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Feeding strategies with total mixed ration and concentrate may improve feed intake and carcass quality of Hanwoo steers

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Abstract

This study examined the impact of using total mixed ration (TMR) and concentrate on feed intake, daily gain, carcass yield grade, and carcass quality grade of Hanwoo steers and its subsequent economic efficiency. Thirty six 7-month-old Hanwoo steers were assigned to one of the four treatment groups, and each group was divided into three repeated pens, with each repeated pen comprising three steers. The treatment groups were: 1) separate feeding with commercial concentrate and forage (namely, SCF) for the entire experimental period; 2) TMR feeding for a growing period followed by SCF for the early and late fattening period (namely, TMRGSCF); 3) TMR feeding for growing and an early fattening period followed by SCF for the late fattening period (namely, TMREFSCF); and 4) TMR feeding for the entire experimental period (namely, TMRW). The results showed that the SCF treatment had significantly ($p < 0.05$) higher feed intake during the growing period than other treatments. In contrast, the total feed intake had little difference during early and late fattening as well as the whole period regardless of feeding strategies. Daily gain showed no difference during the growing period. However, it was significantly higher in SCF and TMREFSCF treatments for the early and late fattening period, respectively ($p < 0.05$). The daily gain during the total raising period is in the order of TMREFSCF > TMRGSCF > SCF > TMRW. Carcass characteristics, including carcass weight, loin eye muscle area, and carcass yield grade, did not significantly differ among different treatments. However, TMRW treatment, wherein TMR was fed for a long time, showed that the cold carcass weight was less compared with other treatments, but carcass yield grade was higher with thinner backfat. Backfat thickness was in the order of SCF > TMRGSCF > TMREFSCF > TMRW, showing that the thickness reduced with longer TMR feeding ($p < 0.05$). TMRGSCF, which numerically had a higher carcass quality grade, showed higher economic efficiency, whereas SCF showed low economic efficiency. In conclusion, it was more feasible to apply TMR strategy in the growing and early fattening period and then SCF for the early or late fattening period to improve carcass yield, quality grade, and economic efficiency.

Keywords: Total mixed ration (TMR), Hanwoo, Carcass quality, Feed intake, Profits

Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: Lee S, Lee SM.
Data curation: Lee S, Lee SM, Lee J.
Formal analysis: Lee S, Lee SM, Lee J.
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Ethics approval and consent to participate
The experiment was conducted under the Korean Animal Protection Act (No. 8852), 2009.

INTRODUCTION

Total mixed ration (TMR) prepared by mixing all feed ingredients, including forages, concentrates, and feed additives, are necessary for the maintenance, milk and meat production of dairy cows. These are well documented in the article published by Schingoethe [1]. Such comparisons are often made with a system of feeding forages supplemented with concentrates [1]. TMR feeding is also beneficial to beef cattle; increasing feed intake and nutrient use efficiency compared with separate feeding of concentrates and forage (SCF) were noted [2,3]. Moreover, feed cost can be significantly reduced using the TMR-feeding strategy, as feed resources, including food to be discarded from human consumption, byproducts of food manufacturing and agricultural industry, and organic wastes, are used [4]. With increased dry matter (DM) intake, it was reported that if ruminants were fed with TMR, characteristics of the rumen such as ruminal pH and acetic acid/propionic acid (A/P) ratio were maintained at stable conditions, and feed efficiency was improved [2,5]. Kim et al. [6] and Kim et al. [7] reported that TMR feeding was adequate on growth and carcass quality grade when animals were fed during a late or whole fattening period, respectively. Moreover, Cho et al. [8] experimented for 10 months (during the late fattening period) by dividing the groups into three: the SCF-feeding group, TMR-feeding group, and TMR with the concentrate-feeding group. It was found that TMR with the concentrate-feeding group showed a higher carcass quality grade. They further suggested that TMR feeding results in a more significant daily gain compared with SCF despite its lower total digestible nutrients (TDN) content because feed intake increases with TMR feeding.

