Effect of Total Digestible Nutrients Level of Concentrates on Growth Performance, Carcass Characteristics, and Meat Composition of Korean Hanwoo Steers

Jun Sang Ahn¹,†, Gi Hwal Son²,†, Min Ji Kim², Chang Six Choi³, Chang Woo Lee³, Joong Kook Park⁴, Eung Gi Kwon¹, Jong Suh Shin², and Byung Ki Park⁴,*

¹Hanwoo Research Institute, National Institute of Animal Science, RDA, Pyeongchang 25340, Korea
²Dept. of Animal Life Science, Kangwon National University, Chunchoen 24341, Korea
³Kangwon Livestock Technology Research Institute, Hoengseong 25266, Korea
⁴Nonghyup Feed Co., LTD., Seoul 05398, Korea

Abstract This study was conducted to investigate the effect of the total digestible nutrients (TDN) level of commercial concentrates on growth performance, carcass characteristics, and meat composition of late fattening Hanwoo steers. A total of 28 steers were randomly assigned to one of four dietary groups; T1 (73.30% TDN), T2 (74.50% TDN), T3 (76.40% TDN), and T4 (77.10% TDN). Average daily gain (ADG) was slightly but not significantly higher in the T2 than in the other treatments. Dry matter intake (DMI) and feed conversion ratio (FCR) were higher in the T2 than in the other treatments; however, the differences were not statistically significant. Carcass fat composition had no effect on the physicochemical characteristics and fatty acid composition of the longissimus muscle. The finding of this study indicate that less than 74% or greater than 75% TDN in the commercial concentrate did not contribute to improve ADG, FCR, marbling score; therefore, in the present study, the recommendable TDN level in the commercial concentrate for late fattening period was 74% to 75% in terms of growth performance and marbling score of Hanwoo steer.

Keywords total digestible nutrients, growth performance, carcass characteristics, meat composition, Hanwoo steers

Introduction

The energy level of feed is known to be a major factor affecting the growth performance, carcass characteristics, and fat deposition in beef cattle (Chung et al., 2015), with total digestible nutrients (TDN) being the most widely used energy
estimation unit. In particular, TDN levels of late fattening concentrates affect average daily gain (ADG) and intramuscular fat deposition of fattening cattle (Jeong et al., 2010). Therefore, it is an important factor for producing high quality meat from Hanwoo steers (Lee, 2017).

Recently, in Korea, studies have been undertaken on the shortening of the fattening period and appropriate age of slaughter to reduce feed costs and decrease the production of inedible fat (Hong, 2016; Yoon et al., 2013). Additionally, studies have been conducted with regard to increasing the TDN level of concentrates to maintain the marbling score while shortening the fattening period have been (Chung et al., 2018; Lee et al., 2013).

Increasing the TDN levels in late fattening concentrate has been reported to improve the dry matter (DM) digestibility, energy availability, ADG, and meat quality grade (Chung et al., 2015; Hwang et al., 2014; Ki et al., 2009). To increase the accumulation of intramuscular fat during the late fattening period of Hanwoo steers, feeding high TDN concentrate is advantageous (Ryu, 2017); however, feeding excessively high TDN concentrate may lead to deposition of inedible fat and cause metabolic diseases (Rossi and Compiani, 2016). The TDN of commercial concentrates fed to late fattening Hanwoo steers in Korea varies from 72% to 75% (as fed basis) according to the feed company. However, previous studies related TDN level of concentrate have been limited to growth performance and carcass characteristics of Hanwoo steers. Until recently, there was no study on physicochemical characteristics, meat color, myoglobin, and fatty acid composition in longissimus muscle determined by the TDN level of late fattening concentrate for Hanwoo steers.

Therefore, the present study was conducted to investigate the effect of TDN levels in commercial concentrate on growth performance, carcass characteristics, and meat composition of Hanwoo steers during the late fattening period.

**Materials and Methods**

**Animals, treatments, and management**

Twenty-eight late fattening Hanwoo steers (666.39±4.70 kg, 24.7±0.5 months of age, and castration: 14.0±0.3 months of age) were randomly assigned to any one of four dietary treatments: 73.30% (T1), 74.50% (T2), 76.40% (T3), and 77.10% (T4) based on the TDN level in commercial concentrate.

The Hanwoo steers in the experiment were managed according to the scientific guidelines of the Animal Experiment Ethics Committee of Kangwon National University (No: KIACUC-16-0010).

Experimental diets were composed of four late fattening concentrates from four Korean feed companies. The concentrates were fed at 1.5% of body weight three times/d (08:30, 13:00, and 18:00), and rice straw (DM 91.58%, crude protein 4.05%, ether extract 0.85%, crude ash 7.58%, neutral detergent fiber 72.40%, and acid detergent fiber 39.27%) was fed as forage at a rate of 1.5 kg/d. Steers were allotted by treatment groups into four pens (10 m×10 m) with the floor covered with 20 cm of sawdust.

The chemical compositions of the experimental diets were analyzed following the standard methods of the AOAC (2005), neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed based on methods described by Van Soest et al. (1991), starch was analyzed following the method described by Hall (2009), soluble protein (SolP) was analyzed according to the procedure described by Krishnamoorthy et al. (1982), neutral detergent insoluble crude protein (NDICP) and acid detergent insoluble crude protein (ADICP) were analyzed following the methods described by Licitra et al. (1996), and TDN was analyzed and evaluated following the method described by NRC (2001). The chemical composition and nutritional value of the diets are shown in Table 1.
Growth performance and blood characteristics

The ADG was calculated by measuring body weight at 10:00 every 2 months. Feed intake was measured daily by measuring the leftover feed still present before the morning feeding. The feed conversion ratio (FCR) was calculated using dry matter intake (DMI) and ADG.

