

Effect of Pasture Finishing on Beef Quality of Japanese Shorthorn Steers

T. Muramoto*, M. Higashiyama and T. Kondo

Department of Integrated Research for Agriculture, National Agricultural Research Center for Tohoku Region
Shimo-kuriyagawa, Morioka-shi, Iwate-ken, 020-0198, Japan

ABSTRACT : Effect of pasture finishing on α -tocopherol and β -carotene concentrations, drip loss, cooking loss, Warner-Bratzler shear force, fatty acid composition, meat color and metmyoglobin percentage of *m. longissimus thoracis* of Japanese Shorthorn steers was studied. Japanese Shorthorn steers (n=8), fattened indoors with a concentrate-based diet until they were 19 months of age were divided into two groups of four steers. Steers of the concentrate-fed group were fattened indoors with a concentrate-based diet until they were slaughtered. Steers of the pasture-fed group were fattened on pasture until they were slaughtered. The α -tocopherol and β -carotene concentrations in the muscle of the pasture-fed group were higher ($p<0.05$) than those of the concentrate-fed group. The drip loss of the muscle of the pasture-fed group was lower ($p<0.05$) than that of the concentrate-fed group. Compared with the concentrate-fed group, the concentration of peroxidisable lipids (fatty acids with three or more unsaturated bonds) in the muscle of the pasture-fed group was high ($p<0.05$). The metmyoglobin percentage during display of the muscle of the pasture-fed group was higher ($p<0.05$) than that of the concentrate-fed group. These results suggested that pasture finishing decreased drip loss of the beef but lowered meat color stability. (*Asian-Aust. J. Anim. Sci.* 2005. Vol 18, No. 3 : 420-426)

Key Words : Pasture, α -Tocopherol, β -Carotene, Fatty Acid, Drip Loss, Metmyoglobin

INTRODUCTION

There are four breeds of Japanese beef cattle called *Wagyu* in Japan. They are Japanese Black, Japanese Brown, Japanese Shorthorn and Japanese Polled breeds. Japanese Shorthorn is being bred mainly in the northern area of Iwate Prefecture in Japan. The selling price of Japanese Shorthorn beef is lower than that of Japanese Black beef. This is mainly because the beef of Japanese Shorthorn does not become marbling beef which is generally preferred by Japanese consumers. Recently, however, the number of Japanese consumers who prefer less marbling beef or lean beef has been increasing. In the beef production of Japanese Shorthorn, therefore, it is important to not only reduce the feeding and management costs but also enhance the lean beef quality. Japanese Shorthorn, as well as other Japanese beef cattle, is generally fattened indoors with a concentrate-based diet until they are slaughtered. Thus, a grazing system seems to be possible way to reduce the feeding and management costs. On the other hand, it is necessary to investigate enough the characteristic of beef of pasture-fed Japanese Shorthorn.

Sanders et al. (1997) reported that 58% of Japanese survey participants (n=10,941) identified muscle color as the most important factor in selecting beef products. Therefore, meat color is considered to be the most important factors in evaluating the quality of lean meat. The red color of fresh beef is due to oxymyoglobin. The discoloration of meat from red to brown during storage

results from the oxidation of oxymyoglobin to metmyoglobin (Faustman and Cassens, 1990). Dietary α -tocopherol (Arnold et al., 1993) and β -carotene (Muramoto et al., 2003a) supplementation to steers have shown to retard metmyoglobin formation of displayed beef. Green pasture contains large amounts of tocopherols (Jukola et al., 1996) and carotenoids (Yang et al., 1992). Therefore, a pasture finishing system seems to be useful way to enhance the meat color stability. However, there are no reports regarding the effect of pasture finishing on metmyoglobin accumulation of displayed beef.

Furthermore, Mitchell et al. (1991) reported that pasture finishing decreased meat tenderness. Enser et al. (1998) observed that pasture finishing influenced the fatty acid composition of muscle, and Turek et al. (1996) reported that dietary fatty acids with different degrees of saturation exerted different effects on human health.