However, TMR, often containing a high moisture level, is easily spoiled due to secondary fermentation and mold development during summer, leading to decreased palatability [5]. In particular, Felton and DeVries [9] argued that an appropriate storage period depending on the ambient temperature is crucial, as TMR with high moisture content may affect the feeding behavior of dairy cows. Hence, feeding TMR with high moisture content (i.e., with silage) may require additional care during storage. Inconsistencies in TMR quality often result in poor or variable carcass qualities compared with that with SCF [2]. There is limited information on whether TMR feeding strategies provide any economic benefit to farmers in Korea.

In this study, the effect of the TMR-feeding strategy on growth performance, carcass characteristics, and economic efficiency was examined by dividing Hanwoo steers into the following groups: 1) feeding commercial concentrates and forage (timothy hay + tall fescue straw) (SCF); 2) feeding TMR for the growing period followed by SCF for the early and late fattening period (TMRGSCF); 3) feeding TMR for the growing and early fattening period and then SCF for the late fattening period (TMRGEFSCF); and 4) feeding TMR for the entire rearing period (TMRW) to develop a TMR-feeding strategy to produce high-quality Hanwoo meat.

MATERIALS AND METHODS

Animal ethics

The experiment was conducted under the Korean Animal Protection Act (No. 8852), 2009. Until recently, Kyungpook National University (KNU) Animal Ethics Board did not provide a certificate for an experiment outside the KNU; thus, we could not get a certificate at the time of this experiment (2012). Instead, we contacted the Animal and Plant Quarantine Agency in Gimcheon-si, Gyeongsangbuk-do, Korea, and were told that the experiment did not violate any regulation under the Korean Animal Protection Act (No. 8852). The animals were cared for and reared under the same management as a commercial farm, and a local and commercial animal rearing system

that routinely recommends a quality beef-producing program in Korea was followed. There was no physical harm to beef cattle throughout the experiment.

Experimental design and animals

The experiment was conducted from July 2012 to June 2014 for 24 months at Hyeongjae Farm located at Daedeok-myeon, Gimcheon-si, Gyeongsangbuk-do, Korea, to identify the impact of feeding strategy on feed intake and carcass characteristics of Hanwoo steers. Thirty six 7-month-old (body weight: 229 ± 3.9 kg) Hanwoo (*Bos taurus coreanae*) steers were used for this experiment. Four experimental treatments with different feeding strategies were established (see Table 1): 1) SCF, 2) TMRGSCF, 3) TMRGEFSCF, 4) TMRW. The area for rearing the experimental animals was 32 m^2 (4 m × 8 m) on a concrete floor with plenty of sawdust for animal welfare, and the steers were assigned to one of the four treatment groups. Each group was divided into three replicates, comprising of three cattle in each area (See Table 1). The animals were weighed at the beginning of the study and at the end of each growth stage, along with the dietary changes.

Experimental diets and feeding regime

As shown in Table 1, the SCF diet had a controlled feeding of concentrates regarding its amount per day and *ad libitum* forage intake during the growing (timothy hay) and early fattening periods (tall fescue hay), followed by *ad libitum* intake of concentrates and controlled feeding of forage during the late fattening period. This is a typified commercial feeding program in this region (Gyeongsangbuk-do, Korea). TMRGSCF treatment applied *ad libitum* intake of TMR and timothy hay during the growing period. Then, the same feeding strategy was applied as SCF treatment for the early and late fattening period. The TMRGEFSCF applied *ad libitum* intake of TMR during the growing and early fattening periods. Then, the same feeding strategy was applied for the late fattening period as SCF treatment. Steers offered TMRW treatment had TMR for the entire experimental period. The experimental diet was offered twice a day at 07:00 and 17:00, and freshwater was available via a water cup throughout the experiment. The feed ingredients and chemical composition of the commercial concentrates and TMR used for the study are presented in Tables 2 and 3.

Table 1. Experimental design and feeding strategies employed in this experiment (as-fed basis unless otherwise stated)

Items	Treatments											
	SCF			TMRGSCF			TMRGEFSCF			TMRW		
	G	EF	LF	G	EF	LF	G	EF	LF	G	EF	LF
Feeding strategies (kg/d)												
Concentrate	3–7	7–9	*Ad lib.*		7–9	*Ad lib.*			*Ad lib.*			
Timothy hay	*Ad lib.*			*Ad lib.*			*Ad lib.*			*Ad lib.*		
Tall fescue straw		*Ad lib.*	1–2		*Ad lib.*	1–2			1–2			
TMR				*Ad lib.*			*Ad lib.*	*Ad lib.*		*Ad lib.*	*Ad lib.*	*Ad lib.*
Number of steers per pen	3			3			3			3		
Number of replicates	3			3			3			3		
Total number of animals	9			9			9			9		
Pen size	4 m × 8 m			4 m × 8 m			4 m × 8 m			4 m × 8 m		

