Effect of rumen-protected fat and/or vitamin C supplementation on growth performance, carcass characteristics and meat composition in Hanwoo steers during late fattening period

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SUMMARY

High-energy diets to steers during the late fattening period, the consumption of large amounts of an energy-rich diet is liable to cause metabolic problems such as ruminal dysfunction and impaired liver-related immune function in beef cattle, as well as an increase in inedible fat. In ruminants, supplementation of rumen-protected fat is an effective approach for increasing energy density and enhancing productivity. In addition, Vitamin C, which is a strong antioxidant, is known to improve meat color by inhibiting phospholipid oxidation and reactive oxygen formation, and has also been found to improve marbling score and meat quality by enhancing adipocyte differentiation. However, studies on Hanwoo steers following the supplementation of rumen protected fat and vitamin C are insufficient.

Thus, this study was conducted to investigate the effect of rumen-protected fat and/or vitamin C supplementation on growth performance, carcass characteristics, and meat composition in Hanwoo steers during late period. Twenty-eight Hanwoo steers (initial body weight 723.0 ± 59.2 kg, approximately 27 months of age) were allotted to 4 treatments as follow: CON = basal diet, T1 = basal diet + rumen-protected fat (RPF) at the level of 0.1% of diet, T2 = basal diet + rumen-protected vitamin C (RPVC) at the level of 0.1% of diet, T3 = basal diet + RPF + RPVC. Final weight, average daily gain and dry matter intake were higher in T1 than in CON ($p < 0.05$). Plasma metabolites were similar among the treatments. Carcass weight and rib eye area was higher in all treatment group than in CON ($p < 0.05$). However, there was no effect according to the treatment on the chemical and fatty acid composition of longissimus muscle.

The present results suggest that rumen-protected fat and/or vitamin C supplementation has positive effects on concentrate feed intake. In particular, rumen-protected fat was founded to be effective in increasing in dry matter intake, average daily gain, carcass weight and rib eye area of Hanwoo steers. However, there was no complementary effect of rumen-protected fat and vitamin C supplementation.

KEY WORDS

Rumen-protected fat; Vitamin C; Growth performance; Carcass characteristics; Hanwoo steers.

INTRODUCTION

Although it is necessary to feed high-energy diets to steers during the late fattening period (1), the consumption of large amounts of an energy-rich diet is liable to cause metabolic problems such as ruminal dysfunction and impaired liver-related immune function in beef cattle, as well as an increase in inedible fat (2). In addition, given that feed efficiency and metabolic diseases are influenced by abnormal rumen and liver function, it is important to manage energy intake (of carbohydrate and fat) and use antioxidants in during the late fattening period of beef cattle.

In ruminants, supplementation of rumen-protected fat is an effective approach for increasing energy density and enhancing productivity. In particular, it has been established that the provision of rumen-protected fat is an effective means of enhancing milk yield and composition, by increasing energy intake without affecting rumen fermentation characteristics (3, 4). In beef cattle, rumen-protected fat has been used to enhance body weight gain and marbling score by increasing energy intake, and in recent years, studies have been conducted with the aim of increasing particular fatty acids, such as polyunsaturated fatty acids, oleic acid, and -linolenic acid, in the diets of beef cattle (5, 6).

Vitamin C, which is a strong antioxidant, is known to improve meat color by inhibiting phospholipid oxidation and reactive oxygen formation (7), and has also been found to improve marbling score and meat quality by enhancing adipocyte differ-

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entiation (8). For example, Yano et al. (9) reported that vitamin C and high-energy feed improve marbling score and fat color in Japanese black steers, whereas Park. (10) has demonstrated that vitamin C (2 g/d) influences meat quality in Hanwoo steers. It has been established that in addition to having antioxidant effects, vitamin C is also associated with the synthesis of immune substances such as prostaglandins and cytokines (11). However, given that ruminants have lower levels of vitamin C compared with monogastric animals, they tend to be prone to vitamin C deficiency under conditions of dietary and environmental stress (9). Although there have been some studies that have investigated supplementation of vitamin C for the purpose of improving meat quality in Hanwoo steers, most studies in Japan apply top dressing levels [40 mg/kg body weight (BW)], and it tends to be difficult to supply constant amounts of feed additives for individual steers when using the top dressing method. Accordingly, in order to efficiently use and supply constant amounts of vitamin C, it is necessary to supply this in a composite feed concentrate in Hanwoo steers. To date, however, there have been no studies that have investigated the effects of the combined provision of supplemental fat and vitamin C.