The purpose of this study was to investigate the effect of pasture finishing on Warner-Bratzler shear force, cooking loss, drip loss, α -tocopherol and β -carotene concentrations, fatty acid composition, meat color and metmyoglobin percentage during display of muscle of Japanese Shorthorn steers.

MATERIALS AND METHODS

Animals and diets

Eight 10-month-old Japanese Shorthorn steers were used. The steers were fattened with concentrate and timothy silage until approximately 19 months of age. The steers aged 19.8 months (414.0 ± 7.1 kg SE) were divided into two groups (concentrate-fed group and pasture-fed group) of

* Corresponding Author: Takayuki Muramoto. Tel: +81-19-643-3412, Fax: +81-19-643-3503, E-mail: muramoto@affrc.go.jp
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four steers. In the concentrate-fed group, each steer was supplied a commercial concentrate (Snow Brand Seed, Hokkaido, Japan) at 1.25% of its body weight and was supplied timothy silage *ad libitum*. The commercial concentrate was composed of grain mixture (67.0%), bran mixture (25.5%), oil seed meal mixture (5.0%) and other additives (2.5%). The steers were fattened indoors until their body weight reached the market weight (600-700 kg). The average slaughter age and live weight were 27.8 ± 1.0 months and 616.0 ± 18.6 kg, respectively. In the pasture-fed group, steers were fattened on semi-natural grassland (predominantly Sedge, *Carex spp.*, 14 ha) during summer (May-September). The steers were never supplied both concentrate and silage. Before the grass amount was limited, the fattening on the pasture was ended, and the steers were immediately slaughtered. The average slaughter age and live weight were 24.0 ± 0.2 months and 439.0 ± 5.4 kg, respectively.

Muscle samples

After slaughter according to industry-accepted procedure, carcasses were kept in a 0°C refrigerator for 48 h. Rib loin was removed from the left side of each carcass and kept in a 0°C refrigerator for 24 h. *M. longissimus thoracis* was identified and removed from each rib loin and samples were excised from the midsection of the muscle. Approximately 500 g of the sample was ground twice through a 3 mm plate of a laboratory meat grinder for analyses of crude fat, α -tocopherol and β -carotene concentrations and fatty acid composition. The ground meats were stored in a -30°C refrigerator until required. About 120 g (3 cm thick) of the sample was vacuum-packaged and stored for an additional 7 days (10 days postmortem) at 2°C for drip loss, cooking loss and Warner-Bratzler shear force analyses. Approximately 300 g of the sample was vacuum-packaged and stored for an additional 5 days (8 days postmortem) at 4°C for meat color and metmyoglobin analyses.

Crude fat, α -tocopherol and β -carotene analyses

Crude fat concentration in each muscle was determined by Soxhlet extraction for 16 h with diethyl ether according to AOAC (1984). The α -tocopherol and β -carotene concentrations in muscles were determined using a modification of the methods of Bennink and Ono (1982) and Simonne et al. (1996), respectively. The 1.0 g samples were placed in a 60 ml tube with 1 ml of 1% (W/V) sodium chloride and 10 ml of 3% pyrogallol-ethanol. The tubes were mixed and preincubated in a 70°C water bath for 5 minutes before 2 ml of 60% (W/V) KOH was added. The samples were saponified at 70°C for 30 minutes. The saponified mixture for α -tocopherol analysis was allowed to

