RESEARCH ARTICLE

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# Effect of short-term fattening period and castration method on productivity, serum testosterone, and economic efficacy in Hanwoo cattle

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## Abstract

The purpose of this study was to evaluate the effects of castration method and short-term fattening periods on Hanwoo cattle. Thirty-two Hanwoo calves (average body weight: 148.4 ± 19.8 kg) were used. The calves were randomly assigned in a 2 × 2 factor according to two castration methods (castration or hemi-castration) and two short-term finishing periods (24 months or 26 months). The final body weight increased significantly as the fattening period increased ($p < 0.05$), and the average daily weight gain was higher in the hemi-castration groups than in the castration groups ($p < 0.05$). After surgical castration, testosterone concentration was higher in the hemi-castration group than in the castration group during the entire experimental period ($p < 0.05$). The rib eye area was wider in the hemi-castration group than in the castration group ($p < 0.01$).An interaction effect was observed between the castration method and short-term fattening period ($p < 0.05$). Marbling and auction price scores differed between castration methods and were higher in the castration group than in the hemi-castration group ($p < 0.01$). Gross receipts and net income increased in the castration group compared to the hemi-castration group ($p < 0.01$) and showed a tendency to increase with the short-term fattening period, but there was no significant difference. Thus, castration to remove both testicles is essential for economic profit through producing high-quality Korean beef meat, and short-term fattening for 26 months, rather than 24 months, can benefit more by increasing carcass weight and meat quality.

**Keywords:** Short-term fattening, Testosterone, Hemi-castration, Hanwoo, Net income

## INTRODUCTION

The Hanwoo beef industry applies a fattening program to produce high-quality meat, and castration is essential for bulls. The fattening period can be divided into long-term fattening (> 30 months) and short-term fattening (< 26 months). Long-term fattening can improve meat quality (intramuscular

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

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**Ethics approval and consent to participate**
This study was reviewed and approved by the operating regulations of the Institutional Animal Care and Use Committee of the National Institute of Animal Science (NIAS-20181355), and the management and experimental procedures of the experiment animals complied with the regulations of the Institutional Animal Care and Use Committee.

fat); however, at the same time, it has disadvantages due to decreased feed efficiency and increased production cost. As the fattening period increases, the average daily gain (ADG) may decrease, and the accumulation of inedible fat may increase, reducing carcass quality [1,2]. In some studies, the appropriate slaughtering age for Korean cattle is estimated to be less than 28 months [3,4]. However, 64% of steers slaughtered in Korea are more than 30 months old [5]. The need to shorten the fattening period has emerged from various viewpoints, such as consumption trends, greenhouse gas reduction, and reduction of production costs.

Testosterone is a representative androgen hormone, and the testis secretes more than 90%. It plays an important role in secondary sexual characteristics and muscle development [6,7]. However, since it has a negative effect on fat development, most Hanwoo bulls are castrated (5–8 months of age) before sexual maturation. Castration is a fattening technique that removes the testis, thereby reducing testosterone and improving intramuscular fat. The castration rate of Hanwoo bulls is over 97% [5]. However, in castrated cattle, the feed efficiency is reduced, and the urethra is not sufficiently developed [8]. The probability of diseases such as urolithiasis increases and the meat quality is reduced due to excessive inedible fat. Conversely, although bulls are superior in feed efficiency and weight gain compared to steers, they are less economical because the carcass price and profitability are low due to the reduced formation of intramuscular fat [9]. To solve this problem, we hypothesized that hemi-castration, in which only one testicle is removed, will result in an appropriate testosterone level to compensate for the shortcomings of castration and non-castration to improve weight gain and intramuscular fat at the same time.

Therefore, this study investigated the growth performance, serum testosterone, sirloin ultrasound, carcass characteristics, and economic efficiency of Hanwoo cattle using a combination of the short-term fattening period and castration methods.

## MATERIALS AND METHODS

### Animals, treatments, and management

Thirty-two Hanwoo calves (average body weight: 148.4 ± 19.8 kg) were used. The calves were randomly assigned in a 2 × 2 factor according to two castration methods (castration and hemi-castration) and two short-term finishing periods (24 and 26 months). Calves were surgically castrated at 7 months of age. Calves were allocated 4 heads per pen (4 × 8 m) and were managed separately for the growing period (6–14 months) and the finishing period (15–24/26 months).

Formula feed (3.0–7.5 kg) and italian ryegrass hay (3.0–4.0 kg) fed during the growing period, and formula feed (8.0–9.5 kg) and rice straw (1.0–3.0 kg) were fed during the fattening period.