SCF, separate feeding of commercial concentrates and forage; TMRGSCF, feeding of TMR up to growing period and SCF from early up to the late fattening period; TMRGEFSCF, feeding of TMR from growing up to early fattening period and SCF up to the late fattening period; TMRW, feeding of TMR for the entire experimental period; G, 7–14 months of age in terms of growth stage, growing period; EF, 15–22 months of age in terms of growth stage, early fattening period; LF, 23–30 months of age in terms of growth stage, late fattening period; *Ad lib.*, *Ad libitum*; TMR, total mixed ration.

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Table 2. Feed ingredients of the commercial concentrates and the total mixed ration (TMR) used in this experiment (% of dry matter unless otherwise stated)

Feed ingredients	Concentrate			TMR		
	Growing	Early fattening	Late fattening	Growing	Early fattening	Late fattening
Corn grain	3.7	4.3	6.55	6.6	-	4
Wheat grain	32.5	21.9	20			
Wheat bran				9.2	8.2	2
Corn germ meal				-	-	8
Barley bran				4.2	4	4
Alfalfa pellet				2.1	2	2
Cracked whole barley				-	-	4
Yeast				0.8	0.8	0.8
Rice bran	4.1	3	3			
Corn gluten feed	20	15	14	17.4	16.1	13.2
Corn flour	7	7	7			
Palm kernel meal	10	3.5	-			
Copra meal	10	7	7			
Cottonseed hulls	2	3	4	2.1	2	2
Distillers stillage				18	17.5	17.4
Spent mushroom substrate				8.3	8.1	8
Whole cottonseed	-	-	3			
Alfalfa hay				2.5	-	-
Tall fescue straw				6.4	6.3	6.2
Annual ryegrass				7.9	8.9	7.6
Moisture				13.3	12.9	11.6
Soybean hulls	-	2.3	-			
Steamed flaked corn	-	25	25		12	8
Distiller's dried grains	-	-	2			
Salt	0.8	0.2	0.2			
Molasses	6.5	4.7	4.2			
Magnesium oxide (50%)	-	0.25	0.4			
Ammonium chloride	0.15	0.15	-			
Sodium bicarbonate	-	0.35	0.6			
Limestone	3.05	1.9	1.3	1.2	1.2	1.2
Soy oil	-	0.3	0.3			
Purified glycerin	-	-	1			
Hydrogenated fat	-	-	0.3			
Mineral, vitamin premix	0.2	0.15	0.15			
Total	100	100	100	100	100	100

Chemical analyses and calculation

Proximate analysis, including DM, organic matter (OM), crude protein (CP), ether extract (EE) of all feed materials, was conducted using the method of AOAC [10]. Acid detergent fiber and neutral detergent fiber (NDF) were determined following a method by Van Soest et al. [11]. Feed intake was calculated based on the difference between the feed provided and the remaining feed, and the remaining feed was collected before providing feed the following day and then measured. Body

Table 3. Chemical composition of experimental diets used in this experiment (% of dry matter unless otherwise stated)

Item	CP	EE	CF	CA	NFE	NDF	TDN
Concentrate (months of age)							
Growing period (7–14)	15.45	3.05	8.60	9.15	63.75	34.07	75.6
Early fattening period (15–22)	15.32	4.13	10.74	6.63	63.18	31.61	79.4
Late fattening period (23–30)	14.43	4.85	10.73	6.07	63.92	33.85	80.9
TMR (months of age)							
Growing period (7–14)	17.12	2.47	23.05	9.63	47.73	46.72	65.8
Early fattening period (15–22)	16.86	2.05	21.84	9.56	49.69	45.47	71.9
Late fattening period (23–30)	15.50	2.55	21.04	9.04	51.87	44.83	76.3
Timothy hay	10.66	2.0	32.70	7.97	46.67	58.25	61.5
Tall fescue hay	7.88	0.85	31.01	8.11	52.15	56.89	58.9

CP, crude protein; EE, ether extract; CF, crude fiber; CA, crude ash; NFE, nitrogen-free extracts; NDF, neutral detergent fiber; TDN, total digestible nutrients; TMR, total mixed ration.

weight gain was calculated by measuring body weight upon starting the experiment and during the growing, early fattening, and shipment period. The daily gain was calculated by dividing body weight gain by the number of rearing days.