cool before 22 ml of 1% (W/V) sodium chloride and hexane:ethyl acetate (9:1) were added. The saponified mixture for β -carotene analysis was allowed to cool before 20 ml of 1% (W/V) sodium chloride, 5 ml of isopropanol and hexane:ethyl acetate (9:1) were added and the mixture was shaken and centrifuged to separate the aqueous and organic phases. An aliquot of the hexane phase was removed and dried under a stream of nitrogen at 60°C. The α -tocopherol and β -carotene standards were maintained via the same procedure as described for the muscle samples. α -Tocopherol and β -carotene were determined by high-performance liquid chromatography with fluorometric detection. The dried samples for α -tocopherol analysis were redissolved in hexane and injected onto a 0.46×25 cm silicagel column (PEGASIL Silica 60-5, Senshu Scientific, Tokyo, Japan). The dried samples for β -carotene analysis were redissolved in ethanol and injected onto a 0.46×15 cm silicagel column (L-column ODS, Chemical Evaluation and Research Institute, Tokyo, Japan). α -Tocopherol and β -carotene were eluted with hexane:isopropanol:acetic acid (1,000:6:5) and acetonitrile:methanol:tetrahydrofuran (55:40:5), respectively, at flow rates of 1.5 ml/min. Detection of the α -tocopherol and β -carotene in the eluant was performed using a spectrofluorometer (RF-10A XL, Shimadzu, Kyoto, Japan) and a spectrofluorometer (SPD-10 AV, Shimadzu, Kyoto, Japan), respectively, equipped with a flow cell. α -Tocopherol was detected by measuring extraction at 298 nm and emission at 325 nm. The detection wavelength for β -carotene was 455 nm. Standard curves for α -tocopherol and β -carotene were prepared by injecting known amounts of α -tocopherol and β -carotene and measuring resultant peak heights.

Fatty acid analysis

Total lipid was extracted from the muscle tissue samples by the method of Folch et al. (1957). The 3.0 g samples for analyses of fatty acid composition were homogenized with 80 ml of a 2:1 (V/V) mixture of chloroform-methanol, after which 20 ml 0.9% NaCl was added, mixed and left to stand for 2 h to allow phase separation. The chloroform-methanol extract was evaporated to dryness in a water bath at 50°C under N₂ flow. The lipid extracts were then converted to fatty acid methyl esters using a boron-trifluoride methylation solution. The resultant fatty acid methyl esters were separated and analyzed using an automated gas chromatograph (GC-17A, Shimadzu, Kyoto, Japan) equipped with a flame ionization detector and a $30 \text{ m} \times 0.25 \text{ mm}$ (film thickness 0.25 μm) silica capillary column (DB-23, Agilent Technologies, Palo Alto, CA). The samples were analyzed under the following operating conditions: injector and detector temperature 250°C, helium gas flow 1.5 ml/min. Oven temperature programming was as

Table 1. Effect of finishing diet on Warner-Bratzler shear force, cooking loss and drip loss of *m. longissimus thoracis* (10 days postmortem) of Japanese Shorthorn steers

	Concentrate-fed ¹	Pasture-fed ²
Shear force (kg)	5.3 ^a (±0.4)	7.2 ^a (±0.6)
Cooking loss (%)	25.4 ^a (±1.0)	24.1 ^a (±0.4)
Drip loss (%)	4.9 ^a (±0.1)	3.0 ^b (±0.4)

¹ Steers were finished indoors with a diet of concentrate and silage (n=4).

² Steers were finished on pasture (n=4).

^{a, b} Means (±SE) within a row followed by different superscripts differ significantly (p<0.05).

follows: 50°C, held for 1 minute, 50-170°C at 10°C/min, 170-210°C at 1.2°C/min. The conditions were chosen to separate fatty acids with a chain length of 14-22 carbons. The fatty acids were identified by comparing their retention times with those of known standard mixtures of fatty acid methyl esters. The results were expressed as a weight percentage distribution of total fatty acid methyl esters.

