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The effects of feeding total mixed ration with high roughage content on growth performance, carcass characteristics, and meat quality of Hanwoo steers

Running title: High roughage fed Hanwoo steers' carcass characteristics and meat quality

Abstract

This study investigated the dietary effect of total mixed ration (TMR) based on high roughage content on the growth performance, carcass characteristics, and meat quality of Hanwoo steers. Twenty-four Hanwoo steers (average body weight, 195.3 ± 4.7 kg; age, 8.5 mon) were randomly allocated to three experimental groups according to forage and concentrate ratio (DM basis): 25:75 (control), 50:50 (T_{50}), and 70:30 (T_{70}). Productivity in the fattening period and final body weight were significantly higher in the control. Average daily gain and feed conversion ratio were the same among treatments. Serum parameters, cholesterol, blood urea nitrogen, and total protein were higher in the control. Carcass weight was comparable in the control and T_{50} but feeding more roughage was significantly correlated with a higher intramuscular fat. Shear strength and drip loss were higher while n-6/n-3 was lower in T_{70} compared to the other groups. However, meat color was not significantly different among treatments. In terms of free amino acid contents, glutamic acid and glycine were higher in the control than T_{50} and T_{70}. Overall, feeding Hanwoo steers with high forage content TMR had the lowest n-6/n-3 ratio of fatty acid content but highest intramuscular fat, shear strength, and drip loss. High forage content TMR is the best feed for Hanwoo steers that gives more benefits

for human health and consumption but also provides the best meat grade and quality, which is important in the beef market in Korea.

Key words Hanwoo steers, meat quality grade, roughage, total mixed ration

Introduction

Research on the productivity and utility of roughage in the beef cattle industry is increasingly important. However, there is little domestic roughage production, and there have been few studies on production, or on the productivity or product quality of cattle fed roughage. Hence in South Korea, Hanwoo farms have recently expanded their roughage cultivation area to self-produce roughage and reduce feed cost. In Jeollanam-do, the roughage cultivation area increased from 32,000 ha in 2011 to 49,000 ha in 2019; 62% of the total production area was for Italian rye grass (IRG), which increased from 13,757 ha in 2011 to 27,474 ha in 2019. In this way, high-quality roughage is being produced based on domestic roughage demand, reducing the need for imported feed ingredients.

In ruminants, roughage is essential for the healthy development of the rumen, and the quality of roughage greatly affects productivity (Maeng et al., 1989). In South Korea, total mixed ration (TMR) has been widely used for dairy cattle, and was introduced to Hanwoo in the 2000s. Kim et al. (2003) and Li et al. (2003) investigated the effects of hay-based high-fiber mixed feed on intraruminal fermentation properties, digestion coefficient, and late fattening-stage growth of Hanwoo steers. Hanwoo cattle fed a mixture of rice straw and grass exhibited an increased growth rate and feed intake than cattle fed only rice straw (Ahn et al., 1984; Cho et al., 1997), whereas no major effect on carcass characteristics was observed (Cho et al., 1997). Cho et al. (2008) investigated the effects of high-fiber mixed feed on weight gain, carcass characteristics, and production cost of Hanwoo steer, and suggested that mixed feed may be superior to conventional rice straw-based rearing methods. Moreover, studies on the value-as-feed of soiling crops and silage in not only Hanwoo steer (Cho et al., 2000) but also wool sheep (Lee et al., 2002) and black goats (Hwang et al., 2008), reported positive results in terms of utility.

Whole-crop barley (WCB) and Italian ryegrass (IRG) are two of the of the most preferred roughages for ruminants especially for beef producers. WCB silage has long been proposed as a roughage ingredient to replace imported grains, and its use has resulted in significantly increased daily weight gain and improved yield grade, carcass quality, backfat fitness, and intramuscular fat compared with rice straw (Seo et al., 2010; Kook et al., 2011). On the other hand, IRG has been also preferred forage crop due to high forage yield and good nutritional quality. Kim et al. (2015) also reported that feeding IRG silage combined with concentrate significantly increased crude fat and lightness (L*) of Hanwoo beef as well as increase the rib-eye area, back fat thickness, and slaughter weight of the carcass trait.