Carcass quality grade analysis

Slaughtering was conducted at a commercial abattoir based on body weight, and carcass quality and quantity were graded following the Korean Institute for Animal Products Quality Evaluation [12]. This procedure included carcass index, backfat thickness, area of the *Longissimus dorsi*, and carcass index, which was calculated as follows:

$$\text{Carcass index} = 68.184 - [0.625 \times \text{back fat thickness (mm)}] + [0.130 \times \textit{longissimus dorsi} (\text{cm}^2)] + [0.024 \times \text{carcass weight (kg)}] + 3.23$$

Moreover, marbling score, meat color, fat color, meat texture, and meat maturity were scored based on the Korean Scoring System [12]. The feed cost was calculated using the amount in Table 6, and the Hanwoo sale price was based on cold carcass weight. Further, the price of the calf was calculated based on the average purchasing price at the beginning of the study.

Statistical analysis

Analysis of variance was conducted with the feeding strategy as the primary effect using the general linear model of the Statistical Analysis System (v.9.1) [13]. Multiple comparison analysis was performed using Duncan's multiple range test [14]. The significance of the treatment was tested at a 5% level.

RESULTS AND DISCUSSION

Feed intake and body weight gain

This study examined the effect of feeding strategies wherein some animals were fed concentrate and forage throughout the rearing period, including feedlot, whereas others were offered TMR during some stages of the animal's life. The idea of feeding concentrates with forage (primarily rice straw), or feeding TMR has been debated for a long time. Moreover, the concept of such a feeding regime is fundamental in Korea, as most feed ingredients are imported; therefore, producing high-

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quality beef and maximizing farming income is imperative for all farmers.

Table 4 presents the effect of feeding strategies on feed intake and body weight gain. During the growing period (7–14 months of age), the total feed intake was 1,554 kg for the SCF group, which was greater ($p < 0.05$) than that of the other experimental groups. Consequently, daily feed intake was higher ($p < 0.05$) in animals offered SCF than the rest of the treatments. However, there was no difference among the TMRGSCF, TMRGEFSCF, and TMRW treatment groups. Thus, daily weight gain was not different across the different treatment groups. These results are in accordance with reports by Jin et al. [15] and Chang et al. [16], wherein there was a difference in feed intake between TMR-based feeding and SCF during the growing period; however, there was no significant difference in body weight gain. Kim et al. [17] argued that compared with SCF feeding, feeding TMR or TMR with fermented feed during the growing period increased daily weight gain, as nutrient use efficiency was improved with fermentation in the rumen.

The feed intake during the early fattening period did not differ among the treatments groups; however, there was a difference in body weight ($p < 0.05$) and daily gain ($p < 0.05$). In particular, animals in the SCF group showed the highest weight gain (0.74 kg/d), whereas those in the TMRW group showed the lowest ($p < 0.05$). There was no significant difference among the treatments groups in terms of total and daily feed intake during the late fattening period. However, the TMRGEFSCF presented a higher ($p < 0.05$) daily gain than that of the other treatments groups. Over the entire experimental period, feed intake was not different; however, the TMRGEFSCF group required the least feed intake per 1 kg weight gain, whereas the TMRW group had the highest feed conversion ratio ($p < 0.05$). Kim et al. [6] reported that the TMR-feeding regime requires more feed compared with SCF-feeding regime to increase body weight. However, in studies by Cho et al. [18] and Kim et al. [17], TMR required less feed amount, which is contradictory to what was observed by Kim et al. [6].

To maximize beef cattle's genetic potential, especially with Hanwoo, regarding which a modern-day breeding program based on marbling and muscle mass is still ongoing, balanced nutrients should be supplied adequately during the right stage of growth. The importance of a balanced supply of nutrients is well documented in the literature [19]. Nevertheless, due to the ongoing breeding program [20,21] and the fundamental complexity of the metabolism of the rumen [22], it is challenging to estimate the requirement of nutrients and the responses of Hanwoo cattle compared with other well-known beef breeds such as Aberdeen-Angus or Japanese Black (Wagyu).