Drip loss, cooking loss and Warner-Bratzler shear force analyses

Muscle samples for drip loss, cooking loss and Warner-Bratzler shear force analyses were weighed after storage for 7 days (10 days postmortem). Drip loss, as a percentage, was determined by use of the sample weights taken before and after storage. The samples used in the determination of drip loss were individually put into plastic bags and were cooked in a water bath at 80°C until the internal meat temperature reached 75°C (Watanabe et al., 1996). The cooked samples were then removed and immediately chilled in ice for 60 minutes. The samples were weighed again. Cooking loss, as a percentage, was determined by use of the sample weights taken before and after cooking. Warner-Bratzler shear force was measured with 1 cm² blocks cut parallel to the direction of the muscle fibers from the sample used in the determination of cooking loss (total of eight shear measurements per sample).

Meat color and metmyoglobin analyses

Three pieces of cores (3×3×1.5 cm) were cut from muscle samples (8 days postmortem) for meat color and metmyoglobin analyses. These samples were placed in a 100 ml disposable weighing boat and stored for 30 minutes at 4°C. After that, CIE (Commission Internationale de l'Eclairage) L* values (lightness), a* values (redness) and b* values (yellowness) and reflectance between 360 and 740 nm (at 10 nm intervals) of triplicate samples were measured using a spectrophotometer (CM-2500d, Konica Minolta, Tokyo, Japan). The measuring time was less than one second. Each sample was placed in the boat again, over-wrapped with oxygen-permeable PVC film and displayed under cool white fluorescent lights (1,000-1,500 lux) at 4°C for 10 days. Reflectances of triplicate samples

Table 2. Effect of finishing diet on crude fat, α-tocopherol and β-carotene concentrations in *m. longissimus thoracis* (3 days postmortem) of Japanese Shorthorn steers

	Concentrate-fed ¹	Pasture-fed ²
Crude fat (%)	3.7 ^a (±0.2)	1.4 ^b (±0.1)
α-Tocopherol (µg/g meat)	2.5 ^b (±0.3)	7.0 ^a (±0.2)
β-Carotene (µg/g meat)	0.07 ^b (±0.01)	0.24 ^a (±0.02)

¹ Steers were finished indoors with a diet of concentrate and silage (n=4).

² Steers were finished on pasture (n=4).

^{a, b} Means (±SE) within a row followed by different superscripts differ significantly (p<0.05).

were obtained daily during display using the spectrophotometer. Metmyoglobin percentages were obtained according to the method of Stewart et al. (1965).

Statistical analysis

The main effects of finishing diet upon Warner-Bratzler shear force, cooking loss, drip loss, α-tocopherol and β-carotene concentrations, fatty acid composition, L*, a* and b* values and metmyoglobin percentage were analyzed by the General Linear Model procedure of SAS (SAS, 1985). Differences between treatment means were evaluated by the Least Significance Difference test.

RESULTS AND DISCUSSION

The effect of finishing diet on Warner-Bratzler shear force of *m. longissimus thoracis* is shown in Table 1. Warner-Bratzler shear force of the muscle of the pasture-fed group tended to be higher (p>0.05) than that of the concentrate-fed group. Mitchell et al. (1991) reported that Warner-Bratzler shear force of muscle of the pasture-fed steers was higher than that of the concentrate-fed steers. However, Varela et al. (2004) observed that meat from pasture-fed steers was tenderer than meat from indoors finished ones at 24 h post mortem, but differences disappeared at 7 days. In their study, there was no effect of finishing system on the intramuscular fat amount of the steers. Generally, compared with the lean beef, the marbling beef is tender. This is because intramuscular fat improves meat tenderness by reducing bulk density and decreasing the strength of the connective tissue (Savell and Cross, 1988). In this study, crude fat concentration in the muscle of the pasture-fed group was lower (p<0.05) than that of the concentrate-fed group (Table 2). The regression formula of Warner-Bratzler shear force (y, kg) and crude fat concentration (x, %) was y=-0.91x+8.60, R=0.63. Generally, the solubility of collagen in the connective tissue decreases with age and meat toughness increases (Cross et al., 1973). In this study, however, the tenderness of the muscle from steers slaughtered at 24 months of age (the pasture-fed group) tended to be lower than that at 27 months of age (the concentrate-fed group). Therefore, the slight difference in