In the growing and fattening period of beef steers, the forage level in diets influences the meat production and meat quality (Sung et al., 2015). Angus steers fed with wet distillers grain inclusion in high forage diet increases intramuscular fat content of the beef (Schoonmaker et al., 2010). Also, high-roughage diets, especially those containing high-quality roughage, produce meat with a deeper red color (Bidner et al., 1986). Among different types of roughage, beef cattle fed grass silage exhibited a better meat color than those fed maize silage (O'Sullivan et al., 2002). Thus, this present study examined the effects of TMR feeding using mostly high-quality roughage on the growth performance, carcass characteristics, and meat quality of Hanwoo steers.

Materials and Methods

Experimental animals, treatments, feed and feeding management

A 615-day rearing experiment was conducted in the testing cowsheds at the Livestock Research Center of the Jeollanam-do Agricultural Research and Extension Services (Gangjin-gun, Jeollanam-do, South Korea). We used 24 castrated Hanwoo steer calves (mean age, 8.5 mon; 195.3 kg ± 4.7 kg), and prepared feed for four different growth stages (rearing, 8.5–12 mon; early fattening, 13–18 mon; mid-fattening, 19–24 mon; late fattening, 25–32 mon). There were a total of three groups defined by the feeding plan at each growth stage: 1) a conventional feeding group (control) were fed 25% roughage as specified by the National Institute of Animal Science (2012), 2) a group fed 50% roughage on average throughout the whole rearing period (T_{50}), and 3) a group fed 70% roughage on average (T_{70}). The animals were divided into three pens with eight animals in each treatment group. In addition, when allocating the calves to the pens, age and body weight were considered to reduce the differences in mean body weight between the pens and minimize uneven feed intake due to dominance hierarchies.

A TMR feed was provided to each group that included IRG, maize silage, and barley grain were produced by the Livestock Research Center. Other ingredients were purchased from Samjeong Natural Co., Ltd. (TMR feed factory, Yeongam, Jeollanam-do, South Korea), and prepared at the same factory in accordance with this study’s feeding program (Hanwoo board, 2009; National Institute of Animal Science, 2012). The feed mixture ratios and chemical composition for each group and growth stage are shown in Table 1. The levels of general components in the feed were analyzed according to the AOAC (2000) method, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to the method of Van Soest et al. (1991). Feed was provided twice per day, at 8.30 AM and 4.30 PM, and the animals were allowed to feed *ad libitum*. Water and mineral blocks (Super Licks, UK) were available to all groups at all times.

Body weight and blood composition

Body weight was measured before the morning feeding at 2-mon intervals from immediately before the start of the experiment to the end of the experiment. Daily weight gain was calculated by dividing the difference between the previous weight measurement and the current weight measurement by the number of days. Feed intake was calculated using a feed intake recording system (Dawoon Electronics Co., Ltd, Incheon, South Korea), and the feed conversion ratio was calculated by dividing the weight gain by the feed intake.

From the start to the end of the experiment, at the same time as weighing, 10 ml of blood was collected from the jugular vein of each animal in a serum vacutainer (BD Vacutainer Serum Tubes [REF 367820], Oakville, ON, USA), centrifuged for 15 min at 4℃ and 2,000 × *g* (Hanil Science Co., Ltd, KRI supra 21 K, Daejeon, South Korea), and stored at -70℃ in an ultra-low temperature upright freezer (Thermo Scientific, Beverly, MA, USA) until analysis. Serum glucose, cholesterol, creatinine, BUN, and total protein were measured using an automated biochemistry analyzer (CIBA-EXPRESS PLUS, Ciba-Corning Diagnostics, MA, USA).

Carcass analysis

For carcass analysis, after the feeding experiment ended, the experimental animals were slaughtered by Seorim Global Co., Ltd. (Damyang, Jeollanam-do, South Korea). The carcasses were hung for 18–24 h at 0℃, and then the meat yield (carcass weight, backfat thickness, and cross-sectional area of longissimus dorsi) and meat quality (intramuscular fat [marbling], meat color, fat color, texture, and maturity) factors were rated by a livestock grader in accordance with the Carcass Grading System for Cattle.

Meat quality characteristics

The general composition of Hanwoo meat samples (sirloin) was analyzed in accordance with AOAC (2000) methods. First, 3 g of pulverized sample was dried for 24 h in a 104℃ dry oven, and the water content was determined by comparing the weight before and after drying. Protein was measured using a Kjeltec System (Kjeltec Auto 2400/2460, Foss Tecator AB, Höganäs, Sweden), fat content was measured using the Soxhlet method, and ash content was measured using an ash analyzer (MAS 70-00, CEM Corp., Matthews, NC, USA).