Consequently, in this study, we sought to investigate the effect of rumen-protected fat and/or vitamin C supplementation on the growth performance, carcass characteristics, and meat composition of Hanwoo steers.

Table 1 - Ingredient and chemical composition of experimental diets for late fattening Hanwoo steers.

Items	Treatments			
	Control	T1	T2	T3
	Ingredient composition (%)			
Corn grain	26.04	26.02	26.04	26.00
Wheat grain	8.00	8.00	8.00	8.00
Barley grain	2.00	2.00	2.00	2.00
Cane molasses	5.50	5.50	5.30	5.50
Tapioca residue	8.75	7.52	8.88	7.00
Wheat bran	-	2.32	-	2.84
Wheat flour	2.00	-	2.00	-
Corn gluten feed	18.35	20.00	18.36	20.00
Rapeseed meal	-	1.62	-	1.48
Coconut meal	10.00	10.00	10.00	10.00
Palm kernel meal	12.00	12.00	12.00	12.00
Cottonseed hull	1.00	1.00	1.00	1.00
Rumen protected fat (Ca-salt)	0.10	1.00	0.10	1.00
Lupin	3.00	-	3.00	-
Emulsifier	0.10	0.06	0.10	0.10
Salt dehydrated	0.50	0.50	0.50	0.50
Limestone (1mm)	1.63	1.42	1.58	1.44
Sodium bicarbonate	0.50	0.50	0.50	0.50
Premix[1)]	0.20	0.20	0.20	0.20
Rumen protected vitamin C	-	-	0.10	0.10
Others (feed additives)	0.34	0.34	0.34	0.34
	Chemical composition (%)			
Dry matter	88.47	88.39	88.49	88.39
Crude protein	12.20	12.20	12.20	12.20
Ether extract	3.86	4.53	3.86	4.54
Crude fiber	7.67	7.63	7.69	7.61
Crude ash	6.23	6.06	6.17	6.05
NFC	38.91	39.14	40.69	40.66
TDN	73.24	73.23	73.23	73.29

NFC, non-fiber carbohydrate; TDN, total digestible nutrients (calculated value).

[1)] Premix provided the following quantities of vitamins and minerals per kilogram of diet: vitamin A, 10,000 IU; vitamin D_3, 1,500 IU; vitamin E, 25 IU; Fe, 50 mg; Cu, 7mg; Zn, 30 mg; Mn, 24 mg; I, 0.6 mg; Co, 0.15 mg; Se, 0.15 mg.

MATERIALS AND METHODS

Animal care

All procedures on animals were carried out in compliance with South Korea regulations (Animal and Plant Quarantine Agency Ministry of Food and Drug Safety Joint Animal Testing and/or Laboratory Animal Related Committee (IACUC; 2020) Standard Operating Guidelines).

Animals, treatments, and management

Twenty-eight Hanwoo steers (initial body weight, 723.0 ± 59.2 kg; approximately 27 months of age) were randomly assigned to one of the following four dietary treatments: CON = basal diet, T1 = basal diet + rumen-protected fat (RPF) at the level of 0.1% of the diet, T2 = basal diet + rumen-protected vitamin C (RPVC) at the level of 0.1% of the diet, and T3 = basal diet + 0.1% RPF + 0.1% RPVC.

The steers were allotted by treatment group into four pens (5 m × 10 m) and fed 5 kg (as-fed basis) of concentrate three times daily (08:30, 13:00, and 18:00), along with a daily ration of 1.5 kg rice straw (as-fed basis). Basal diets were formulated for the late fattening period of steers according to National Research Council recommendations (12). Water was freely available at all times, and other feeding management was conducted in accordance with the practices of the farm. The chemical compositions of the experimental diets were analyzed according to the methods of the Association of Official Analytical Chemists (AOAC, 13) and are shown in Table 1. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to the methods of Van Soest (14) using a filter bag (Ankom F57; Ankom Technology, NY, USA).