For the analyses of blood metabolites, blood samples (3 mL) were taken every 2 months from the jugular vein of the experimental animals using an 18-gauge needle and a blood collection tube (Vacutainer, Becton-Dickinson, Franklin Lakes, NJ, USA) coated with heparin.

Blood samples were centrifuged at 1,250×g for 10 min to separate the plasma and were analyzed using an automatic blood analyzer (Hitachi 7020, Hitachi Ltd., Tokyo, Japan). The analyses included measurements of albumin (ALB), alanine aminotransferase (ALT), blood urea nitrogen (BUN), calcium (Ca), cholesterol (CHO), gamma-glutamyl transpeptidase (GGT), glucose (GLU), magnesium (Mg), non-esterified fatty acid (NEFA), phosphorus (P), triglyceride (TG), and total protein (TP).

Carcass characteristics and physicochemical characteristics of longissimus muscle

At the end of the experimental period (30 months of age), all animals were slaughtered at the local slaughterhouse to assess carcass yield and quality traits. Carcass evaluation was performed at the 13th rib section from the left side of each carcass by meat graders using the criteria provided by the Korean carcass grading system (MAFRA, 2017). Marbling score, meat color, fat color, texture, and maturity were measured as the carcass quality traits. Carcass weight, back fat thickness, and rib eye area were measured as the carcass yield traits, and then the carcass yield index was calculated using the values of these traits.

### Table 1. Chemical composition of concentrates for late fattening Hanwoo steers

| Items (%) | T1   | T2   | T3   | T4   |
|-----------|------|------|------|------|
| DM        | 87.50| 86.10| 86.10| 87.10|
| CP        | 14.20| 14.50| 14.60| 15.70|
| SolP      | 4.90 | 4.10 | 4.40 | 4.20 |
| NDICP     | 2.59 | 2.07 | 2.04 | 2.97 |
| ADICP     | 1.30 | 1.57 | 1.38 | 1.51 |
| EE        | 3.13 | 3.81 | 4.53 | 5.14 |
| Ash       | 8.09 | 7.80 | 7.28 | 8.00 |
| Ca        | 1.34 | 1.12 | 0.84 | 1.12 |
| P         | 0.44 | 0.44 | 0.49 | 0.48 |
| NDF       | 30.00| 27.40| 27.90| 23.10|
| ADF       | 13.50| 14.10| 14.80| 10.30|
| Lignin    | 2.48 | 2.76 | 2.92 | 2.71 |
| Sugar     | 8.90 | 8.80 | 8.00 | 7.80 |
| Starch    | 36.90| 38.70| 36.00| 43.10|
| NFC       | 47.10| 48.50| 46.10| 52.70|
| TDN       | 73.30| 74.50| 76.40| 77.10|

DM, dry matter; CP, crude protein; SolP, soluble protein; NDICP, neutral detergent insoluble crude protein; ADICP, acid detergent insoluble crude protein; EE, ether extract; Ca, calcium; P, phosphorus; NDF, neutral detergent fiber; ADF, acid detergent fiber; NFC, non-fibers carbohydrate; TDN, total digestible nutrients.
The carcass yield index = \[68.184 − \{0.625 \times \text{back fat thickness (mm)}\} + \{0.130 \times \text{rib eye area (cm}^2)\} − \{0.024 \times \text{carcass weight (kg)}\} + 3.23.\]

A total of 1 kg of longissimus muscle was collected to analyze the quality of the carcass of the Hanwoo steers based on the TDN level in the concentrate. The longissimus muscle was removed from the fat, connective tissues, and blood in a low temperature room at 5℃ and used for meat composition analysis. For the storage stability test, samples were cut into 1 cm thickness, packed in a polyethylene bag, and stored at 4℃ for 9 d (0 d, 3 d, 6 d, and 9 d).

The chemical compositions of the longissimus muscle were measured according to the standard methods of the AOAC (2005). To measure the pH of meat, 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). The pH values were measured immediately after homogenization using a pH meter (Orion 230A, Thermo Fisher Scientific Inc., Waltham, MA, USA).

The water holding capacity (WHC) was measured according to the procedure of Hofmann and White (1982). Briefly, a 0.3 g sample of muscle was placed in a filter (Whatman No. 1 GE Healthcare, Amersham, UK) press device and compressed for 5 min. Then, the WHC was calculated from duplicate samples as the ratio of the meat film area to the total area using an arealine meter (Super PLANIX-a, Tamaya Technics Inc., Tokyo, Japan).

For the measurement of cooking loss, 1 cm-thick steaks were placed in a polyethylene bag and heated in a water bath at 75℃ for 40 min, and subsequently cooled to room temperature (25℃–30℃) for 30 min. The percent cooking loss was determined by the difference in steak weights taken before and after cooking. Drip loss was measured as the weight loss during the suspension of a standardized (2×2×1 cm) sample sealed in a polyethylene bag at 4℃ after 9 d of storage.

Shear force values were determined using a texture analyzer (TA 1, LLOYD instruments Ltd., Fareham, UK) with the following operating parameters: load cell, 50 kg; test and trigger speed, 50 mm/min; and trigger forces, 0.01 kgf.

Texture profile analyses were performed by placing samples in a polyethylene bag and heating them in a constant temperature bath until the core temperature reached 75℃. After forming each longissimus muscle sample to 1×1×1 mm, the hardness, elasticity, cohesiveness, gumminess, and chewiness were measured using a texture analyzer equipped with a cylindrical probe of Ø35 mm (TA-XT plus, Stable Micro Systems Co., Ltd., London, UK). The samples were measured by pressing 80% of the sample height twice with pretest, test, and post-test speeds of 1 mm/s.