In the present study, with similar feed intakes across the treatments groups, feeding TMR during the growing period and early fattening period and finishing with SCF regime (TMRGEFSCF) caused greater overall daily gain and better feed conversion ratio than the other treatments. It is unclear what caused such differences; however, one reason may be associated with the supply of nutrients. Because of the numerical difference in the DM intake across the treatments, there were marginal differences in the supply of nutrients to animals in CP and TDN throughout the experiment. For example, steers of TMRGEFSCF were offered 1.1, 1.5, and 1.2 kg CP/d and 4.5, 6.5, and 7.1 kg TDN/d during the growing, early, and late fattening periods, respectively. This can be performed by a simple calculation based on the chemical composition of the diets, feed intake, and feeding days presented in Tables 3 and 4. Therefore, SCF and TMRGSCF steer consumed 1.14 and 1.19 kg CP/d, whereas the TMRGEFSCF and TMRW animals consumed 1.52 kg CP/d on average. Likewise, the TMRW group consumed 200 g more CP/d compared with the other treatment groups during the late fattening period (1.41 vs. 1.21 for TMRW and other treatment groups, respectively). Such difference may be partly responsible for the growth of steers during the experiment, along with dietary changes. Schroeder and Titgemeyer [19] suggested that energy supply impacts the efficiency of protein utilization. In this study, energy supply, expressed in the

Table 4. Effect of feeding strategies on animal performance of Hanwoo steers

Growth stage (months of age)	Item	Treatment			
		SCF	TMRGSCF	TMRGEFSCF	TMRW
Growing period (7–14)	Days on feeding (d)	203	203	203	203
	Total feed intake (kg)	1,554±30.5[a]	1,413±59.9[b]	1,383±61.7[b]	1,377±76.5[b]
	Concentrate (kg)	995±0.6	-	-	-
	TMR (kg)	-	1,351±59.9	1,321±61.7	1,315±76.5
	Tall fescue (kg)	-	-	-	-
	Timothy (kg)	559±30.0	62±0.0	62±0.0	62±0.0
	Daily feed intake (kg/d)	7.66±0.15[a]	6.96±0.29[b]	6.81±0.30[b]	6.78±0.38[b]
	Initial body weight (kg)	228±5.2	229±3.6	229±2.3	229±4.6
	Final body weight (kg)	394±10.7	405±3.6	403±6.9	401±8.1
	Body weight gain (kg)	166±5.7	177±2.5	173±5.8	172±5.8
	Daily gain (kg/d)	0.82±0.03	0.87±0.02	0.85±0.03	0.84±0.03
Early fattening period (15–22)	Days on feeding (d)	242	242	242	242
	Total feed intake (kg)	2,026±176.7	2,116±85.3	2,187±91.7	2,175±68.8
	Concentrate (kg)	1,549±165.6	1,638±75.5	-	-
	TMR (kg)	-	-	2,187±91.7	2,175±68.8
	Tall fescue (kg)	477±23.0	478±10.4	-	-
	Timothy (kg)	-	-	-	-
	Daily feed intake (kg/d)	8.37±0.73	8.74±0.35	9.04±0.38	8.99±0.28
	Initial body weight (kg)	394±10.7	405±3.6	403±6.9	401±8.1
	Final body weight (kg)	573±23.1	582±11.5	564±3.1	543±14.1
	Body weight gain (kg)	180±20.1[a]	177±13.1[a]	161±7.0[ab]	143±11.7[b]
	Daily gain (kg/d)	0.74±0.10[a]	0.73±0.05[a]	0.66±0.03[ab]	0.59±0.05[b]
Late fattening period (23–30)	Days on feeding (d)	259	259	259	259
	Total feed intake (kg)	2,298±71.4	2,280±149.8	2,371±76.7	2,352±118.2
	Concentrate (kg)	1,981±71.4	1,963±149.8	2,054±76.7	-
	TMR (kg)	-	-	-	2,352±118.2
	Tall fescue (kg)	317±0.0	317±0.0	317±0.0	-
	Timothy (kg)	-	-	-	-
	Daily feed intake (kg/d)	8.87±0.28	8.80±0.58	9.15±0.30	9.08±0.46
	Initial body weight (kg)	573±23.1	582±11.5	564±3.1	543±14.1
	Final body weight (kg)	725±23.0[a]	726±27.1[a]	751±12.5[a]	676±13.3[b]
	Body weight gain (kg)	152±14.7[b]	145±16.2[b]	187±10.8[a]	132±7.0[b]
	Daily gain (kg/d)	0.59±0.06[b]	0.56±0.07[b]	0.72±0.04[a]	0.51±0.03[b]
Overall (7–30)	Days on feeding (d)	704	704	704	704
	Total feed intake (kg)	5,878±90.9	5,809±201.7	5,941±186.0	5,904±166.3
	Concentrate (kg)	4,526±101.7	3,601±224.0	2,054±76.7	-
	TMR (kg)	-	1,351±59.9	3,508±119.1	5,842±166.3
	Tall fescue (kg)	794±23.0	795±10.4	317±0.0	-
	Timothy (kg)	559±30.0	62.0±0.0	62.0±0.0	62.0±0.0
	Initial body weight (kg)	228±5.2	229±3.6	229±2.3	229±4.6
	Final body weight (kg)	725±23.0[a]	726±27.1[a]	751±12.5[a]	676±13.3[b]
	Body weight gain (kg)	497±18.8[a]	498±26.1[a]	520±14.6[a]	447±17.6[b]
	Daily gain (kg/d)	0.71±0.03[a]	0.71±0.03[a]	0.74±0.02[a]	0.63±0.02[b]
	Feed / Gain (kg/kg)	11.8±0.2[b]	11.7±0.4[b]	11.4±0.4[b]	13.2±0.4[a]