Table 3. Effect of finishing diet on fatty acid composition (%) of total lipid in *m. longissimus thoracis* (3 days postmortem) of Japanese Shorthorn steers

	Concentrate-fed ¹	Pasture-fed ²
C14:0	2.90 ^a (±0.14)	1.23 ^b (±0.10)
C14:1	0.90 ^a (±0.04)	0.10 ^b (±0.03)
C15:0	0.38 (±0.01)	0.43 (±0.01)
C16:0	27.1 ^a (±0.31)	22.2 ^b (±0.54)
C16:1	4.08 ^a (±0.12)	2.25 ^b (±0.08)
C17:0	0.83 (±0.01)	1.00 (±0.04)
C17:1	0.70 (±0.00)	0.75 (±0.03)
C18:0	12.7 ^b (±0.27)	17.2 ^a (±0.30)
C18:1	40.0 ^a (±0.33)	35.8 ^b (±0.56)
C18:2, n-6	3.75 ^b (±0.21)	7.73 ^a (±0.71)
C18:3, n-3	0.40 ^b (±0.00)	1.43 ^a (±0.13)
C20:0	ND ³	0.10 (±0.02)
C20:2, n-6	0.03 ^b (±0.01)	0.25 ^a (±0.01)
C20:3, n-6	0.23 ^b (±0.01)	0.80 ^a (±0.11)
C20:4, n-6	0.93 ^b (±0.05)	2.78 ^a (±0.33)
C20:5, n-3	0.08 ^b (±0.02)	0.85 ^a (±0.12)
C22:5, n-3	0.30 ^b (±0.02)	1.25 ^a (±0.14)
C22:6, n-3	ND ³	0.10 (±0.03)
Saturated (SFA)	43.9 (±0.46)	42.2 (±0.90)
Monounsaturated	45.7 ^a (±0.21)	38.9 ^b (±0.64)
Polyunsaturated (PUFA)	5.70 ^b (±0.28)	15.2 ^a (±1.58)
PUFA/SFA	0.13 ^b (±0.01)	0.37 ^a (±0.05)
n-6	4.93 ^b (±0.28)	11.6 ^a (±1.17)
n-3	0.78 ^b (±0.04)	3.63 ^a (±0.42)
n-6/n-3	6.58 ^a (±0.47)	3.25 ^b (±0.07)
Total peroxidisable ⁴	1.93 ^b (±0.09)	7.20 ^a (±0.86)

¹ Steers were finished indoors with a diet of concentrate and silage (n=4).

² Steers were finished on pasture (n=4). ³ Not determined.

⁴ Fatty acids with three or more unsaturated bonds.

^{a, b} Means (±SE) within a row followed by different superscripts differ significantly (p<0.05).

the Warner-Bratzler shear force of the muscle between the groups was considered to have been caused by the difference in crude fat concentration in the muscle.

The effect of finishing diet on cooking loss and drip loss of *m. longissimus thoracis* of Japanese Shorthorn steers is shown in Table 1. There was no difference (p>0.05) in the cooking loss of the muscle between the concentrate-fed group and the pasture-fed group. This result was consistent with the result reported by Varela et al. (2004), who also observed that the finishing diet did not affect the drip loss of the muscle. However, in this study, the drip loss of the muscle of the pasture-fed group was lower (p<0.05) than that of the concentrate-fed group.