Meat color was measured using a colorimeter (Colorimeter CR-300, Minolta Co., Osaka, Japan) immediately after removing the meat from the polyethylene bag. The color pigment values of lightness (CIE L*), redness (CIE a*), and yellowness (CIE b*) were repeatedly measured in the same manner. The standard white plate had a Y value=93.60, an x value=0.3134, and a y value=0.3194.

The determination of 2-thiobarbituric acid reactive substances (TBARS) in the longissimus muscle was performed according to the methods described by Witte et al. (1970). Briefly, each sample (10 g) was added to 25 mL of 20% trichloroacetic acid (in 2 M phosphoric acid) and homogenized for 30 s. The samples were diluted with distilled water until the total amount of the homogenate was 50 mL and were then centrifuged (3,000×g, 4℃, 10 min). After centrifugation, the supernatant was filtered using filter paper and 5 mL of 0.005 mM 2-thiobarbituric acid was added to the filtrate (5 mL) and allowed to stand at room temperature for 15 h. The absorbance of the solution was measured at 530 nm using a UV/VIS spectrophotometer (M2e, Molecular Devices, Sunnyvale, CA, USA). TBARS was calculated according to the following equation: TBARS (mg of malondialdehyde/kg of sample)=(OD of sample−OD of blank sample)×5.2.

Deoxymyoglobin (DeoxyMb), oxymyoglobin (OxyMb), and metmyoglobin (MetMb) were measured following the method described by Krzywicki (1979). The samples were packed in a linear low density polyethylene wrap for food packaging.
(oxygen transmission rate: 35 273 cc/m² · 24 h · atm, 0.01 mm thickness; 3M Co, Korea) and the absorbance was measured at 473, 525, 572, and 730 nm using a UV spectrophotometer (UV-240 1PC, Shimadzu) following the method described by Demos et al. (1996) to calculate the percentage of MetMb. R630–R580, which is an index of red intensity by OxyMb, was calculated by the reflectance difference at 630 nm and 580 nm, and DeoxyMb was calculated by subtracting OxyMb and MetMb from 100.

Fatty acid composition of the longissimus muscle was measured according to the methods of Folch (1957). In brief, 0.5 g lyophilized samples were homogenized in chloroform-methanol (2:1) and 0.88% NaCl solution. After homogenizing, the bottom layer separated by centrifugation (1,250×g, 4℃, 30 min) was transferred to another tube, and the organic solvent was flushed with nitrogen gas. Next, 1 mL of 0.5 N methanolic NaOH was added to the tube, the mixture was heated for 15 min, and then cooled. Two milliliters of 14% BF3-methanol were added, heated, and then cooled. After cooling, 1 mL heptane and 2 mL saturated NaCl solution was added, and the mixture was allowed to stand at room temperature for 40 min. The supernatant was transferred to a vial using a micropipette, and fatty acids were analyzed by gas chromatography (Shimadzu-17A, Shimadzu, Kyoto, Japan). The analysis condition is column: 100 m×0.25 mm ID, 20 um film; carrier gas: 20 cm/sec, set at 140℃; column flow: rate mL/min; split ratio: 100:1; injection port temperature 260℃; detection port temperature: 260℃; oven temperature: 140℃ (5 min) to 240℃ at 4℃/min.

Statistical analyses
The least squares method was used to estimate the environmental effects on data. The following linear model was used: 
$$y_{ij} = \mu + TRT_i + e_{ij},$$
where, $\mu$=overall average, $TRT_i$=effect of treatment (1–4), $e_{ij}$=random error effect.

The linear model was analyzed using the SAS package 9.1 software program and the variance analysis was performed using the Type III squared fit for unbalanced data among the four squares presented in the SAS/GLM analysis. The statistical significance of the differences between the least squares averages of the treatments was tested with 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) the effects ($I \neq j$).

Results and Discussion

Growth performance and blood metabolites characteristics
Table 2 shows the effect of the TDN level of commercial concentrates on the growth performance of the late fattening Hanwoo steers. There was no significant difference between the treatments for the initial and final body weights. The ADG was highest in the T2, but it was not significantly different from that in the other treatments. Concentrate intake was slightly but not significantly lower in the T2 than in the other treatments, and the rice straw intake was the same in all the treatments. DMI was lowest in the T2; however, the FCR was 5.8%–17.6% lower in the T2 than in the other treatments due to the difference in ADG, and was highest in the T3.

The energy level of the concentrate during the late fattening period affects ADG and feed efficiency (Andersen and Ingvartsen, 1984) because ADG during the late fattening is closely related to energy demand (Martin et al., 1979). In addition, the late fattening period is the stage where the meat quality is completed; thus, setting the TDN level of concentrate during this period is more effective than setting it during the growing and early fattening periods (Kim, 2015). Increasing the TDN level in concentrate influences the increase in DM degradability and energy availability (Ki, 2009), increases the DMI
Effect of TDN Level of Concentrate for Hanwoo Steers

Table 2. Effects of TDN level of commercial concentrates on growth performance of late fattening Hanwoo steers

| Items                        | T1      | T2      | T3      | T4      | SEM    | Pr>F  |
|------------------------------|---------|---------|---------|---------|--------|-------|
| Body weight (kg)             |         |         |         |         |        |       |
| Initial                      | 670.45  | 659.83  | 669.02  | 666.25  | 3.942  | 0.95  |
| Final                        | 795.80  | 793.25  | 786.93  | 795.28  | 4.535  | 0.91  |
| Average daily gain           | 0.79    | 0.82    | 0.71    | 0.77    | 0.013  | 0.74  |
| Feed intake (DM, kg)         |         |         |         |         |        |       |
| Concentrate                  | 10.44   | 10.18   | 10.74   | 10.47   | 0.460  | 0.85  |
| Rice straw                   | 0.71    | 0.71    | 0.71    | 0.71    | -      | -     |
| DMI                          | 11.15   | 10.89   | 11.45   | 11.18   | 0.460  | 0.75  |
| Feed conversion ratio        | 14.11   | 13.28   | 16.13   | 14.52   | 0.320  | 0.51  |

TDN, total digestible nutrients; DMI, dry matter intake.