Feeds were provided twice daily (AM 8:00, PM 17:00), and water was freely available. The ingredients and chemical compositions of the experimental diets are shown in Table 1.

### Growth performance

Body weight was measured once a month from the start of the test using a cattle weighbridge installed in the feedlot. The ADG was calculated by dividing the weight gain by the number of feeding days. The dry matter intake (DMI) was calculated by the difference between the feed provided amount and the residual amount, and was investigated every day. The feed conversion ratio (FCR) was calculated by dividing DMI by ADG.

### Blood collection and testosterone analysis

Blood was collected at monthly intervals for analysis of testosterone concentrations. Before the morning feeding, the animals were fixed in a frame, and 10 mL was collected from the jugular vein


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**Table 1.** Ingredient and chemical composition of the experimental diets

| Item | Formula feed | | Roughage | |
|---|---|---|---|---|
| | Growing | Fattening | Italian ryegrass | Rice straw |
| Ingredient composition (%) | | | | |
| Corn grain | 24.90 | 43.70 | - | - |
| Wheat grain | 8.00 | 7.00 | - | - |
| Rice | - | 2.00 | - | - |
| Cane molasses | 3.00 | 3.60 | - | - |
| Wheat flour | - | 1.50 | - | - |
| Wheat bran | 6.90 | 3.00 | - | - |
| Corn gluten feed | 21.00 | 11.00 | - | - |
| Soybean Meal | 5.20 | 10.40 | - | - |
| Coconut meal | 3.00 | - | - | - |
| Palm kernel meal | 12.00 | 6.00 | - | - |
| Corn-DDGS | 8.00 | 2.60 | - | - |
| Lupin flake | 3.00 | 2.00 | - | - |
| Cottonseed | - | 3.00 | - | - |
| Protected fat | - | 0.40 | - | - |
| Salt dehydrate | 0.60 | 0.70 | - | - |
| Limestone | 2.90 | 1.90 | - | - |
| Sodium bicarbonate | 0.30 | 0.70 | - | - |
| MSG-CMS | 0.50 | - | - | - |
| Vitamin premix[1)] | 0.10 | 0.10 | - | - |
| Mineral premix[2)] | 0.10 | 0.10 | - | - |
| Feed additives | 0.50 | 0.30 | - | - |
| Chemical composition (%) | | | | |
| Dry matter | 88.06 | 86.97 | 84.64 | 91.64 |
| Crude protein | 16.02 | 14.50 | 10.38 | 4.73 |
| Ether extract | 4.37 | 4.38 | 2.79 | 2.29 |
| Crude ash | 6.52 | 5.88 | 6.45 | 12.59 |
| Neutral detergent fiber | 29.32 | 17.45 | 56.09 | 63.19 |
| Acid detergent fiber | 13.29 | 7.56 | 31.20 | 36.78 |

[1)]Vitamin premix provided the following quantities of vitamins per kilogram of the diet: vitamin A, 10,000 IU; vitamin $D_3$, 1500 IU; vitamin E, 25 IU.

[2)]Mineral premix provided the following quantities of minerals per kilogram of the diet: Fe, 50 mg; Cu, 7 mg; Zn, 30 mg; Mn, 24 mg; I, 0.6 mg; Co, 0.15 mg; Se, 0.15 mg.

Corn-DDGS, corn dried distill's grains with solubles; MSG-CMS, condensed molasses soluble-mono sodium glutamate.

through a syringe (18-gauge needle). Blood was placed in a vacuum serum tube, stabilized at 4℃ for 12 h, and then centrifuged (1,250×g for 20 min) to collect the supernatant (serum).

Testosterone was analyzed using a bovine ELISA kit (CSB-E13194B, CUSABIO, Houston, TX, USA). Fifty microliters of serum were added to each well of the microtiter plate (pre-coated with goat-anti-rabbit antibody), to which 50 μL of horseradish peroxidase (HRP)-conjugate and antibody were added. The mixture was then incubated at 37℃ for 1 h. Each well was aspirated and washed thrice with wash buffer (200 μL). Fifty microliters of substrate A and fifty microliters of substrate B were added to each well and incubated at 37℃ for 15 min. Then, 50 μL of stop solution was added to each well. The optical densities were determined within 10 min using a microplate reader set to 450 nm.