Growth performance and plasma metabolism

Feed intake was measured daily prior to morning feeding, and the amount of feed consumed was determined by measuring the orts. Average daily gain (ADG) was calculated based on the number of days in each month, and the feed conversion ratio (FCR) was calculated using dry matter intake (DMI) and ADG.

For the analysis of plasma metabolites, 10-mL blood samples were collected from the jugular vein of the experimental animals using an 18-gauge needle and heparin-coated blood collection tubes (Vacutainer, Becton-Dickinson, NJ, USA). The collected blood samples were stored in an icebox and transferred to the laboratory within 6 h of collection, wherein they centrifuged at 1,250 × *g* for 10 min to separate the plasma, which was subsequently analyzed using an automatic blood analyzer (Hitachi 7020; Hitachi Ltd., Tokyo, Japan). The samples were analyzed for albumin, calcium, creatinine, glucose, total cholesterol, total protein, triglyceride, and blood urea nitrogen (BUN).

Carcass characteristics and chemical composition of the *longissimus* muscle

At the end of the experimental period, the steers were slaughtered at a local slaughterhouse to determine the effects of treatment on carcass traits (yield and quality). Carcass evaluation was performed at the 13^{th} rib section from the left side of each carcass by meat graders, using criteria provided by the Korean carcass grading system (15). To analyze the composition of the *longissimus* muscle, the fat and connective tissues of meat samples were removed in a low temperature room (5°C).

The chemical composition of the *longissimus* muscle was determined according to the standard methods of the AOAC (13). For the measurement of meat pH, approximately 10 g of *longissimus* muscle was cut into small pieces and homogenized with 90 mL of distilled water (PolyTron PT-2500 E; Kinematica, Lucerne, Switzerland). pH values were measured immediately after homogenization using an Orion 230A pH meter (Thermo Fisher Scientific Inc., MA, USA).

The fatty acid composition of the *longissimus* muscle was determined according to the methods of Folch et al. (16). Lyophilized samples (0.5 g) were homogenized in chloroform-methanol (2:1) and 0.88% NaCl solution, after which the bottom layer was separated by centrifugation (1,250 × *g*, 4°C, 30 min) and transferred to a fresh tube, wherein the organic solvent was flushed with nitrogen gas. Following the addition of 1 mL of 0.5 N methanolic NaOH to the tube, the mixture was heated for 15 min and then cooled. Thereafter, 2 mL of 14% BF_3-methanol was added to the tube followed by heating and subsequent cooling, after which, a heptane-NaCl solution (1:2 v/v) was added, and the mixture was allowed to stand at room temperature for 40 min. The supernatant was transferred to a vial, and fatty acids were analyzed by gas chromatography (Shimadzu-17A; Shimadzu, Kyoto, Japan).

Table 2 - Effects of rumen protected fat and vitamin C on growth performances of late fattening Hanwoo steers.

Items	Treatments			
	Control	T1	T2	T3
Initial BW (kg)	713.69±21.61	729.79±21.00	734.53±22.57	713.83±21.61
Final BW (kg)	764.13±25.41^{b}	818.86±22.99^{a}	807.79±24.57^{ab}	790.65±23.84^{ab}
ADG (kg/d)	0.36±0.09^{b}	0.68±0.08^{a}	0.58±0.08^{ab}	0.54±0.08^{ab}
Intake (DM, kg/steer/day)				
Concentrate	6.53±0.47^{b}	8.68±0.63^{a}	8.48±0.51^{a}	8.17±0.56^{a}
Rice straw	0.59±0.02	0.62±0.01	0.62±0.01	0.62±0.01
DMI	7.13±0.51^{b}	9.31±0.71^{a}	9.11±0.63^{ab}	8.79±0.60^{ab}
Feed conversion ratio	19.81±7.12	13.69±3.54	15.71±4.22	16.28±5.51

BW, body weight; ADG, average daily gain; DM, dry matter; DMI, dry matter intake.
^{a,b}Means with difference superscript in the same row are significantly different (P<0.05).

Table 3 - Effects of rumen protected fat and vitamin C on plasma metabolite concentrations of late fattening stage Hanwoo steers.