(Chung et al., 2015), and improves ADG (Jin et al., 2012). However, in the present study, there was no improvement in ADG and FCR with increasing TDN levels in concentrate, and it was found to be most effective at the quantities in the T2. Lee (2017) reported that there was no difference in the ADG and FCR between the control (TDN 72.21%) and the high energy treatment (TDN 75.96%). In contrast, Ahn et al. (2016) reported that the ADG and FCR of the treatments with lower TDN were better than those of the control.

Table 3 shows the effect of the TDN level of commercial concentrates on blood metabolites in the late fattening Hanwoo steers. The difference among treatments for GLU concentrations was small during the initial period but was significantly higher during the final period in the T2 compared to the T1 and T4 (p<0.05). The NEFA concentration was not significantly different between the treatments during the initial and final periods.

Plasma GLU and NEFA are indexes that are related to the energy intake of cattle (Kim, 2018), which are inversely related to each other. Plasma GLU is known to be the main raw material for the intramuscular fat synthesis of ruminants (Smith and Crouse, 1984). The present study showed that the marbling score (Table 4) was higher in the treatment group that had the

Table 3. Effects of TDN level of commercial concentrates on plasma metabolite concentrations of late fattening Hanwoo steers

| Items     | T1     | T2     | T3     | T4     | SEM   | Pr>F  |
|-----------|--------|--------|--------|--------|-------|-------|
| ALB (g/dL)| 3.85   | 3.68   | 3.75   | 3.71   | 0.020 | 0.13  |
| ALT (IU/L)| 17.70  | 18.78  | 18.03  | 18.19  | 0.360 | 0.25  |
| BUN (mg/dL)| 12.32  | 10.88  | 13.21  | 11.02  | 0.181 | 0.19  |
| Ca (mg/dL)| 8.88   | 8.67   | 8.88   | 8.82   | 0.026 | 0.42  |
| CHO (mg/dL)| 127.93 | 126.87 | 136.09 | 126.67 | 1.892 | 0.63  |
| GGT (mg/dL)| 37.39b | 21.95a | 32.28b | 35.93b | 0.627 | 0.05  |
| GLU (mg/dL)| 64.00  | 61.47  | 68.74  | 63.77  | 0.438 | 0.36  |
| Mg (mg/dL)| 3.23   | 3.32   | 3.20   | 3.24   | 0.015 | 0.18  |
| NEFA (uEq/L)| 149.18 | 121.69 | 150.30 | 164.51 | 2.542 | 0.22  |
| P (mg/dL)| 6.31   | 6.70   | 6.80   | 6.67   | 0.042 | 0.85  |
| TG (mg/dL)| 24.38  | 32.41  | 32.74  | 24.31  | 0.741 | 0.46  |
| TP (g/dL)| 7.26   | 7.30   | 7.14   | 7.05   | 0.042 | 0.33  |

TDN, total digestible nutrients; ALB, albumin; ALT, alanine aminotransferase; BUN, blood urea nitrogen; Ca, calcium; CHO, cholesterol; GGT, gamma glutamyl transferase; GLU, glucose; Mg, magnesium; NEFA, non-esterified fatty acid; P, phosphorus; TG, triglyceride; TP, total protein.

\*a,b Means with difference superscript in the same row are significantly different(p<0.05).
highest blood GLU concentration, which was consistent with previous study results. However, there was no consistent trend of plasma GLU based on feed energy level. Chung et al. (2015) reported that the plasma GLU concentration in the high energy feeding group was low and genetically influenced by the breeding value, and plasma GLU could be changed by various factors.

Although there was no difference among treatments for TP, ALB, and BUN concentrations during the initial period, TP concentration during the final period was the highest in the T3 and lowest in the T2 (p<0.05). Plasma TP performs a variety of physiological functions such as metabolic transport, maintenance of the cellular environment, synthesis of immune substances, and maintenance of osmotic pressure (Kim et al., 2000). Plasma TP concentrations can be increased as the protein level of the feed increases (Otto et al., 2000). In the present study, plasma TP concentration was highest in the T4, which had the highest crude protein content (Table 1), and plasma TP concentration increased in proportion to the protein content of the concentrate.

CHO and TG concentrations increased during the final period of treatment compared to the initial period in all treatment groups; however, there was no significant difference among treatments. ALT and GGT concentrations also showed little difference among treatments during the final period. The concentrations of Ca, Mg, and P were not statistically different among treatments during the initial and final periods.

Thus, the results of the present study rarely showed statistical significance based on the treatment groups; therefore, we considered that the TDN level of commercial concentrate did not affect the concentration of blood metabolites.

**Carcass characteristics and meat composition**

Table 4 shows the effect of the TDN level of commercial concentrates on the carcass characteristics of Hanwoo steers. The back fat thickness was the thickest in the T4 and the thinnest in the T3; however, there was no consistent trend or statistical significance based on TDN levels. The rib eye area was slightly but not significantly lower in the T3 than in the other treatments. The yield index was slightly but not significantly higher in the order of T3, T2, T1, and T4, and the TDN level of the concentrate had little effect on the carcass yield traits of Hanwoo steers.
The carcass weight is highly correlated with the slaughtered weight. In the present study, similar results were obtained because the weight was not different during the late fattening period. Chung et al. (2015) also reported that the back fat thickness of Hanwoo steers slaughtered at 26 and 30 months of age was higher in the high energy treatment than in the control. It is considered that the lower rib eye area in the T3 was due to the influence of the management of the early fattening period, which is the maximum development time for the rib eye area, rather than the differences in the TDN level (Kim, 1998). The highest carcass yield index in the T3 was attributed to the effect of relatively thin back fat thickness (Lee et al., 2011) compared to the other treatments.