In the analysis of physicochemical characteristics, pH was measured by homogenizing 2 g of sample in 18 mL of distilled water with a homogenizer (Polytron PT 10-35 GT, Kinematica, Lucerne, Switzerland) at 15,800 × *g* for 30 s, passing the solution through a Whatman No. 4 filter paper, and measuring the filtrate with a pH meter (Orion 2-Star, Thermo Scientific). For water holding capacity, 5 g of ground sample was collected, placed in a 50-mL tube with cotton wool, and centrifuged for 10 min at 112 × *g* before weighing. To ascertain loss on heating, a 2-cm-long sample was cut and weighed, before placing in a vacuum pack and heating at a constant temperature of 80℃. When the core temperature of the sample reached 70℃ (~8 min), the sample was cooled with cold water and then weighed. To measure shear strength, holes were made using a 1-cm-diameter cork in the samples from the loss-on-heating test. After fitting a Warner-Bratzler blade to a texture analyzer (TA-XT2, Stable Micro Systems, Surrey, UK), the blade was positioned perpendicular to the direction of the muscle fibers, and the shear strength (kg) was measured. The device conditions were set to pre-test speed 2.0 mm/s, test speed 2.0 mm/s, and post-test speed 5.0 mm/s. To measure drip loss, a 1-cm piece of sample was cut and weighed, placed in oxygen-permeable paper, stored for 48 h in a 4℃ refrigerator, and then weighed. To measure surface meat color, three locations on the sample surface were arbitrarily selected, and a color meter (Model CR-410, Minota Co. Ltd., Osaka, Japan) was used to measure the CIE L^* (lightness), CIE a^* (redness), and CIE b^* (yellowness). As a reference color, a white plate was used with L^* 89.2, a^* 0.921, and b^* 0.783.

To analyze the fatty acid composition, 1 g of sample was mixed with 0.7 mL of 10 N KOH in water, and placed in a thermostatic water bath preheated to 55℃. While heating for 1 h 30 min, the mixture was vigorously stirred once every 30 min. Next, the mixture was cooled for 1–2 min and then heated for another 1 h 30 min in the 55℃ water bath while being vigorously stirred once every 30 min. After heating, the mixture was cooled in cold water, before adding 3 mL of hexane and centrifuging for 5 min at 1,008 × *g*. After using a Pasteur pipette to transfer the mixture to a vial, a gas chromatograph-flame ionization detector (Agilent Technologies, 7889 Series, Santa Clara, CA, USA) was used to analyze the fatty acid composition. To measure the free amino acid content, the method of Hughes et al. (2002) was used to extract free amino acids. After adding 10 mL of 2% TCA solution to 2.5 g of finely pulverized sample, homogenization was performed for 1 min at 20 412 × *g* min. The homogenate was centrifuged for 15 min at 17,000 × *g*, filtered using a 0.45-μm membrane filter, and derivatized by the Waters AccQ-Tag method (1993, Waters Corporation, Milford, MA, USA) to make the free amino acid sample, which was measured using RP-HPLC. The column used here was an AccQ·Tag column (3.9 × 150 mm, Waters), the injected volume was 5 μL, column temperature was 37℃, detector was a fluorescent detector (Waters 2475, Millipore Co-operative, Milford, MA, USA), excitation wavelength was 250 nm, and emission wavelength was 395 nm. A gradient method was used for analysis with mobile phase solvents of Waters AccQ·Tag eluent A (solvent A) and 60% acetonitrile (solvent B).

Statistical analysis

All the results obtained in the present study were analyzed using the SAS package (Statistical Analysis System, 2003). Duncan's multiple range test was used to compare means between the groups at a significance level of 5%.