### *Longissimus dorsi* ultrasound

*Longissimus dorsi* ultrasound was performed from 20 months of age to before slaughter at intervals of 2 months. The transverse section between the 13th thoracic and 1st lumbar vertebra was captured using an ultrasound diagnostic machine. Back fat thickness, rib eye area, and marbling score were determined using the Nonghyup Korean beef ultrasound meat quality diagnosis estimation program.

### Carcass characteristics

All animals were slaughtered at the slaughterhouse at either 24 or 26 months depending on the short-term fattening period. After the carcass was chilled in a refrigerator at 4℃ for 24 h, carcass weight was measured. Yield grades (A, B, and C) and quality grades ($1^{++}$, $1^{+}$, 1, 2, and 3) of carcasses were evaluated with the Korean carcass grading system [10]. The auction price was determined as the final contract price after the yield and quality of carcass were evaluated.

### Economic analysis

A partial budget analysis was conducted to evaluate the economic ramifications of the short-term fattening period and the castration method. Gross receipts were determined based on the selling price per carcass and product. The operating costs were calculated by adding the feed costs and other costs. Feed costs include commercial concentrate and roughage costs. Other cost includes water, power and fuel, veterinary and medicine, automobile, farm implements, farm building and facilities, miscellaneous materials, interest on borrowed capital, land rent, hired labor, excretion disposal, and production management costs as provided by the Livestock Production Cost Survey [11]. Net income was calculated as gross receipts minus operating costs.

### Statistical analysis

The experiment was conducted using a 2 (castration method: castration vs. hemi-castration) × 2 (short-term finishing period: 24 months vs. 26 months) factorial design. The growth performance, sirloin ultrasound traits, carcass traits, and economics were analyzed using PROC MIXED of SAS 9.3 (SAS Institute, Cary, NC, USA). Serum testosterone levels for each month were analyzed individually using the PROC ANOVA in SAS. When the $p$ value was less than 0.05, the post-test was performed using Tukey's test, and differences between treatments were considered significant at $p < 0.05$.

## RESULTS

### Growth performance

A comparison of growth performance according to the short-term fattening period and castration method for Hanwoo cattle is shown in Table 2. The final body weight increased significantly as the fattening period increased ($p = 0.019$), and and tended to be higher in the hemi-castration groups than in the castration groups ($p = 0.070$). ADG ($p = 0.038$) and feed intake ($p = 0.016$) were affected by the castration method and were higher in the hemi-castration groups than in the castration groups. FCR was not affected by castration method ($p = 0.142$) or short-term fattening period ($p = 0.283$).

### Serum testosterone

The changes in serum testosterone concentrations according to the short-term fattening period and castration method of Hanwoo cattle are shown in Fig. 1. Testosterone concentration did not


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**Table 2. Comparison of growth performance according to short-term fattening period and castration method in Hanwoo**

| Item | Castration | | Hemi-castration | | SEM | *p*-value | | |
|---|---|---|---|---|---|---|---|---|
| | 24 months | 26 months | 24 months | 26 months | | CM | SFP | CM × SFP |
| Initial body weight (kg) | 149.33 | 149.38 | 147.53 | 147.25 | 3.503 | 0.808 | 0.977 | 0.967 |
| Final body weight (kg) | 680.80 | 729.25 | 716.00 | 749.63 | 10.603 | 0.070 | 0.019 | 0.413 |
| Average daily gain | 0.93 | 0.93 | 1.00 | 0.96 | 0.015 | 0.038 | 0.701 | 0.288 |
| Feed intakes (DM/kg) | 8.43 | 8.44 | 8.53 | 8.55 | 0.022 | 0.016 | 0.703 | 0.988 |
| Formula feed | 6.37 | 6.49 | 6.44 | 6.57 | 0.017 | 0.005 | 0.001 | 0.838 |
| Roughage | 2.06 | 1.95 | 2.09 | 1.98 | 0.021 | 0.399 | 0.010 | 0.950 |
| Feed conversion ratio | 9.75 | 10.04 | 9.10 | 9.98 | 0.230 | 0.142 | 0.283 | 0.183 |

CM, castration method; SFP, short-term fattening period.