The marbling score was 20.4%–43.5% higher in T2 than those in the other treatments; however, meat and fat color were the same for all treatments. The texture was higher in the T1 and T2 than in the T3 and T4; however, there were no statistically significant differences among treatments. Intramuscular fat is correlated with meat quality grade (Lee et al., 2004). Glucose is involved in intramuscular fat synthesis and regulation of subcutaneous adipose tissue and fatty acid synthesis. In the present study, although the highest TDN, starch, and non-fibers carbohydrate (NFC) contents were found in the T4, the muscle fat percentage was lower than that of the T2 because of the increase in subcutaneous fat due to excessive energy increase (Carsten et al., 1991) and the effect of the rumen function decreased (Kim, 2006). Paek et al. (2005) reported that the body fat ratio of the TDN 74% treated group was lower than that of the TDN 72% in their study of energy levels in late fattening concentrates. On the other hand, in T3, the TDN level was higher than that of T2, but the ether extract content of the concentrate was more affected than the starch and NFC (Table 1). Also, as the ether extract content of the feed was increased, the intramuscular fat level was decreased (Ryu, 2017). These results indicate that the TDN level during the late fattening period is an important factor for the increase of intramuscular fat; however, if it exceeds a certain level, there is an increase in the inedible fat (subcutaneous fat) and a decrease of carcass yield grade (Cho et al., 2013; Jeong et al., 2010). In addition, we recommend that it will be necessary to maintain the TDN level at an appropriate level since it involves the cost of increasing the TDN level.

Table 5 shows the effect of the TDN level of commercial concentrates on meat composition in Hanwoo steers. There were no differences in the chemical composition, WHC, and cooking loss of the *longissimus* muscle among the treatments. The effect of TDN level on the physicochemical characteristics of the *longissimus* muscle was not significant, and the shear force and physical

| Items (%)          | T1  | T2  | T3  | T4  | SEM  | Pr>F |
|-------------------|-----|-----|-----|-----|------|------|
| Moisture          | 66.05 | 69.27 | 66.90 | 67.97 | 0.686 | 0.72 |
| Ether extract     | 10.71 | 9.30  | 11.80 | 10.51 | 0.743 | 0.82 |
| Crude protein     | 21.10 | 20.64 | 20.50 | 20.75 | 0.187 | 0.83 |
| Ash               | 0.78  | 0.79  | 0.81  | 0.77  | 0.014 | 0.31 |
| Cooking loss      | 33.91 | 33.26 | 31.70 | 32.02 | 0.467 | 0.15 |
| Water holding capacity | 64.28 | 64.10 | 65.03 | 68.58 | 0.785 | 0.36 |
| Shear force (kgf) | 5.21  | 5.04  | 5.09  | 5.21  | 0.200 | 0.66 |
| Hardness (gf)     | 22.63 | 21.54 | 22.76 | 22.47 | 0.362 | 0.66 |
| Gumminess (gf)    | 7.88  | 7.58  | 7.92  | 7.88  | 0.138 | 0.68 |
| Chewiness (gf)    | 4.24  | 3.97  | 4.31  | 4.14  | 0.100 | 0.58 |
| Springiness       | 0.53  | 0.51  | 0.53  | 0.51  | 0.005 | 0.57 |
| Cohesiveness      | 0.34  | 0.33  | 0.33  | 0.34  | 0.003 | 0.83 |
| Resilience        | 0.21  | 0.21  | 0.21  | 0.22  | 0.002 | 0.06 |

TDN, total digestible nutrients.
characteristics (e.g., elasticity, cohesiveness, adhesiveness, and chewiness) of the longissimus muscle were relatively low in the T2 compared to the other treatments. Previous studies have shown no differences among the different grades in WHC, cooking loss, moisture, and crude protein content (Lee et al., 2012), which were similar results to those of the present study.

Table 6 shows the effect of the TDN level of commercial concentrates on the pH, TBARS, meat color, and myoglobin in longissimus muscle of Hanwoo steers during storage at 4°C.