[a,b]Means in the same row with different superscripts are significantly different at $p < 0.05$.

SCF, separate feeding of commercial concentrates and forage; TMRGSCF, feeding of TMR up to growing period and SCF from early up to the late fattening period; TMRGEFSCF, feeding of TMR from growing up to early fattening period and SCF up to the late fattening period; TMRW, feeding of TMR for the entire experimental period; TMR, total mixed ration.

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form of TDN was numerically higher in SCF (4396 kg for the period) than in the TMRW (4262 kg for the period), whereas the CP supply followed an opposite trend (i.e., 799 kg vs. 963 kg for the SCF and TMRW, respectively). Such discrepancy could cause an imbalance in the supply of energy and protein to the rumen and the animal [23–25], resulting in lower daily gain and a higher feed conversion ratio (see Table 4).

It is interesting to note that animals in the SCF, TMRGSCF, and TMRGEFSCF treatment groups grew faster ($p < 0.05$) than those in the TMRW groups (Table 4), even if the animals in the TMRW group consumed more CP compared with the others. Numerous reports have described the advantages of TMR for ruminants [2,5,17]. This is often associated with stable rumen metabolism by pH, ammonia-N, and stable VFA production compared with that due to SCF. Nevertheless, steers finished with the SCF (i.e., TMRGEFSCF group) had a more significant daily gain with a better feed conversion ratio. This study indicated that a way to minimize the daily feed intake and maximize daily body weight gain was to offer TMR from the growing to early fattening period and SCF for the late fattening period for Hanwoo steers.

Carcass quality and grade

The effect of the feeding strategies on carcass characteristics and quality grade of Hanwoo steers is presented in Table 5. Carcass weight was numerically higher in the TMREFSCF group than in other treatment groups without any significant differences. Cho et al. [8] observed lower carcass weight after TMR feeding for 10 months during the late fattening period than that of the SCF group. In contrast, Jin et al. [15] reported that feeding barley silage-based- or rye silage-based-TMR from the growing to late fattening period resulted in higher carcass weight than the SCF group. Our results are in accordance with the findings of Cho et al. [8]. Discrepancies between studies are attributable to several factors, yet ingredients and chemical composition of TMR are variable across the studies. For example, the CP content of TMR used in this study ranged from 15.50% to 17.12%, whereas the CP content of TMR from Cho et al. [8] ranged from 12.11% to

Table 5. Effect of feeding strategies on carcass characteristics of Hanwoo steers