Results and Discussion

Growth characteristics

The effects of TMR feeding using high-quality roughage (IRG, maize silage, and barley grain) on weight gain characteristics of Hanwoo steers were investigated and compared with those for conventional feeding. The total weight gain, daily weight gain, and feed conversion ratio of the Hanwoo steer at each growth phase are shown in Table 2. For Hanwoo steer calves with a mean weight of 195.3 kg, during the 105-day rearing stage, the total weight gain was 79.0 kg in the control group, 76.4 kg in T_{50}, and 80.2 kg in T_{70}; the total weight gain was significantly higher in T_{70} than in the control group ($p<0.05$), and there were no significant differences between the groups in terms of end weight, daily weight gain, or feed conversion ratio. During the 150-day early fattening stage, the total weight gain was 135.0 kg in the control group, 123.8 kg in T_{50}, and 112.1 kg in T_{70}, which was significantly higher in the control group ($p<0.05$), but there were no differences between the groups in terms of feed conversion ratio. During the 150-day mid-fattening stage, total weight gain was higher in the control group (conventional feeding; $p<0.05$), but there were no differences in daily weight gain or feed conversion ratio. During the 210-day late fattening stage, total weight gain was 176.0 kg in the control group, 172.3 kg in T_{50}, and 185.9 kg in T_{70}, meaning that the highest total weight gain was in T_{70} ($p<0.05$). This result was considered to be the result of compensatory growth, since the ratio of concentrates in the early and mid-fattening stages (25–40%) was low in T_{70}, but the ratio of concentrates increased in the late fattening stage (60%). Overall, a high proportion of forage in TMR resulted in lower rate of growth across the whole experimental period. This result is in agreement with Thomas et al. (1988) and Baker et al. (1992) who reported that cattle fed diets containing a higher proportion of grass silage sustained a lower growth rate than cattle given high-concentrate diets.

Carcass analysis

Table 2 shows the live weight, carcass weight, backfat characteristics, meat yield, and meat quality characteristics measured after the feeding experiment was completed. In terms of live weight, the groups fed a high-quality roughage-based diet had lower mean body weight than the control group (conventional diet) ($p<0.05$), and carcass weight exhibited a similar pattern with lower weights observed in the treatment groups than the control group ($p<0.05$). These results can be considered to reflect the weight gain during the feeding experiment. On the other hand, the sirloin cross-sectional area and intramuscular fat (Table 2) had comparable results in T_{50} and T_{70} and both significantly higher in intramuscular fat than the control group ($p<0.05$). However, T_{50} was also significantly higher in the sirloin cross-sectional area than the control group ($p<0.05$), whereas there no significant change in backfat thickness or meat yield index was found. This study corroborates with Sung et al. (2015) study on Hanwoo steers fed with high forage diet and high forage diet with chromium methionine that tended to show and significantly higher intramuscular fat than low forage diet and low forage diet with chromium methionine, respectively. They also explained that the precursor of intramuscular fat is the glucose that usually from the high ruminal starch digestion, which increases the organic acids that are later converted to glucose. This indicates that high roughage diet in this study contains high quality roughages that was converted to glucose that produced significantly high intramuscular fat. Kim et al. (2015) reported that the carcasses of Hanwoo steers fed with an IRGS/concentrate diet resulted in an increase in backfat thicknesss and rib-eye area compared with those fed with rice straw/concentrate diet. Our study is in agreement with their result for cross-sectional area of sirloin; however, no significant change in the backfat thickness was observed in our study. However, live weight and carcass weight were reduced in steers fed with high forage content (T_{70}). Our result is in agreement with the findings of Steen (1995), who found that the carcass weight of steers reduced when concentrates intake was reduced.

Blood characteristics

Table 3 shows the changes in serum concentration of metabolites in Hanwoo steer by growth stage depending on the ratio of roughage in their diet. Serum cholesterol was higher in the control group in the mid- and late fattening stages ($p<0.05$), and BUN and total protein were higher in the early and late fattening stages ($p<0.05$). Metabolites in the blood are indicators that enable measurement of the use and metabolism of nutrients (Vernon, 1992; Choi et al., 2009). Cholesterol concentration is positively correlated with energy intake (Arave et al., 1975), and the higher cholesterol levels in the control group in the fattening stages was thought to be due to the higher intake of concentrates relative to the treatment groups. Enright et al. (1990) and Choi et al. (2009) reported that decreased serum BUN levels indicate the accumulation of nitrogen in tissues engaged in protein synthesis. The BUN levels from the present study were in the normal range of 10–20 mg/dl (Kwon et al., 2005; Choi et al., 2006). Therefore, the differences between the groups are thought to be due to the type of feed and differences between individual animals (Choi et al., 2006, 2009).