| Items                        | Storage (days) | T1   | T2   | T3   | T4   | SEM  | Pr>F |
|------------------------------|----------------|------|------|------|------|------|------|
| pH                           | 0              | 5.64 | 5.56 | 5.56 | 5.58 | 0.012| 0.77 |
|                              | 3              | 5.58 | 5.57 | 5.55 | 5.57 | 0.010| 0.56 |
|                              | 6              | 5.56 | 5.53 | 5.53 | 5.59 | 0.009| 0.90 |
|                              | 9              | 5.69 | 5.64 | 5.63 | 5.72 | 0.016| 0.62 |
| TBARS (mg MA/kg)             | 0              | 0.19 | 0.13 | 0.20 | 0.19 | 0.011| 0.74 |
|                              | 3              | 0.32 | 0.35 | 0.32 | 0.37 | 0.018| 0.56 |
|                              | 6              | 0.38 | 0.51 | 0.44 | 0.43 | 0.029| 0.88 |
|                              | 9              | 0.53 | 0.57 | 0.54 | 0.50 | 0.032| 0.13 |
| Lightness (L*)               | 0              | 37.94| 38.05| 37.11| 37.57| 0.479| 0.98 |
|                              | 3              | 33.34| 32.49| 31.78| 33.26| 0.464| 0.26 |
|                              | 6              | 31.09| 30.42| 29.50| 30.80| 0.373| 0.70 |
|                              | 9              | 30.38| 29.60| 28.91| 30.15| 0.430| 0.44 |
| Redness (a*)                 | 0              | 27.18| 25.85| 26.42| 25.31| 0.376| 0.50 |
|                              | 3              | 22.65| 22.39| 22.21| 22.54| 0.344| 0.62 |
|                              | 6              | 18.30| 18.43| 17.72| 20.35| 0.346| 0.29 |
|                              | 9              | 11.23| 12.34| 12.52| 12.69| 0.469| 0.38 |
| Yellowness (b*)              | 0              | 14.93| 14.12| 14.28| 14.13| 0.199| 0.90 |
|                              | 3              | 12.18| 11.81| 11.30| 12.20| 0.231| 0.35 |
|                              | 6              | 9.37 | 9.25 | 8.51 | 10.22| 0.215| 0.71 |
|                              | 9              | 6.56 | 7.07 | 6.62 | 7.40 | 0.276| 0.16 |
| DeoxyMb                      | 0              | 16.42| 16.68| 16.47| 16.01| 0.168| 0.81 |
|                              | 3              | 7.62 | 8.71 | 8.31 | 8.45 | 0.399| 0.42 |
|                              | 6              | 10.67| 11.36| 10.56| 10.63| 0.190| 0.17 |
|                              | 9              | 9.44 | 9.44 | 8.68 | 9.99 | 0.210| 0.83 |
| OxyMb                        | 0              | 81.14| 81.43| 80.80| 81.00| 0.241| 0.15 |
|                              | 3              | 77.64| 75.01| 72.73| 75.38| 0.755| 0.66 |
|                              | 6              | 67.91| 65.14| 67.74| 67.92| 0.905| 0.42 |
|                              | 9              | 45.77| 39.72| 41.19| 46.94| 1.764| 0.59 |
| MetMb                        | 0              | 2.44 | 1.88 | 2.73 | 2.99 | 0.294| 0.33 |
|                              | 3              | 14.74| 16.29| 18.96| 16.17| 0.811| 0.83 |
|                              | 6              | 21.42| 23.49| 21.70| 21.45| 0.901| 0.34 |
|                              | 9              | 44.79| 50.83| 50.13| 43.07| 1.813| 0.65 |

TDN, total digestible nutrients; TBARS, 2-thiobarbituric acid reactive substances; DeoxyMb, deoxymyoglobin; OxyMb, oxymyoglobin; MetMb, metmyoglobin.
content in the *longissimus* muscle of Hanwoo steers. There was no significant difference among the treatments for the pH of *longissimus* muscle during the entire storage period (0 d, 3 d, 6 d, and 9 d). The pH of meat is an important criterion for quality assessment, and affects the color, hardness, rancidity, and WHC (Guignot et al., 1994). The normal pH range is reported to be less than 5.75 (Wulf and Page, 2000). In the present study, the pH of all treatments was not affected by the different TDN level of concentrate. Therefore, the TDN level of concentrate was considered to have little effect on the pH of *longissimus* muscle, and the reason for the increase in pH on 9 d of storage is presumed to be related to the formation of basophilic materials by the gradual increase of protein degradation in intracellular muscle after slaughter.

TBARS value was increased as the storage period was increased in all treatments but there was no statistical difference in the treatment interval. TBARS is a measure of the level of malondialdehyde caused by lipid oxidation, which has been reported to increase with the passage of meat storage (Demeyer et al., 1974). In the present study, it was also found that as the storage period was increased, the TBARS value increased and lipid acidification progressed, and the increased result of TBARS in the T2 was influenced by the marbling score (Table 4). TBARS value is known to be influenced by fat content of the *longissimus* muscle (Lorenzo and Pateiro, 2013). Kim (2011) reported that, although there was no statistical significance, the value of TBARS during the storage period of Hanwoo steers increased with increasing meat quality grade, which was similar to the results of the present study.

There was no effect of TDN level on changes of color pigment values (lightness, redness, and yellowness) during the different storage periods in the *longissimus* muscle. Meat color is the most important factor of the purchasing requirements of consumers, and is influenced by feed type, storage condition, microbial contamination, and rancidity. However, TDN level of concentrate was found to have a limited effect on the change of meat color in the present study.

The DeoxyMb, OxyMb, and MetMb ratios were no significant differences in the treatments based on the TDN levels of concentrate. Myoglobin is oxidized to the DeoxyMb, OxyMb, and MetMb stages; therefore, the ratio of MetMb increases with increasing storage period (Faustman et al., 2010). In addition, Kim et al. (2002) reported that the 7th day MetMb ratio in the *longissimus* muscle of Hanwoo steers was 29.27% to 40.63%, which is similar to the results of the present study.

Table 7 shows the effect of the TDN level of commercial concentrates on the fatty acid composition in *longissimus* muscle of Hanwoo steers. Compositions of oleic and palmitic acid were similar among the treatments. In addition, α-linolenic, EPA, UFA, and SFA compositions did not show a consistent trend based on TDN level. Fatty acid composition of meat can be influenced by the type of feed (Lee et al., 2011), fattening period (Yoshimura and Namikawa, 1983), and meat quality grade (Smith et al., 2009). However, the effect on the fatty acid composition in the *longissimus* muscle of Hanwoo steers is small. Lee (2005) reported that there was no difference in the fatty acid composition in the *longissimus* muscle of 30-mo-old slaughtered Hanwoo steers fed concentrate with different TDN levels (low, medium, and high). The fatty acid ratio was approximately 50% for oleic acid, approximately 30% for palmitic acid, and approximately 10% for stearic acid, which is similar to the results of the present study.

The finding of this study indicate that less than 74% or greater than 75% TDN in the commercial concentrate did not contribute to improve ADG, FCR, marbling score; therefore, in the present study, the recommendable TDN level in the commercial concentrate for late fattening period was 74% to 75% in terms of growth performance and marbling score of Hanwoo steer.

**Conflicts of interest**

The authors declare no potential conflict of interest.
Acknowledgements

This research was supported by the “RDA Research Associate Fellowship Program” of the National Institute of Animal Science, Rural Development Administration, Korea.

