Food Science of Animal Resources

Food Sci. Anim. Resour. 2019 June 39(3):388~401
DOI https://doi.org/10.5851/kosfa.2019.e32

pISSN : 2636-0772 eISSN : 2636-0780
http://www.kosfaj.org

ARTICLE

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

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OPEN ACCESS

Received March 14, 2019
Revised April 4, 2019
Accepted April 5, 2019

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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 back fat thickness was thicker in the T4 and marbling score was higher in the T2 than in the other treatments; however, the differences were not statistically significant. The TDN level of concentrates 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.

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
		% of DM		
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.

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.

The carcass yield index=[68.184−{0.625×back fat thickness (mm)}]+{0.130×rib eye area (cm^2)}−{0.024×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 area-line 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/m^2 · 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% BF_3-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, μ=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%: Ho: 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

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	Initial						Final					
	T1	T2	T3	T4	SEM	Pr>F	T1	T2	T3	T4	SEM	Pr>F
ALB (g/dL)	3.85	3.68	3.75	3.71	0.020	0.13	4.23	3.31	4.81	3.85	0.049	0.19
ALT (IU/L)	17.70	18.78	18.03	18.19	0.360	0.25	19.31	23.06	17.88	20.87	0.533	0.32
BUN (mg/dL)	12.32	10.88	13.21	11.02	0.181	0.19	13.69	8.15	20.75	11.53	0.497	0.25
Ca (mg/dL)	8.88	8.67	8.88	8.82	0.026	0.42	9.48	7.89	10.96	8.89	0.093	0.42
CHO (mg/dL)	127.93	126.87	136.09	126.67	1.892	0.63	131.37	127.67	151.33	132.61	2.923	0.58
GGT (mg/dL)	37.39^{b}	21.95^{a}	32.28^{b}	35.93^{b}	0.627	0.05	42.813	62.64	23.10	60.43	2.115	0.22
GLU (mg/dL)	64.00	61.47	68.74	63.77	0.438	0.36	83.73^{bc}	137.62^{a}	121.89^{ab}	75.88^{bc}	1.979	0.03
Mg (mg/dL)	3.23	3.32	3.20	3.24	0.015	0.18	3.57	2.99	3.98	3.25	0.036	0.08
NEFA (uEq/L)	149.18	121.69	150.30	164.51	2.542	0.22	251.35	119.71	291.49	176.29	7.201	0.15
P (mg/dL)	6.31	6.70	6.80	6.67	0.042	0.85	7.38	6.23	8.56	7.06	0.077	0.37
TG (mg/dL)	24.38	32.41	32.74	24.31	0.741	0.46	61.86	68.87	43.19	67.92	1.530	0.52
TP(g/dL)	7.26	7.30	7.14	7.05	0.042	0.33	7.98^{ab}	6.05^{c}	9.65^{a}	7.24^{bc}	0.086	0.01

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

Table 4. Effects of TDN level of commercial concentrates on carcass characteristics of Hanwoo steers

Items	T1	T2	T3	T4	SEM	Pr>F
Yield traits[1)]						
Carcass weight (kg)	465.32	467.41	465.67	470.44	3.010	0.98
Rib eye area (cm^2)	100.74	100.49	93.83	102.34	0.676	0.36
Back fat thickness (mm)	14.87	14.33	12.57	17.77	0.290	0.15
Yield index	64.03	64.29	64.57	62.31	0.799	0.60
Quality traits[2)]						
Marbling (No.)	3.33	4.78	3.97	3.81	0.091	0.14
Meat color (No.)	5.00	5.00	5.00	5.00	-	-
Fat color (No.)	3.00	3.00	3.00	3.00	-	-
Texture (No.)	1.71	1.85	1.42	1.42	0.036	0.28
Maturity (No.)	2.14	1.98	2.00	2.14	0.018	0.58

[1)] Area was measured from *longissmus* muscle taken at 13th rib and back fat thickness was also measured at 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 with higher numbers for better quality (1, devoid; 9, abundant); meat color (1, bright red; 7, dark red); texture (1, soft; 3, firm); maturity (1, youthful; 9, mature).
TDN, total digestible nutrients.

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

Table 5. Effects of TDN level of commercial concentrates on physicochemical characteristics in *longissimus* muscle of Hanwoo steers

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

Table 6. Effects of TDN level of commercial concentrates on pH, TBARS, meat color, and myoglobin in *longissimus* muscle of Hanwoo steers during storage at 4℃

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.

Table 7. **Effects of TDN level of commercial concentrates on fatty acid composition in *longissimus* muscle of Hanwoo steers**

Items	T1	T2	T3	T4	SEM	Pr>F
C14:0 (Myristic, %)	3.62	3.60	3.49	3.50	0.044	0.48
C16:0 (Palmitic, %)	29.74	30.97	29.93	30.26	0.293	0.18
C16:1n7 (Palmitoleic, %)	4.96	5.63	5.39	5.67	0.125	0.42
C18:0 (Stearic, %)	10.18	9.93	10.88	9.70	0.259	0.47
C18:1n9 (Oleic, %)	49.64	48.12	48.29	49.05	0.373	0.10
C18:2n6 (Linoleic, %)	1.51	1.39	1.67	1.45	0.042	0.65
C18:3n6 (γ-Linolenic, %)	0.01	0.01	0.01	0.01	0.000	0.89
C18:3n3 (α-Linolenic, %)	0.12	0.13	0.13	0.14	0.003	0.73
C20:4n6 (Arachidonic, %)	0.19	0.19	0.18	0.19	0.006	0.40
C20:5n3 (Eicosapentaenoic, %)	0.02	0.02	0.02	0.02	0.001	0.99
C22:6n3 (Docosahexaenoic, %)	0.01	0.01	0.01	0.01	0.001	0.99
SFA	43.53	44.51	44.29	43.46	0.309	0.54
MUFA	54.60	53.75	53.68	54.72	0.179	0.54
PUFA	1.86	1.75	2.02	1.82	0.053	0.13
n-3	0.16	0.16	0.16	0.17	0.004	0.62
n-6	1.71	1.58	1.86	1.65	0.041	0.11
n-6/n-3	11.06	10.10	11.55	9.98	0.336	0.29

TDN, total digestible nutrients; SFA, saturated fatty acid; MUFA, mono-unsaturated fatty acid; PUFA, poly-unsaturated fatty acid.

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.

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