Meat quality characteristics

When six animals were analyzed in each group, water content, crude protein, crude fat, and crude ash content in Hanwoo sirloin were not affected by the amount of roughage in the feed. These results are shown in Table 4 alongside the pH, water holding capacity, loss on heating, shear stress, and drip loss. The shear strength value and drip loss of Hanwoo steers fed TMR with high forage content (T_{70}) were significantly higher than that of other cattle ($p<0.05$). However, previous studies reported no significance in pH, WHC, cooking loss, shear strength, or drip loss with changes in forage content. Furthermore, our results are in disagreement with the study of Frank et al. (2016), who reported that meat with high IMF has lower drip loss and water loss. The muscular condition of experimental animal rigor mortis affected the shear strength and drip loss when fed with TMR with high forage content. pH is closely related to changes in quality, such as water holding capacity and tenderness, and so is fundamental to assessing the quality of meat (Weatherly et al., 1998). Water holding capacity refers to the ability of meat to retain initial or added water content when subjected to physical forces such as shear stress, pulverization, pressure, or heat. Water holding capacity affects meat color, texture, hardness of fresh meat, tenderness of cooked meat, and juiciness, and water holding capacity has been reported to increase with changes in the protein structure and ionic strength of meat (Wu and Smith, 1987). According to Laster et al. (2008) and Obuz et al. (2004), shear strength, which reflects tenderness, decreases with increasing meat quality grade, which is contrary to the results of the present study. Drip loss is caused by changes in the microscopic structure of muscle due to sarcomere contraction; as muscle contracts, the space inside the muscle decreases, and water leaks out of the muscle, resulting in weight loss (Kim et al., 1994).

Meat color is determined by several factors, but is most strongly influenced by the concentration and chemical state of myoglobin inside the muscle. Meat color darkens with increased age, and also differs depending on feed and species. The lightness, redness, and yellowness of sirloin were measured, and none showed any differences between the groups (Table 4). Therefore, increasing the ratio of roughage in feed had no major effect on meat color. The fatty acid composition showed no significant differences between groups, and so was believed to be unaffected by the ratio of roughage (Table 5). As anticipated, the ratio of oleic acid (46.94–47.42%) was the highest, followed by palmitic acid (24.43–25.34%) and stearic acid (11.31–11.59%). The ratio of saturated fatty acid (SFA) among all fatty acids was 39.80–39.03% in all groups, and the ratio of unsaturated fatty acid (UFA) was 55.67–56.41%. Mahecha et al. (2009) reported that the ratio of SFA:UFA in beef was 47.53:52.47, representing a higher ratio of SFA and lower ratio of UFA compared with the results of the present study. In addition, the ratio of monounsaturated fatty acid among UFA was 52.68–53.05%, and the ratio of polyunsaturated fatty acid was 2.91–3.04%. The UFA/SFA ratio in Hanwoo steer has been found to be in the range 1.41–1.45. The contents of linoleic acid (C18:2) and linolenic acid (C18:3) of steers fed with a high forage content increased and decreased, respectively. Our results show that steers fed with a high forage content TMR had a lower n-6/n-3 value, which is in agreement with the results of Wood et al. (1999). Wood et al. (1999) also stated that feeding grass or grain diets is important in changing the n-6/n-3 value; therefore, feeding high roughage diet TMR in Hanwoo steers favors low n-6/n-3 value. The high n-6/n-3 value promotes the heart disease and cancer (Kang, 2004); hence, low n-6/n-3 value in Hanwoo steers fed with a high forage content TMR gives more benefits for human health and consumption by decreasing the risk of heart disease and cancer.

The free amino acid concentration, which affects the savory and sweet tastes of beef, showed lower glutamic acid and glycine ($p<0.05$) in steers fed with a high forage content diet. Other amino acids were observed at higher levels in the control group, but there were no significant differences according to the ratio of roughage in the diet (Table 6). The free amino acid content in the carcasses of feeder cattle has been reported to be affected by the amino acid content of the feed ingredients (Kim et al., 2011). The free amino acids related to beef taste are caused by the hydrolysis of cooked free amino acids and reaction with lipid oxidation products, and is reported to be affected by the initial state of the meat (Shibamoto, 1980). However, the free amino acid concentration in beef is not the only factor affecting its taste, and taste is known to be produced by interactions between amino acids, sugars, and fatty acids during heating (Macleod, 1994). Sirloin from Hanwoo steer fed a high-roughage diet (T_{70}) exhibited slightly higher scores for meat color and tenderness, but the other variables showed no significant differences between the treatment groups and the control group.