Author Contributions

Conceptualization: Park BK. Data curation: Ahn JS, Kim MJ. Formal analysis: Son GH, Kim MJ. Methodology: Kwon EG, Park BK. Software: Park JK. Validation: Park BK. Investigation: Choi CS, Lee CW. Writing - original draft: Ahn JS, Son GH. Writing - review & editing: Ahn JS, Son GH, Kim MJ, Choi CS, Lee CW, Park JK, Kwon EG, Shin JS, Park BK.

Ethics Approval

Protocols involving the use of experimental animals were approved by the ethical and scientific guidelines of the Animal Experiment Ethics Committee of Kangwon National University (No: KIACUC-16-0010), and ruminal fistulas were transplanted in Korean native Hanwoo and Holstein cows.

References

Ahn GC, Kwak HJ, Oh YK, Lee YK, Jang SS, Lee SS, Park KK. 2016. Characteristics of wet distillers grains on in vitro ruminal fermentation and its effects on performance and carcass characteristics of finishing Hanwoo steers. Asian-
Australas J Anim Sci 29:530-538.
Andersen HR, Ingvartsen KL. 1984. The influence of energy level, weight at slaughter and castration on growth and feed efficiency in cattle. Livest Prod Sci 11:559-569.
Association of Official Analytical Chemists [AOAC]. 2005. Official methods of analysis of AOAC international. 18th ed. AOAC International, Gaithersburg, MD, USA.
Carstens GE, Johnson DE, Ellenberger MA, Tatum JD. 1991. Physical and chemical components of the empty body during compensatory growth in beef steers. J Anim Sci 69:3251-3264.
Cho WG, Lee SJ, Ko YH, Chang IS, Lee SS, Moon YH. 2013. Effects of dietary type during late fattening phase on the growth performance, blood characteristics and carcass traits in Hanwoo steers. J Anim Sci Technol 55:443-449.
Chung KY, Chang SS, Lee EM, Kim HJ, Park BH, Kwon EG. 2015. Effects of high energy diet on growth performance, carcass characteristics, and blood constituents of final fattening Hanwoo steers. Korean J Agric Sci 42:261-268.
Chung KY, Lee SH, Cho SH, Kwon EG, Lee JH. 2018. Current situation and future prospects for beef production in South Korea-A review. Asian-Australas J Anim Sci 31:951-960.
Demeyer D, Hoozée J, Mesdøm H. 1974. Specificity of lipolysis during dry sausage ripening. J Food Sci 39:293-296.
Demos BP, Gerrard DE, Mandigo RW, Gao X, Tan J. 1996. Mechanically recovered neck bone lean and ascorbic acid improve color stability of ground beef patties. J Food Sci 61:656-659.
Faustman C, Sun Q, Mancini R, Suman SP. 2010 Myoglobin and lipid oxidation interactions: Mechanistic bases and control. Meat Sci 86:86-94.
Folch J, Lees M, Stanley GHS. 1957. A simple method for the isolation and purification of total lipides from animal tissues. J Biol Chem 226:497-509.
Guignot F, Touraille C, Ouali A, Renerre M, Monin G. 1994. Relationships between post-mortem pH changes and some traits of sensory quality in veal. Meat Sci 37:315-325.
Hall MB. 2009. Determination of starch, including maltooligosaccharides, in animal feeds: Comparison of methods and a method recommended for AOAC collaborative study. J AOAC Int 92:42-49.
Hofmann AW, White WM. 1982. Mantle plumes from ancient oceanic crust. Earth Planet Sci Lett 57:421-436.
Hong BC. 2016. Analyses of optimal feeding period to improve productivity for Hanwoo cattle farm. Ph.D. dissertation, Kangwon National Univ., Chuncheon, Korea.
Hwang JA, Islam MM, Ahmed ST, Mun HS, Kim GM, Kim YJ, Yang CJ. 2014. Seamustard (Undaria pinnatifida) improves growth, immunity, fatty acid profile and reduces cholesterol in Hanwoo steers. Asian-Australas J Anim Sci 27:1114-1123.
Jeong J, Seong NI, Hwang IK, Lee SB, Yu MS, Nam IS, Lee MI. 2010. Effects of level of CP and TDN in the concentrate supplement on growth performances and carcass characteristics in Hanwoo steers during final fattening period. J Anim Sci Technol 52:305-312.
Jin GL, Kim JK, Qin WZ, Jeong J, Jang SS, Sohn YS, Choi CW, Song MK. 2012. Effect of feeding whole crop barley silage or whole crop rye silage based-TMR and duration of TMR feeding on growth, feed cost and meat characteristics of Hanwoo steers. J Anim Sci Technol 54:111-124.
Ki KS, Lim YS, Jin ZL, Lee HJ, Kim SB, Lee WS, Yang SH, Cho WM, Kim HS, Jeo JM, Lee ID. 2009. Effect of crude protein and total digestible nutrient levels on intake, digestibility, nitrogen and energy utilization in growing dairy goats. J Korean Soc Grassl Forage Sci 29:269-276.
Kim BK. 2006. Effects of feeding high quality roughage (timothy hay) during growing period on growth performance and
carcass characteristics of Hanwoo steers. Korean J Food Sci Anim Resour 26:212-217.

Kim JH. 2015. Studies on the effect of finishing feeding regimen on the performance, carcass grade and economic analysis in Hanwoo steers. M.S. thesis, Gyeongnam National Univ., Jinju, Korea.

Kim KH, Ra CS, Shin JS. 2000. Relationship between blood metabolites and both growth and carcass traits in Korean cattle. Ann Anim Resour Sci 11:133-144.

Kim MJ. 2018. A study on relationship of blood metabolites and carcass traits in Hanwoo steers. M.S. thesis, Kangwon National Univ., Chuncheon, Korea.