Mitsumoto et al. (1995) reported that dietary α -tocopherol supplementation showed smaller increases of drip loss during display compared to the control. α -Tocopherol acts as an antioxidant by reacting with free radicals (Schaefer et al., 1995) arising from oxidative reactions initiated in the phospholipid-rich membranes of meat (Buckley et al., 1989). Dietary α -tocopherol is

absorbed by steers and incorporated into cellular membranes (Arnold et al., 1993). Membranal α -tocopherol restricts disruption of cell membranes by reacting with free radicals (Mitsumoto et al., 1998). Green pasture not only contains large amounts of tocopherols (Jukola et al., 1996) but also large amounts of other antioxidants such as carotenoids (Yang et al., 1992). Yang et al. (2002) reported that α -tocopherol and β -carotene concentrations in muscles from pasture-fed (132 days) cattle were higher than those from grain-fed (132 days) cattle. Simonne et al. (1996) also observed that the β -carotene concentration in muscle of steers finished (161 days) on pasture was higher than that of steers finished (72 days) on a feedlot diet. The effect of finishing diet on α -tocopherol and β -carotene concentrations in *m. longissimus thoracis* is shown in Table 2. α -Tocopherol and β -carotene concentrations in the muscle of the pasture-fed group were higher (p<0.05) than those of the concentrate-fed group. The regression formula of drip loss (y, %) and muscle α -tocopherol concentration (x, μ g/g meat) was $y=-0.40x+5.81$, R=0.72. The regression formula of drip loss (y, %) and muscle β -carotene concentration (x, μ g/g meat) was $y=-11.59x+5.69$, R=0.89. Therefore, it is considered that the drip loss of the muscle of the pasture-fed group was reduced mainly by the large amounts of antioxidants.

There has been an increased interest in recent years in ways to manipulate the fatty acid composition of meat. This is because meat is seen to be a major source of fat, especially of saturated fatty acids (SFA) which have been implicated in diseases associated with modern life. Table 3 shows the effect of finishing diet on fatty acid composition of total lipid in *m. longissimus thoracis*. The principal fatty acids in the muscle were C18:1, C16:0 and C18:0. These results agreed with the result reported by Varela et al. (2004). There were lower (p<0.05) concentrations of C14:0, C14:1, C16:0, C16:1 and C18:1 in the muscle of the pasture-fed group compared with the muscle of the concentrate-fed group. Concentrations of C18:0, C18:2n-6, C18:3n-3, C20:2n-6, C20:3n-6, C20:4n-6, C20:5n-3 and C22:5n-3 in the muscle of the pasture-fed group were higher (p<0.05) than those of the concentrate-fed group. Yang et al. (2002) also reported that all of the highly unsaturated fatty acids, C18:3n-3, C20:4n-6, C20:5n-3 and C22:5n-3, were more prevalent in the muscle from pasture-fed cattle. Garton (1960) reported that C18:3n-3 is the major fatty acid present in grass. Although a high proportion of this fatty acid is hydrogenated in the rumen and transformed into C18:0, a significant amount escapes the rumen to be absorbed intact in the small intestine (Sanudo et al., 2000).

The effect of finishing diet on SFA, monounsaturated fatty acid and polyunsaturated fatty acid (PUFA) concentrations in *m. longissimus thoracis* is shown in Table

Table 4. Effect of finishing diet on L*, a* and b* values of *m. longissimus thoracis* (8 days postmortem) of Japanese Shorthorn steers

	Concentrate-fed ¹	Pasture-fed ²
L* value	39.6 ^a (±0.4)	34.7 ^b (±0.3)
a* value	26.8 ^a (±0.4)	21.5 ^b (±0.5)
b* value	16.3 ^a (±0.3)	12.3 ^b (±0.4)

¹ Steers were finished indoors with a diet of concentrate and silage (n=4).

² Steers were finished on pasture (n=4).

^{a, b} Means (±SE) within a row followed by different superscripts differ significantly (p<0.05).