Conclusion

Feeding of TMR with high forage content increased the shear strength and drip loss of the carcasses. Moreover, the intramuscular fat or the intramuscular fat was higher in TMR with 50:50 and 70:30 forage and concentrate ratio than control. Also, steers fed TMR with high forage content the lowest n-6/n-3 ratio. Lowest n-6/n-3 ratio of fatty acid content but highest intramuscular fat in steers fed with high forage content TMR is more beneficial for human health and consumption as well as for the Hanwoo producers.

Conflicts of Interest

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Ku MJ; Data curation: Ku MJ, Choi YS; Formal analysis: Mamuad LL, Lee SS: Methodology: Ku MJ, Choi YS, Nam KC, Cho YI: Software: Ku MJ, Choi YS, Mamuad LL, Nam KC: Validation: Ku MJ, Choi YS, Kim SS, Mamuad LL, Lee SS: Investigation: Ku MJ, Mamuad LL, Kim SS, Nam KC, Cho YI, Lee SS: Writing - original draft: Ku MJ, Mamuad LL, Lee SS: Writing - review & editing: Ku MJ, Mamuad LL, Nam KC, Cho YI, Lee SS.

Ethics Approval

The experimental protocol was approved by the Institutional Animal Care and Use Commitee at the Livestock Research Institute, Jeollanamdo Agricultural Research & Extension Service (JARES) (JLRI-IACUC 2015-02).

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Table 1. Feed mixture ratios and chemical composition (%) of Hanwoo steers fed with conventional (control; 25% roughage), 50% roughage (T_{50}), and 70% roughage (T_{70}) diets by growth stage (dry weight, %)

Composition	Growing (8.5–12 mon)			Early fattening (13–18 mon)			Mid-fattening (19–24 mon)			Late fattening (25–32 mon)		
	Control	T_{50}	T_{70}	Control	T_{50}	T_{70}	Control	T_{50}	T_{70}	Control	T_{50}	T_{70}
Feed mixture ratios												
Alfalfa	5.18	3.27	-	-	-	-	-	-	-	-	-	-
Rice straw	-	-	-	12.8	17	-	8.4	14	-	6	7.8	6.8
Corn silage	12.96	21.8	32.3	14	22	24	10.4	10	22	-	-	-
Italian rye grass (dry)	32.98	36.6	48	18.3	25	56	16.7	16	34	4.1	20	34
Barley	8.25	5.25	3.92	5.5	6.1	4	6.2	6	6	8.6	5.8	3.4
Corn gluten feed	4.48	4.16	1.96	6	3.3	1.2	7.7	6.5	3.8	12	11	10
Molasses	5.54	5.25	2.94	2.6	2.4	2.4	2.8	3.3	2.2	4.4	3.4	3
Wheat bran	4.48	4.16	1.96	6	3.3	1.2	5.6	4.4	1.8	4.2	4.8	3.2
Coconut meal	2.24	1.58	0.98	3	1.7	0.6	2.8	2.2	0.9	1.5	1.5	1
Corn flakes	3.06	3.07	-	18.3	11	9.2	18.2	22	16	29.9	27	25
Cottonseed	-	-	-	-	-	-	4.2	3.3	4	4	3.9	2.7
Apple pomace	1.06	0.99	0.69	1.5	0.8	0.3	1.3	1	0.4	0.7	0.7	0.5
Rice bran	8.25	4.95	2.94	5.5	5	8	6.3	5	5	8.2	5.8	2.7
Palm kernel meal	1.18	1.39	0.49	2	1	0.4	1.9	1.5	0.6	1	1	0.7
Water	9.42	6.44	2.94	3	2.2	2	5.2	3.3	2	13.1	5.8	6
Vitamin and mineral supplement	0.24	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Limestone	0.59	0.59	0.59	1.1	0.7	0.6	0.6	0.7	0.6	0.9	0.8	0.6
Salt	0.12	0.2	0.1	0.2	0.1	0	0.2	0.1	0.1	0.2	0.1	0.1
Chemical composition (%)												
Water	36.7	44.8	41.3	24.1	35	39.5	34.8	33.1	36.9	24.1	23.5	22.6
Crude protein	11.8	10.4	10.1	9.9	7.7	6.5	8.6	8.1	7.5	9.6	8.7	7.5
Crude fat	2.9	2.5	3.7	4.2	3.4	3	3.5	3.4	3.1	3.8	3.3	3
Crude fiber	15.7	13.7	15.8	22.1	16	15.2	13.4	14.7	15.3	17.3	16.9	15.1
Crude ash	7	7.4	7.3	10	10.3	8.9	5.7	5.8	6.3	6.1	6.5	6.2
Calcium	0.8	0.7	0.8	1.3	0.6	0.5	0.4	0.5	0.5	0.6	0.6	0.5
Phosphorus	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.3
Neutral detergent fiber	31.3	33.2	37.2	42.4	38.6	33	33.8	34.2	33.2	36.4	36.6	40.9
Acid detergent fiber	16.1	15.6	17	24.5	24.7	20.2	20.9	19.7	20.6	23.9	19.8	22.9
Total digestible nutrient	59.9	54.9	56.1	61.2	59.1	59.1	63.8	65.3	60.7	71.5	70.1	69.8