Item	Treatments			
	SCF	TMRGSCF	TMRGEFSCF	TMRW
Carcass traits				
Cold carcass weight (kg)	428.3±28.6^{ns}	428.7±28.0	442.7±13.5	399.0±13.5
Backfat thickness (mm)	19.3±3.2^{a}	17.3±5.1^{ab}	12.3±1.4^{bc}	10.1±1.9^{c}
Longissimus muscle area (cm^2)	93.3±7.8^{ns}	105.3±9.3	102.7±5.0	98.33±8.5
Yield grade[1)]	1.4±0.4^{ns}	2.0±0.9	2.2±0.2	2.7±0.0
Quality traits[2)]				
Marbling score	6.3±2.1^{ns}	7.5±1.1	6.1±0.7	7.1±1.0
Meat color	4.6±0.7^{ns}	4.5±0.2	5.0±0.0	4.9±0.2
Fat color	3.0±0.0^{ns}	3.0±0.0	3.0±0.0	3.0±0.0
Texture	1.0±0.0^{ns}	1.1±0.2	1.1±0.2	1.1±0.2
Maturity	2.0±0.0^{ns}	2.0±0.0	2.0±0.0	2.0±0.0
Quality grade	3.8±1.0^{ns}	4.6±0.5	3.8±0.4	4.2±0.5

[1)]1, C grade; 2, B grade; 3, A grade.

[2)]Marbling score, 1 (devoid) to 9 (abundant); Meat color, 1 (dark red) to 7 (bright red); Fat color, 1 (white) to 7 (yellow); Texture, 1 (good) to 3 (bad); Maturity, 1 (fine) to 3 (coarse); Quality grade, 1^{++} grade = 5 (best), 1^{+} grade = 4, 1 grade = 3, 2 grade = 2, 3 grade = 1 (poor).

SCF, separate feeding of commercial concentrates and forage; TMRGSCF, feeding of TMR up to growing period and SCF from early up to the late fattening period; TMRGEFSCF, feeding of TMR from growing up to early fattening period and SCF up to the late fattening period; TMRW, feeding of TMR for the entire experimental period; ns, not significant; TMR, total mixed ration.

13.36%. Due to inconsistencies in TMR ingredients, it is inappropriate to compare several studies in the literature. Concerning TMR, such a discrepancy may be problematic in standardizing TMR quality. Hanwoo farmers in Korea argue that inconsistencies in TMR quality may result in various carcass qualities. However, backfat thickness was substantially greater ($p < 0.05$) in the SCF group than in the TMRW group, suggesting that long-term feeding of TMR results in less lipid accretion subcutaneously ($p < 0.05$). Backfat thickness is vital for evaluating meat quality in several meat-grading systems globally [12].

Backfat thickness in the SCF group was unexpected because a concentrate-based feeding system is more efficient regarding energy and protein use in domestic production of ruminant compared with a forage-based feeding system, producing less fatty carcass [25,26]. What was noticeable was in feeding concentrate and rice straw during the growing period. Such a feeding strategy may explain energy balance and protein supply discrepancies because energy is provided by readily available carbohydrates, such as starch. However, rice straw may not provide any relevant protein as it lacks any nutrients. Indeed, Steen et al. [27] reported that feeding high-concentrate and barley straw *ad libitum* produced fattier carcasses (39% more fat gain) than a pasture-based production system when the Charolais cross was used as the experimental animal.

Backfat thickness was in the order of SCF > TMRGSCF > TMREFSCF > TMRW, showing that long-term feeding of TMR resulted in thinner back fat ($p < 0.05$). These results are similar to the results from studies conducted by Cho et al. [8] and Kim et al. [7] but different from those by Kim et al. [6] and Jin et al. [15]. The effect of feeding TMR on the backfat thickness is not uniform, as discussed above, due to variations in the nutrient composition of TMR diets. Therefore, standardization of TMR regarding chemical composition and possibly physical properties is needed for broader use in the Hanwoo industry in Korea for beef production. The quality traits determined at postmortem, including marbling score, meat color, fat color, maturity, and quality grade, were not different among the treatments groups.

Based on these experimental results, combining TMR and SCF feeding strategy would improve carcass traits, especially the loin eye muscle area. However, caution needs to be taken as the carcass yield and quality grade vary depending on the mixing ratio of forage with concentrates and ingredients of TMR feed [2,28,29].