3. There was no difference (p>0.05) in the SFA in the muscle between the concentrate-fed group and the pasture-fed group. However, the monounsaturated fatty acid concentration in the muscle of the pasture-fed group was lower (p<0.05) than that of the concentrate-fed group. On the other hand, the PUFA concentration in the muscle of the pasture-fed group was higher (p<0.05) than that of the concentrate-fed group. The PUFA/SFA ratio usually grows linearly when forage intake increases (French et al., 2000). In this study also, the PUFA/SFA ratio in the muscle of the pasture-fed group was higher (p<0.05) than that of the concentrate-fed group. This parameter is commonly used to calculate the risk factor of foods with regard to blood cholesterol rise. The PUFA/SFA is recommended to be above 0.45 (Department of Health, 1994). Therefore, the PUFA/SFA ratio in pasture-fed steers (0.37) was more favorable than that in concentrate-fed steers (0.13) but not met the recommended value.

The effect of finishing diet on n-6 PUFA and n-3 PUFA concentrations in *m. longissimus thoracis* is shown in Table 3. Both the n-6 PUFA and the n-3 PUFA concentrations in the muscle of the pasture-fed group were higher (p<0.05) than those of the concentrate-fed group. The n-6/n-3 ratio is an index of the role played by fatty acids in human atherosclerosis (Sanders, 1988). The n-6/n-3 ratio is recommended to be below 4 (Department of Health, 1994). Therefore, the n-6/n-3 ratio in pasture-fed steers (3.25) was more favorable than that in concentrate-fed steers (6.58) and met the recommended value.

The effect of finishing diet on lightness (L* values), redness (a* values) and yellowness (b* values) of *m. longissimus thoracis* is shown in Table 4. The L*, a* and b* values of the muscle of the pasture-fed group were lower (p<0.05) than those of the concentrate-fed group. These results suggested that meat color of the muscle of the pasture-fed group was darker than that of the concentrate-fed group. Myoglobin concentration increases with age of animal, and consequently meat color becomes dark (Renerre, 1990). However, the slaughter age of the pasture-fed group (24 months of age) was smaller than that of the concentrate-fed group (27 months of age). On the other hand, Vestergaard et al. (2000) showed that pasture feeding produced muscles with a higher proportion of oxidative

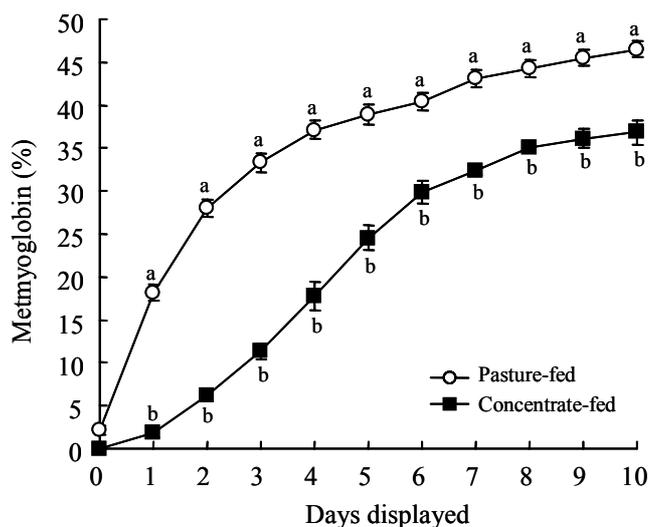


Figure 1. Effect of finishing diet on metmyoglobin percentages of *m. longissimus thoracis* (8 days postmortem) of Japanese Shorthorn steers. Steers of the concentrate-fed group (n=4) were finished indoors with a diet of concentrate and silage. Steers of the pasture-fed group (n=4) were finished on pasture. Each muscle sample was over-wrapped with PVC film and displayed under fluorescent light at 4°C for 10 days. Standard error bars are indicated. ^{a, b} Values on the same display days with a different superscript letter differ (p<0.05).

fibers and a darker color when compared to muscles from grain-fed cattle. Therefore, if proportion of oxidative fibers was increased in the pasture-fed group, and consequently meat color became dark, that was considered to have been caused by the pasture finishing.

