. At 5 days of storage, MetMb concentration of meat from cattle with S+Vit E supplementation was significantly lower ($p<0.05$) than that from cattle with Vit E supplementation; there was no significant difference MetMb concentration of meat from cattle with S supplementation with that from other groups. At 10 days of storage, MetMb concentration of meat from cattle with S+Vit E supplementation was significantly lower ($p<0.05$) than that from cattle with S supplementation; in turn, MetMb concentration of meat from cattle with S supplementation was significantly lower ($p<0.05$) than that from cattle with Vit E supplementation. On the other hand, at 5 days of storage, OxyMb concentration of meat from cattle with S+Vit E supplementation was significantly higher ($p<0.05$) than that from cattle with S or Vit E supplementation. At 10 days of storage, OxyMb concentration of meat from cattle with S+Vit E supplementation was significantly higher ($p<0.05$) than that from cattle with of meat from cattle with S supplementation; in turn, OxyMb concentration of meat from cattle with S supplementation was significantly higher ($p<0.05$) than that from cattle with Vit E supplementation. These results indicated that dietary Vit E supplementation has the better effect on the lipid stability whereas dietary S supplementation has the better effect on the OxyMb stability. This may due to the difference phases (solubility) between them. Decker et al. (2000) described that Vit E is lipid soluble whereas sulfhydryls are cytosolic soluble.

These results also indicated that the dietary combination S+Vit E supplementation has the better effect on the OxyMb stability than S or Vit E. Sulfhydryls have the direct effect on the OxyMb stability whereas tochoperols have indirect effect on that. Faustman and Wang (2000) described that myoglobin is a sarcoplasmic protein in close proximity to phospholipid membranes of sub cellular organelles and of the cell and suggested that α-tocopherol delays the release of prooxidative products of lipid oxidation from biomembranes, which in turn delays OxyMb oxidation. Thus, the dietary combination S and Vit E supplementation created the hurdle protection for beef from OxyMb oxidations.

At 10 days of storage, the redness value of meat from cattle with S supplementation was significantly higher ($p<0.05$) than that from cattle with Vit E supplementation (Table 5). This may due to the difference MetMb concentration among them. Renerre (2000) stated that it is possible to follow the decrease of redness value by following the accumulation of MetMb during oxidation. At the same time, the hue-angle value of meat from cattle with S and S+Vit E supplementations was significantly lower ($p<0.05$) than that from cattle with Vit E supplementation (Table 5). This may due to the difference redness value between them. Kim et al. (2006) stated that the larger hue-angle value, the less red color of meat. Furthermore, Renerre (2000) stated that during storage of meat, the increase in hue-angle value indicates the degree of change

Table 5. The CIE color values of *M. longissimus* from Hanwoo (Korean cattle) with different feed supplementation during refrigerated storage[1]

Items	Storage time (day)	Feed supplementation		
		S	Vit E	S+Vit E
Lightness (L*)	0	37.74±1.95	38.23±2.74	38.25±2.80
	5	38.52±2.41	38.82±2.74	38.68±2.58
	10	37.72±3.01	37.57±2.69	37.46±2.42
Redness (a*)	0	14.40±2.82	15.35±3.10	15.01±2.70
	5	15.90±1.41^{b}	16.06±1.76^{b}	16.79±1.05^{a}
	10	14.28±2.12^{a}	13.18±2.62^{b}	14.13±2.89^{ab}
Yellowness (b*)	0	6.05±1.71	6.59±1.99	6.48±1.81
	5	7.90±1.68^{b}	8.07±1.10^{b}	8.45±0.61^{a}
	10	6.89±1.69	6.96±1.84	6.54±2.31
Chroma (C*)	0	15.64±3.23	16.72±3.61	16.37±3.16
	5	17.76±1.68^{b}	17.98±2.04^{b}	18.80±1.14^{a}
	10	15.91±2.41	15.07±2.30	15.64±3.37
Hue-angle (H°)	0	22.39±2.68	22.66±2.96	22.91±2.86
	5	26.35±1.29	26.61±1.24	26.74±1.28
	10	25.59±4.87^{b}	28.32±9.05^{a}	24.33±6.05^{b}

[1] Values are presented as mean±standard deviation.

[a, b] Means in the same row with different superscripts are significantly different ($p<0.05$).

from redness to yellowness values. These results indicated that dietary S supplementation has the better effect on the color stability than Vit E supplementation. This may due to the dietary S supplementation has the better effect on the OxyMb stability than Vit E supplementation.

In conclusion, the dietary combination S and Vit E didn't affect yield and quality grades of carcass and proximate composition, physical properties and aroma of meat. They affected the lipid and myoglobin stabilities of meat during refrigerated storage. The dietary Vit E supplementation has the better effect on the lipid stability whereas dietary S supplementation has the better effect on the OxyMb stability and the dietary combination S and Vit E created the hurdle protection for beef from OxyMb oxidations so that improved the color stability of meat.

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