Items	Initial (0 day)				Mid (60 days)				Final (120 days)				P-value		
	Control	T1	T2	T3	Control	T1	T2	T3	Control	T1	T2	T3	TRT	Time	TRT * Time
Albumin (g/dl)	3.90±0.08	3.79±0.08	3.94±0.08	4.00±0.08	3.95±0.06	3.90±0.06	4.01±0.07	3.85±0.06	4.02±0.09	4.00±0.08	4.07±0.09	4.07±0.08	0.241	0.035	0.766
BUN (mg/dl)	13.82±0.83	15.97±0.81	17.41±0.87	14.09±0.83	12.89±0.98	12.81±0.94	12.14±1.02	12.93±0.97	16.77±1.01	15.41±0.91	16.90±0.97	16.30±0.95	0.406	0.001	0.260
Total protein (g/dl)	7.13±0.14	6.60±0.13	7.10±0.14	7.12±0.14	6.93±0.16	6.62±0.16	6.86±0.17	6.70±0.16	7.20±0.12	7.09±0.11	7.25±0.12	7.20±0.11	0.080	0.001	0.337
Glucose (mg/dl)	65.74±3.06	61.76±2.97	56.59±3.19	65.31±3.06	57.20±1.75	55.05±1.68	56.13±1.81	55.45±1.72	69.55±2.20	70.72±1.99	74.01±2.13	72.92±2.07	0.528	0.001	0.122
Cholesterol (mg/dl)	153.60±10.48	159.28±10.18	159.08±10.94	155.31±10.48	169.58±14.00	210.76±13.49	166.62±14.53	183.02±13.81	187.81±14.45	200.77±15.98	183.32±14.99	221.04±15.44	0.403	0.001	0.470
Triglyceride (mg/dl)	15.80±2.91	16.70±2.83	16.82±3.04	15.94±2.91	19.62±2.37	22.19±2.28	20.94±2.46	27.93±2.34	17.89±2.50	19.72±2.76	19.28±2.59	26.63±2.67	0.026	0.344	0.124
Creatinine (mg/dl)	1.39±0.05	1.57±0.05	1.54±0.05	1.48±0.05	1.52±0.06	1.45±0.05	1.42±0.06	1.34±0.06	1.49±0.07	1.30±0.06	1.51±0.07	1.37±0.07	0.632	0.175	0.057
Calcium (mg/dl)	8.93±0.16	8.88±0.15	8.95±0.16	9.20±0.16	9.27±0.16	9.01±0.16	8.87±0.17	9.12±0.16	9.08±0.13	9.03±0.11	9.18±0.12	9.23±0.12	0.340	0.374	0.755

TRT, Treatment; BUN, blood urea nitrogen.

Statistical analysis

The least squares method was used to estimate the environmental effects on body weight, ADG, carcass traits, and chemical composition of the *longissimus* muscle. We used the following linear model:

$$y_{ijkl} = \quad + TRT_i + \; _1X_{1ij} + \; _2X_{2ik} + e_{ijkl},$$

where is the overall average, TRT_i is the effect of treatment (1–4), X_1 and X_2 are the covariation of castration age and measurement month, respectively, $_1$, and $_2$ are regression coefficients, and e_{ijkl} is the random error effect. The least squares method was used to estimate environmental effects on feed intake and the FCR for each treatment using the following equation:

$$y_{ij} = \mu + TRT_i + e_{ij},$$

where μ is the overall average, TRT_i is the effect of treatment (1–4), and e_{ij} is the random error effect.

The linear model was analyzed using the SAS 9.1 (SAS Institute, Cary, USA) software package and variance analysis was performed using a Type III squared fit for unbalanced data among the four squares obtained in the SAS/generalized linear model analysis. Statistically significant differences for the treatments between the least squares averages were determined using the following null hypothesis at a significance level of 5%:

$$H_0: LSM(i) = LSM(j),$$

where LSM (i(j)) is the least squares average of the I (j) and the effects (I ≠ j).

The two-way analysis of variance (ANOVA) was applied to determine significant differences of blood metabolites between treatment groups (experimental time and feed additives) using general linear mixed model.

RESULTS

Growth performance and plasma metabolism

The effects of rumen-protected fat and/or vitamin C supplementation on the growth performance of Hanwoo steers are shown in Table 2. We found that the final BW and ADG were higher in the T1 group steers than in those of the control group ($p < 0.05$). Similarly, the final BW and ADG of T2 and T3 steers were slightly higher than those of steers in the control group, although in this case the differences were not statistically significant. Furthermore, concentrate intake was higher in the treat-

Table 4 - Effects of rumen protected fat and vitamin C on carcass characteristics of Hanwoo steers.