Analysis of economic efficiency

An analysis of the economic efficiency of TMR-feeding strategies is presented in Table 6. Total feed cost was the lowest for the TMRW group and highest for the SCF-feeding group. The difference between the two was 142,150 won (Korean currency). Paek et al. [30] argued that feed cost depends on the TDN contents, and Kim et al. [7] stated that the TMR-feeding strategy requires > 29% higher feed cost than the SCF-feeding strategy, as feed intake increases with TMR-feeding. Kwak et al. [31] stated that TMR using agricultural byproducts could reduce the feed cost by 30%–44% compared with SCF. This study did not present much difference in feed cost among treatment groups because the TDN content was high in TMR feed. The ingredients sourced were not from agricultural byproducts but from the commercial sector.

The carcass price was in the order of TMRGSCF > TMREFSCF > TMRW > SCF. The TMRGSCF group had the highest carcass price because the auction price was high due to the wide loin eye muscle area and high-quality carcass grade (Table 6). Kim et al. [7] also reported that the TMR-feeding strategy produced high economic efficiency, as the strategy resulted in a higher rate of *Longissimus dorsi* and grade 1 than the SCF-feeding strategy. The TMRGSCF feeding group, which showed the highest carcass quality grade, had the highest profit, and the SCF-feeding group, which showed the lowest carcass quality grade, had the lowest profit. The income relative index was

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Table 6. Effect of feeding strategies on estimated profits for Hanwoo steers

	Treatments			
	SCF	TMRGSCF	TMRGEFSCF	TMRW
Concentrate cost (won)[1)]	2,830,531	2,280,111	1,322,776	-
Forage cost (won)[2)]	649,320	346,342	160,878	37,882
TMR cost (won)[3)]	-	753,858	1,957,297	3,299,819
Total feed cost (won)	3,479,851	3,380,311	3,440,951	3,337,701
Cold carcass weight (kg)	428	429	443	399
Cold carcass price (won/kg)	15,452	17,680	16,538	17622
Income, carcass (won/head)	6,628,092	7,579,416	7,321,373	7,031,178
Calf price (won)	2,050,000	2,050,000	2,050,000	2,050,000
Income [B − (A + C)] (won)[4)]	1,098,241	2,149,105	1,830,422	1,643,477
Income relative index (%)	100	196	167	150

Won, Korean currency (1 USD was equal to ~1,100 Korean won at the time of study in 2012).

[1)]A unit cost: 597, 620 and 644 Korean won/kg, as-fed for the feed of growing, early fattening, and late fattening period, respectively.

[2)]A unit cost: 388 and 611 Korean won/kg as-fed for tall fescue straw and timothy hay, respectively.

[3)]A unit cost: 558, 558, and 575 Korean won/kg as-fed for feed of growing period, early fattening and late fattening period, respectively.

[4)]A, total feed cost; B, income, carcass; C, calf price.

Feed cost and calf purchasing cost were reflected with the cost during the whole experiment.

SCF, separate feeding of commercial concentrates and forage; TMRGSCF, feeding of TMR up to growing period and SCF from early up to the late fattening period; TMRGEFSCF, feeding of TMR from growing up to early fattening period and SCF up to the late fattening period; TMRW, feeding of TMR for the entire experimental period; TMR, total mixed ration.

higher in the TMRGSCF, TMREFSCF, and TMRW groups, where TMR feeding is provided by 96%, 67%, and 50%, respectively, than the SCF group. In particular, TMRGSCF, wherein TMR feeding was provided for a short-term, showed a high relative profit.

CONCLUSION

This study examined the effect of feeding strategies: 1) SCF, 2) TMRGSCF, 3) TMRGEFSCF, 4) TMRW. In summary, applying the TMR diet during the growing period and up until the early fattening period and then finishing with concentrate and forage produced better quality carcass in Hanwoo steers. Thus, with this strategy, farmers would get a better economic return. However, care must be taken to interpret the outcome from the animal as the quality of TMR diets varies to a great extent. Nevertheless, countries such as Korea, where feed resources are limited and dependent on imported ones, should consider TMR for their indigenous breed, Hanwoo.

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