Kim YG. 1998. Studies on the meat quantity and quality characteristics by growing ages and feeding treatments in Korean native bulls or steers. Ph.D. dissertation, Gyeongsang National Univ., Jinju, Korea.

Kim YJ. 2011. Effect of the palatability, physico-chemical properties and microbial determinants of Hanwoo meat with different marbling scores during refrigeration. M.S. thesis, Sangji Univ., Wonju, Korea.

Kim YS, Liang CY, Kim JY, Park YS, Hwang HS, Lee SK. 2002. Effects of dietary vitamin E and selenium supplementation on meat color stability of Hanwoo (Korean native cattle) bull beef during retail display. Korean J Food Sci Anim Resour 22:108-114.

Krishnamoorthy U, Muscato TV, Sniffen CJ, Van Soest PJ. 1982. Nitrogen fractions in selected feedstuffs. J Dairy Sci 65:217-225.

Krzywicki K. 1979. Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of beef. Meat Sci 3:1-10.

Lee CR. 2017. Effects of energy-enriched concentrate on growth performance and carcass characteristics of Hanwoo steers. M.S. thesis, Kyungpook National Univ., Sangju, Korea.

Lee JH. 2005. Effect of the optimum energy levels and fattening periods for beef quality and yield in hanwoo steers. M.S. thesis, Gyeongsang National Univ., Jinju, Korea.

Lee JM, Choe JH, Jin HJ, Kim TI, Park BY, Hwang DY, Koh KC, Kim CJ, Hwang KS. 2012. Effect of marbling score on carcass grade factors, physico-chemical and sensory traits of *M. longissimus dorsi* in Hanwoo. Korean J Food Sci Anim Resour 32:659-668.

Lee JM, Choi JH, Park HK, Kim YH, Park BY, Kim KT, Koh KC, Seo SC, Hwang KS. 2011. Effect of backfat thickness on the carcass grade factors and carcass price in Hanwoo cows and steers. Korean J Food Sci Anim Resour 31:280-289.

Lee JM, Park BY, Cho SH, Kim JH, Yoo YM, Chae HS, Choi YI. 2004. Analysis of carcass quality grade components and chemophysical and sensory traits of *M. longissimus dorsi* in Hanwoo. J Anim Sci Technol 46:833-840.

Lee SM, Chang SS, Jung KY, Kim HC, Choi SH, Kwon EG, Park BK, Yang BS, Lee SS, Cho YM. 2013. Effects of feeding patterns of concentrate on growth performance, blood parameters and carcass characteristics in fattening Hanwoo cows. J Anim Sci Technol 55:33-39.

Lee SM, Son JI. 2011. Effect of dietary cracked whole barley on the meat compositional properties of Hanwoo steer loin beef. J Anim Sci Technol 53:357-365.

Licitra G, Hernandez TM, Van Soest PJ. 1996. Standardization of procedures for nitrogen fractionation of ruminant feeds. Anim Feed Sci Tech 57:347-358.

Lorenzo JM, Pateiro M. 2013. Influence of type of muscles on nutritional value of foal meat. Meat Sci 93:630-638.

Martin TG, Mollett TA, Stewart TS, Erb RE, Malven PV, Veenhuizen EL. 1979. Comparison of four levels of protein supplementation with and without oral diethylstilbestrol on blood plasma concentrations of testosterone, growth hormone...
and insulin in young bulls. J Anim Sci 49:1489-1496.

Ministry of Agriculture, Food and Rural Affairs [MAFRA]. 2017. Grade rule for cattle carcass in Korea. Korea Ministry of Government Legislation. Available from: http://www.law.go.kr/main.htm. Accessed Nov 30, 2017.

NRC. 2001. Nutrient requirement of dairy cattle. 7th ed. National Academy Press, Washington, DC, USA.

Otto F, Vilela F, Harun M, Taylor G, Baggasse P, Bogin E. 2000. Biochemical blood profile of Angoni cattle in Mozambique. Isr J Vet Med 55:95-102.

Paek BH, Hong SG, Kwon EG, Cho WM, Yoo YM, Shin KJ. 2005. Effects of energy level of concentrate feed on meat quality and economic evaluation in finishing Hanwoo steers. J Anim Sci Technol 47:447-456.

Roth CAS, Compiani R. 2016. Ruminal acidosis of beef cattle and related diseases. Large Anim Rev 22:273-279.

Ryu CH. 2017. Investigation of the relationship dietary crude protein and energy levels, and growth performance and carcass characteristics of Hanwoo using statistical meta-analysis. Ph.D. dissertation, Chonbuk National Univ., Cheongju, Korea.

Smith SB, Crouse JD. 1984. Relative contributions of acetate, lactate and glucose to lipogenesis in bovine intramuscular and subcutaneous adipose tissue. J Nutr 114:792-800.

Smith SB, Gill CA, Lunt DK, Brooks MA. 2009. Regulation of fat and fatty acid composition in beef cattle. Asian-Australas J Anim Sci 22:1225-1233.

Van Soest PJ, Robertson JB, Lewis BA. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 74:3583-3597.

Witte VC, Krause GF, Bailey ME. 1970. A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. J Food Sci 35:582-585.

Wulff DM, Page JK. 2000. Using measurements of muscle color, pH, and electrical impedance to augment the current USDA beef quality grading standards and improve the accuracy and precision of sorting carcasses into palatability groups. J Anim Sci 78:2595-2607.

Yoon JH, Won JI, Lee KS, Kim JB, Lee JK. 2013. Estimation of resonable market month of age for Hanwoo steer. J Anim Sci Technol 55:405-416.

Yoshimura T, Namikawa K. 1983. Influence of breed, sex anatomical location on lipid and fatty acid composition of bovine subcutaneous fat. Jpn J Zootech Sci 54:97-105.