Items	Treatments			
	Control	T1	T2	T3
Yield traits[1]				
Carcass weight (kg)	452.16±16.71[b]	495.55±15.29[a]	476.14±16.11[ab]	463.15±15.91[b]
Back fat thickness (mm)	12.72±2.88[b]	20.54±2.63[a]	19.56±2.77[a]	17.84±2.74[a]
Rib eye area (cm^2)	83.77±3.62[b]	94.55±3.31[a]	90.08±3.49[ab]	86.83±3.45[b]
Yield index	63.49±2.01	58.96±1.84	59.46±1.94	60.43±1.91
Quality traits[2]				
Marbling score	4.79±0.69	5.21±0.66	6.02±0.70	5.45±0.72
Meat color	4.77±0.15	4.89±0.14	4.64±0.15	4.93±0.15
Fat color	2.79±0.10	3.02±0.09	2.90±0.10	2.96±0.10
Texture	1.21±0.15	1.10±0.14	1.06±0.15	1.21±0.15
Maturity	2.51±0.16	2.83±0.15	2.94±0.16	2.48±0.15

[a,b]Means with difference superscript in the same row are significantly different (P<0.05).

[1] Area and back fat thickness were measured from the *longissimus* muscle taken at the 13th rib. Yield index was calculated using the following equation: [68.184 – (0.625 × back fat thickness (mm)) + (0.130 × rib eye area (cm^2)) – (0.024 × dressed weight amount (kg))] + 3.23.

[2] Grading ranges are 1 to 9 for marbling score, where higher numbers indicate better quality (1 = devoid, 9 = abundant); meat color (1 = bright red, 7 = dark red); texture (1 = soft, 3 = firm); and maturity (1 = youthful, 9 = mature).

ment groups than in the control group ($p < 0.05$), and FCR was slightly, although non-significantly, higher in T1 steers than in those of the other treatment groups.

The effects of rumen-protected fat and/or vitamin C supplementation on the concentrations of plasma metabolites in Hanwoo steers are shown in Table 3. In blood collected at the midpoint (60 d) and end (120 d) of the study period, Blood albumin, BUN, total protein, glucose, cholesterol, and triglyceride were significantly changed according to the experimental period. Triglyceride was higher in the treated groups than in the control group, especially in the T3 group.

Collectively, our findings indicated that blood metabolites late fattening Hanwoo steers are thought to have a greater variation depending on the time of blood collected rather than the experimental treatment. However, supplementation of protective fat or/and vitamin C appears to have an effect on the increase in triglyceride concentrations.

Carcass characteristics and chemical composition of the *longissimus* muscle

The effects of rumen-protected fat and/or vitamin C supplementation on the carcass characteristics of Hanwoo steers are shown in Table 4. We found that carcass weight and rib eye area were higher in T1 steers than in those in the control group ($p < 0.05$), whereas they tended to be higher in T2 and T3 steers than in the controls. The back fat thickness of steers was higher in all three treatment groups than in the control group ($p < 0.05$), and marbling score was slightly higher in treatment group steers than in control group steers, although the differences were not significant. Contrastingly meat color, fat color, texture, and maturity varied little among the four groups.

The effects of rumen-protected fat and/or vitamin C supplementation on the chemical and fatty acid composition of the *longissimus* muscle are shown in Tables 5 and 6, respectively. The pH of the *longissimus* muscle was observed to be slightly, but not significantly, higher in the treatment groups than in the control. The order of moisture and crude protein content of the *longissimus* muscle, from highest to lowest, was control, T1, T3, and T2, whereas the order of the ether extract of the *longissimus* muscle was the exact opposite (T2, T3, T1, and control). However, in all instances, the differences were not statistically significant.

Oleic and palmitic acid contents were similarly found to be comparable among all treatment groups, and likewise, there were no significant differences among groups with respect to individual fatty acids, saturated fatty acids, and monounsaturated fatty acids, or polyunsaturated fatty acid contents.