Table 2. Steer productivity characteristics and carcass outcomes of Hanwoo steers fed with conventional (control; 25% roughage), 50% roughage (T_{50}), and 70% roughage (T_{70}) diets

Item	Control	T_{50}	T_{70}	SEM[1)]
Steer productivity characteristics				
Start weight (kg)	536.9^{a}	521.5^{ab}	505.1^{b}	12.532
End weight (kg)	712.9^{a}	693.8^{b}	691.0^{b}	13.654
Total weight gain (kg)	176.0^{b}	172.3^{b}	185.9^{a}	4.347
Daily weight gain (kg)	0.84	0.82	0.89	0.039
Feed conversion ratio	17.90	16.45	15.25	0.762
Meat yield characteristics				
Live weight (kg)	712.9^{a}	693.8^{b}	691.0^{b}	13.654
Carcass weight (kg)	409.6^{a}	400.9^{a}	392.9^{b}	15.401
Backfat thickness (mm)	10.7	11.3	14.0	3.982
Cross-sectional area of sirloin (cm^2)	78.1^{b}	84.4^{a}	79.3^{ab}	8.345
Meat yield index	65.0	65.7	63.5	2.701
Meat yield grade (A:B:C, %)	0:100:0	12:76:12	25:50:25	-
Carcass grading characteristics				
Intramuscular fat	5.7^{b}	6.4^{a}	6.0^{a}	1.996
Meat quality grade (1^{++}:1^{+}:1:2,%)	28:29:14:29	13:62:25:0	38:25:12:25	-

[1)]Standard error of the means (n = 6)

^{a,b}Values with different letters differ significantly ($p<0.05$).

Table 3. Blood characteristics of Hanwoo steers fed with conventional (control; 25% roughage), 50% roughage (T_{50}), and 70% roughage (T_{70}) diets by growth stage

Item	Period	Control	T_{50}	T_{70}	SEM[1)]
Glucose (mg/dL)	Growing	63.27	62.50	63.98	3.056
	Early fattening	60.27	61.83	64.56	2.899
	Mid-fattening	72.35	73.15	75.17	2.571
	Late fattening	60.17	66.04	64.50	3.254
Cholesterol (mg/dL)	Growing	156.6	148.0	146.2	6.781
	Early fattening	189.3	149.1	136.0	6.248
	Mid-fattening	129.3^{a}	104.8^{ab}	98.5^{b}	5.893
	Late fattening	160.4^{a}	104.3^{ab}	92.2^{c}	6.735
Creatine (mg/dL)	Growing	1.00	0.86	0.88	0.054
	Early fattening	1.32	1.25	1.12	0.076
	Mid-fattening	0.98	0.92	0.87	0.069
	Late fattening	1.27	1.23	1.16	0.078
BUN[2] (mg/dL)	Growing	11.34	11.98	11.76	0.765
	Early fattening	13.53^{a}	9.55^{ab}	8.62^{b}	0.585
	Mid-fattening	8.62	5.89	7.21	0.693
	Late fattening	14.56^{a}	8.63^{ab}	7.27^{b}	0.791
Total protein (g/dL)	Growing	11.21	11.76	11.98	0.107
	Early fattening	13.51^{a}	9.58^{ab}	8.69^{b}	0.121
	Mid-fattening	8.43	7.22	6.61	0.092
	Late fattening	11.20^{a}	8.97^{ab}	7.56^{b}	0.106

[1)]Standard error of the means (n = 8)

[a,b]Values with different letters differ significantly ($p<0.05$)

[2] Blood urea nitrogen

Table 4. General components, meat quality properties, and meat color of loins from Hanwoo steers fed with conventional (control; 25% roughage), 50% roughage (T_{50}), and 70% roughage (T_{70}) diets