Renerre and Bonhomme (1991) showed that an increase in the chilling rate reduced redness in beef. Mallikarjunan and Mittal (1994) reported that variations in carcass weight and fat thickness might alter the carcass chilling rate and consequently meat color. The average weight of the left side of carcass was 177.8 kg in the concentrate-fed group and 111.0 kg in the pasture-fed group, while the subcutaneous fat depth (measured at the 6-7th rib site) was 14 mm in the concentrate-fed group and 9 mm in the pasture-fed group. Therefore, the low redness of the muscle of the pasture-fed group at the beginning of display was considered to have been caused by the difference in the carcass weight and the subcutaneous fat depth.

It is important to determine metmyoglobin percentage of muscle in order to evaluate meat color stability. The effect of finishing diet on metmyoglobin percentages of *m. longissimus thoracis* is shown in Figure 1. At day 0 of display, there was no difference (p>0.05) in the percentage of metmyoglobin of the muscle between the groups. However, during day 1 to 10 of display, the metmyoglobin percentages of the muscle from the pasture-fed group were higher (p<0.05) than those of the concentrate-fed group. Green et al. (1971) reported that consumers would reject

beef containing over 30-40% metmyoglobin. Muramoto et al. (2004a) reported that meat color stability of *m. longissimus thoracis* of Japanese Shorthorn steers was higher than that of Japanese Black steers, based on a threshold value of 30% metmyoglobin. Therefore, in this study, 30% metmyoglobin was chosen as a threshold value. The metmyoglobin percentage of the muscle of the concentrate-fed group was beyond the threshold value at day 7 of display, while the metmyoglobin percentage of the muscle of the pasture-fed group was beyond the threshold value at day 3 of display. These results suggested that meat color stability of the muscle of the pasture-fed group was inferior to that of the concentrate-fed group.

Muramoto et al. (2003b) reported that meat color stability of *m. longissimus thoracis* became low with slaughter age. However, in this study, the slaughter age of the pasture-fed group (24 months of age) was about 4 months less than that of the concentrate-fed group (27 months of age). Muramoto et al. (2004b) reported that muscle α -tocopherol concentration, which can retard metmyoglobin formation in muscles, was 3.5 $\mu\text{g/g}$ meat for longissimus muscle. Therefore, in this study, α -tocopherol concentration in the muscle of the pasture-fed group (7.0 $\mu\text{g/g}$ meat) was sufficient level to retard metmyoglobin formation. Moreover, Muramoto et al. (2003a) observed that the color shelf-life of longissimus muscle was longer in the muscle containing 0.187 μg β -carotene/g meat than in the muscle containing 0.026 μg β -carotene/g meat. Therefore, in this study, β -carotene concentration in the muscle of the pasture-fed group (0.24 $\mu\text{g/g}$ meat) was sufficient level to extend the color shelf-life of the muscle.

Arnold et al. (1993) reported that lipid oxidation and color development in ruminant meats was influenced by not only the concentration of the tissue antioxidant but also the fatty acid composition. Although highly unsaturated fatty acids represent only a small percentage of the total lipid, small differences in their contents can account for quite large effects in terms of oxidation (Shahidi, 1992). In this study, the concentration of peroxidisable lipids (fatty acids with three or more unsaturated bounds) in the muscle of the pasture-fed group was higher ($p < 0.05$) than that of the concentrate-fed group (Table 3). It was considered that indirect oxidation of oxymyoglobin was accelerated by significant amounts of free radicals generated during the inhibition of the oxidation of large amounts of peroxidisable lipids contained in cell membranes. Therefore, large amounts of peroxidisable lipids could be one of the factors lowering the meat color stability of the muscle of the pasture-fed steers.

CONCLUSIONS

Compared with beef from concentrate-fed steers, α -

tocopherol and β -carotene concentrations in beef of pasture-fed steers were high, and drip loss of that beef was low. Fatty acid composition of beef of pasture-fed steers was favorable as food, but the concentration of peroxidisable lipids of that beef was high, and color stability was low. Thus, further investigation is needed to determine the conditions needed to improve the color stability of beef of pasture-fed steers.

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