DISCUSSION

Growth performance and plasma metabolites

In this study, we found that rumen-protected fat and/or vitamin C supplementation had a positive effect on ADG and FCR, which is similar to the findings of previous studies (17). In addition, the increase in fat intake, as a consequence of supplementation with rumen-protected fat (Table 1), was considered to have been effective in improving the ADG of Hanwoo steers during the late fattening period. Consistently, (5) has reported that ADG was enhanced in Hanwoo steers (24 months of age) fed diets supplanted with rumen-protected fat, whereas Park et al. (17) have reported that there was no significant difference in the ADG of Hanwoo steers receiving diets supplemented with rumen-protected vitamin C (1–3 g/d). In this study, our observation that ADG was lower in steers fed a diet supplemented with both rumen-protected fat and vitamin C than in those receiving a diet supplement with only rumen-protected fat or vitamin C, indicates that there was no complementary effect of combined rumen-protected fat and vitamin C supplementation.

Plasma cholesterol is generally known as a fat-related indicator, and the concentration in Korean cow is 170–230 mg/dl at previous study (18). Plasma cholesterol concentration has been shown to be related to fat content (marbling score) of the *longissimus* muscle in beef cattle, and although we detected no statistically significant differences among the four experimental groups in the present study, we observed higher concentrations of cholesterol in the plasma of treatment group steers, along with a higher marbling score (Table 4) and fat content (Table 5), than in the control steers.

These findings are consistent with those reported in previous studies, in which plasma cholesterol concentrations were observed to increase with an increase energy (lipid) intake (19). Similarly, (20) have reported higher blood cholesterol concentrations in crossbreeds with high carcass fat content than in Chianina cattle, and that there was a correlation between the concentration of cholesterol and carcass fat content (*longissimus* muscle).

Table 5 - Effects of rumen protected fat and vitamin C on chemical composition in *longissimus* muscle of Hanwoo steers.

Items	Treatments			
	Control	T1	T2	T3
pH	5.37±0.23	5.58±0.18	5.44±0.21	5.46±0.15
Dry matter (%)	35.82±2.11	36.74±1.29	37.92±0.68	37.15±1.24
Moisture (%)	64.18±0.65	63.26±0.79	62.08±0.33	62.85±0.54
Crude protein (%)	28.85±1.12	28.14±1.09	26.65±1.77	27.74±2.07
Ether extract (%)	14.13±.0.76	15.87±0.31	17.49±0.86	16.48±0.20
Ash (%)	2.64±0.09	2.48±0.21	2.51±0.23	2.25±0.33

[a,b]Means with difference superscript in the same row are significantly different (P<0.05).
[1)] Area and back fat thickness were measured from the *longissimus* muscle taken at the 13th rib. Yield index was calculated using the following equation: [68.184 – (0.625 × back fat thickness (mm)) + (0.130 × rib eye area (cm^2)) – (0.024 × dressed weight amount (kg))] + 3.23.
[2)] Grading ranges are 1 to 9 for marbling score, where higher numbers indicate better quality (1 = devoid, 9 = abundant); meat color (1 = bright red, 7 = dark red); texture (1 = soft, 3 = firm); and maturity (1 = youthful, 9 = mature).

Table 6 - Effects of rumen protected fat and vitamin C on fatty acid composition in *longissimus* muscle of Hanwoo steers.

Items	Treatments			
	Control	T1	T2	T3
C12:0 (Lauric, %)	1.36±0.11	1.35±0.12	1.05±0.12	1.35±0.12
C14:0 (Myristic, %)	3.33±0.22	3.25±0.22	3.22±0.22	3.25±0.22
C14:1 (Myristoleic, %)	0.71±0.06	1.00±0.08	1.10±0.08	0.90±0.08
C16:0 (Palmitic, %)	26.78±1.02	27.18±0.45	26.10±0.45	27.18±0.45
C16:1 (Palmitoleic, %)	5.12±0.65	4.51±0.55	4.09±0.55	4.51±0.55
C18:0 (Stearic, %)	10.91±0.32	11.91±1.22	13.02±1.22	12.01±1.22
C18:1 (Oleic, %)	47.63±0.38	46.35±1.64	48.09±1.81	46.35±1.84
C18:2 (Linoleic, %)	2.25±0.04	2.06±0.06	2.00±0.06	2.06±0.06
C18:3 (Linolenic, %)	0.18±0.01	0.19±0.02	0.20±0.02	0.19±0.02
C20:0 (Arachidic, %)	0.10±0.00	0.11±0.01	0.11±0.01	0.11±0.01
C20:1 (Eicosenoic, %)	0.11±0.01	0.12±0.01	0.10±0.01	0.12±0.01
Others	1.52±0.12	1.97±0.13	0.92±0.13	1.97±0.13
SFA	42.50±0.42	43.90±0.43	43.50±0.43	43.90±0.43
MUFA	53.66±0.45	51.88±0.44	53.38±0.44	51.88±0.44
UFA	56.00±0.51	54.13±0.54	55.58±0.54	54.13±0.54
MUFA/SFA	1.18±0.02	1.18±0.07	1.23±0.07	1.18±0.07