Item	Control	T_{50}	T_{70}	SEM[1)]
Water content (%)	60.06	58.11	58.80	3.723
Crude protein (%)	21.03	20.24	21,44	2.128
Crude fat (%)	18.53	22.13	20.80	1.357
Crude ash (%)	0.93	0.94	0.85	0.052
pH	5.61	5.66	5.59	0.035
Water holding capacity (%)	76.69	75.26	74.29	5.189
Loss on heating (%)	13.30	13.38	13.85	2.592
Shear strength (kg.f)	1.77[b]	1.91[a]	1.93[a]	0.064
Drip loss (%)	26.37[ab]	24.78[b]	28.46[a]	2.018
L value	42.50	42.70	42.95	2.295
a value	27.28	27.38	27.00	1.593
b value	13.13	13.34	13.11	1.231

Standard error of the means (n = 6)

L : lightness, a: redness, b : yellowness

[a,b]Values with different letters differ significantly ($p<0.05$).

Table 5. Fatty acid composition (%) of Hanwoo loins from steers fed with conventional (control; 25% roughage), 50% roughage (T_{50}), and 70% roughage (T_{70}) diets

Item	Control	T_{50}	T_{70}	SEM[1)]
Capric acid (C10:0)	0.03	0.03	0.03	0.000
Lauric acid (C12:0)	0.07	0.07	0.06	0.002
Myristic acid (C14:0)	2.76	2.85	2.83	0.081
Myristoleic acid (C14:1)	0.78	0.92	0.87	0.074
Palmitic acid (C16:0)	25.28	24.43	25.34	0.258
Palmitoleic acid (C16:1)	3.77	3.86	3.91	0.101
Heptadecenoic acid (C17:1)	0.63	0.65	0.62	0.088
Stearic acid (C18:0)	11.59	11.56	11.31	0.150
Oleic acid (C18:1)	46.98	46.94	47.42	0.349
Linoleic acid (C18:2)	1.91	1.86	1.67	0.917
Linolenic acid (C18:3)	0.73	0.82	0.86	0.052
Arachidic acid (C20:0)	0.07	0.07	0.07	0.000
Arachidonic acid (C20:4)	0.33	0.32	0.25	0.022
SFA[2)]	39.80	39.00	39.03	0.338
UFA[3)]	55.67	56.08	56.41	0.369
MUFA[4)]	52.68	53.05	52.88	0.322
PUFA[5)]	2.99	3.04	2.91	0.024
UFA/SFA	1.41	1.45	1.41	0.019
n-6/n-3	2.63[a]	2.29[a]	1.98[b]	0.166

[1)]Standard error of the means (n = 6)

[2)]Saturated fatty acid

[3)]Unsaturated fatty acid

[4)]Monounsaturated fatty acid

[5)]Polyunsaturated fatty acid

497 Table 6. Free amino acid composition (mg/100 g) of Hanwoo loins from steers fed with conventional (control; 25% roughage), 50% roughage (T_{50}), and 70% roughage (T_{70}) diets

Item	Control	T_{50}	T_{70}	SEM[1)]
Alanine	38.94	34.56	26.20	2.912
Arginine	5.84	5.34	5.29	0.081
Asparagine	13.28	12.65	10.59	1.168
Aspartic acid	3.42	2.86	2.44	0.766
Cystine	9.77	8.92	6.80	0.654
Glutamic acid	30.62[a]	19.23[ab]	6.79[b]	2.789
Glycine	21.36[a]	18.92[a]	13.14[b]	2.125
Histidine	6.44	6.22	4.22	0.823
Isoleucine	7.61	6.83	5.87	0.890
Leucine	20.90	19.16	16.06	3.112
Lysine	8.36	7.88	6.86	1.598
Methionine	0.34	0.25	0.33	0.002
Phenylalanine	11.45	10.12	7.94	1.669
Proline	2.16	2.03	1.58	1.011
Serine	13.10	12.44	10.00	1.768
Taurine	15.39	14.35	14.09	1.562
Threonine	8.04	7.76	6.27	0.993
Tryptophan	10.68	9.14	9.74	1.540
Tyrosine	10.80	10.05	8.29	1.898
Valine	9.83	9.15	7.86	1.161

499 [1)]Standard error of the means (n = 6)

500 [a,b]Values with different letters differ significantly ($p<0.05$).

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