SFA, saturated fatty acid; MUFA, mono-unsaturated fatty acid; UFA, unsaturated fatty acid.

Carcass characteristics and chemical composition of the *longissimus* muscle

It has been established that rumen-protected fat supplementation influences body fat and marbling score, whereas rumen-protected vitamin C has been reported to influence the deposition of intramuscular fat. Back fat thickness is known to increase concomitantly with an increase in energy intake (21), and although we detected no significant differences in the TDN content of steers receiving the different treatments, back fat thickness tended to increase in the rumen-protected fat supplementation groups fed concentrates with a high fat content, which is consistent with previously reported observations (22). Our observations that marbling score in Hanwoo steers was improved by supplementation with rumen protected fat is consistent with the findings of Park et al. (17), whereas in contrast, Ryu. (23) reported a reduction in marbling score in response to an increase in the fat content of dietary concentrate. However, in the results of this study, the marbling score showed a tendency to increase in the treatment groups, but there was no statistical significance. In addition, there was a study that reported increase in adipocyte differentiation in a previous study in which vitamin C was fed (8), but in this study, there was no statistical difference on marbling score between the treatments. This is thought to be due to the difference in fattening stage and period of supplementation.

pH, which is an important measure in meat quality assessment, affects meat color, hardness, rancidity, and water-holding capacity (24), and in beef cattle, meat pH values are typically lower than 5.75 (25). In the present study, we found that the pH of the *longissimus* muscle among all treatments ranged from approximately 5,4 to 5,6, thereby indicating that neither rumen-protected fat nor vitamin C had any substantial effects on *longissimus* muscle pH.

In general, marbling score and meat quality grade are known to be related to the chemical composition of the carcass, and in this regard, our results are consistent with those reported in a previous study (26), in which it was found that marbling score and meat quality grade increased with an increase in *longissimus* muscle fat content, whereas there were concomitant reductions moisture and protein content.

The fatty acid composition of beef has been found to be affected by feed type, fattening period, and meat quality grade (27). The fatty acid characteristics of feed in particular have been shown to be associated with changes in carcass fatty acid composition (28). However, in the present study, we found that rumen-protected fat and vitamin C had little effect on the fatty acid composition of the *longissimus* muscle, a finding that has similarly been reported by (29). Consistently, Lee. (30) established that there was no difference in the fatty acid composition of the *longissimus* muscle with respect to dietary energy level (low, medium, and high) in Hanwoo steers slaughtered at 30 months of age and that in terms of individual fatty acids, the proportions were approximately 50% oleic acid, 30% palmitic acid, and 10% stearic acid; this is consistent with the observations in our study.

CONCLUSION

The results obtained in this study revealed that supplementation of cattle feed with rumen-protected fat and/or vitamin C has positive effects on ADG, FCR, carcass weight, rib eye area, and marbling score in Hanwoo steers during the late fattening period. In contrast, supplementation appeared to have no significant effects on plasma metabolites or meat chemical composition, and we failed to detect any complementary effect of combined rumen-protected fat and vitamin C supplementation at a 0.1% level in the basal diet.

These findings indicate that supplementation of feed with rumen-protected fat and/or vitamin C can improve feed efficiency and meat carcass traits in Hanwoo steers during the fattening period, and would accordingly be beneficial with respect to enhancing the productivity of these cattle. Further studies should, however, be conducted to evaluate the changes in carcass traits and meat chemical composition in response to supplementing feed with higher levels of rumen-protected fat and vitamin C.

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