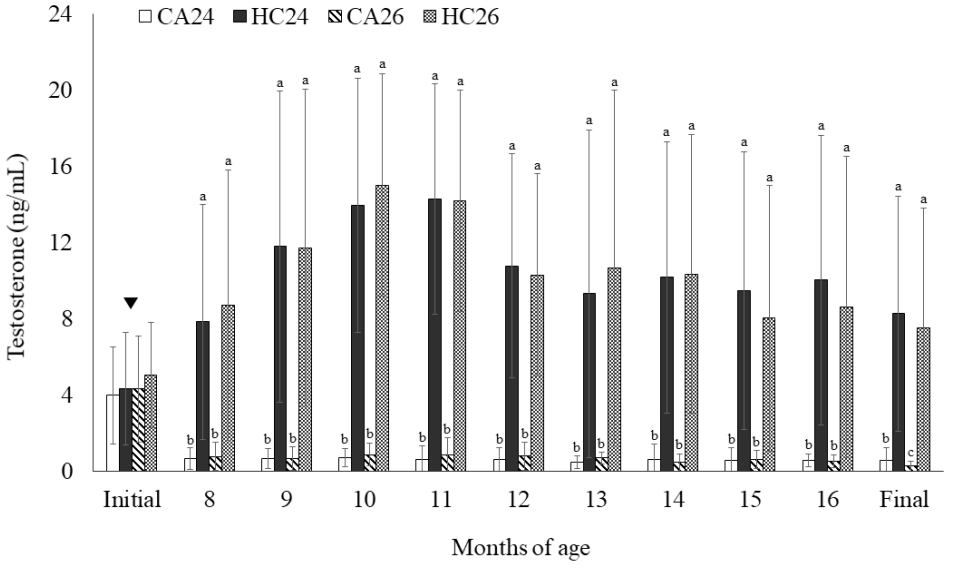


**Fig. 1. Changes of serum testosterone concentration on before and after castration according to castration method (castration: CA, hemi-castration: HC) and short-term fattening period (24 months: 24, 26 months: 26) in Hanwoo (mean ± SD).** Castration (▼) was performed at seven months of age. [a–c]Means with difference superscripts in the same row are significantly different ($p < 0.05$).

differ between the groups treated before castration; however, after surgical castration, there was a significant difference according to the castration method ($p < 0.05$). In particular, in the castration group, testosterone concentration rapidly decreased to 0.25–0.86 ng/mL after surgical castration. In contrast, in the hemi-castration group, testosterone concentration continued to increase until 10–11 months after surgical castration. Even after that, the concentration was higher than in the castration group ($p < 0.05$). The testosterone concentrations in the hemi-castration group ranged from 7.51–15.10 ng/mL.

## *Longissimus dorsi* ultrasound

The changes in *longissimus dorsi* ultrasound according to the short-term fattening period and castration method of Hanwoo cattle are shown in Table 3. Ultrasound back fat thickness was affected by the castration method ($p < 0.001$). It was thicker in the castrated group than in the hemi-castrated group during the entire measurement period (20–26 months). The ultrasound rib eye area was found to be at a similar level between treatments, regardless of the castration method

**Table 3.** Comparison of sirloin ultrasound traits according to short-term fattening period and castration method in Hanwoo

| Item | Months | Castration | | Hemi-castration | | SEM | *p*-value | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 24 months | 26 months | 24 months | 26 months | | CM | SFP | CM × SFP |
| Back fat thickness (mm) | | | | | | | | | |
| | 20 | 8.70 | 7.25 | 4.41 | 4.63 | 0.577 | 0.001 | 0.107 | 0.040 |
| | 22 | 9.60 | 8.63 | 5.21 | 5.81 | 0.605 | 0.001 | 0.612 | 0.089 |
| | 24 | 10.80 | 9.38 | 5.38 | 5.94 | 0.666 | 0.001 | 0.257 | 0.025 |
| | 26 | - | 11.00 | - | 6.56 | 0.884 | 0.001 | - | - |
| Rib eye area ($cm^2$) | | | | | | | | | |
| | 20 | 93.40 | 93.38 | 92.94 | 91.13 | 0.961 | 0.778 | 0.385 | 0.399 |
| | 22 | 98.73 | 98.88 | 99.12 | 98.00 | 1.074 | 0.884 | 0.691 | 0.596 |
| | 24 | 102.27 | 103.13 | 102.29 | 100.88 | 1.062 | 0.996 | 0.850 | 0.313 |
| | 26 | - | 106.00 | - | 102.25 | 1.440 | 0.815 | - | - |
| Marbling score | | | | | | | | | |
| | 20 | 3.07 | 3.13 | 1.41 | 1.63 | 0.217 | 0.001 | 0.432 | 0.678 |
| | 22 | 3.60 | 3.50 | 1.41 | 1.63 | 0.265 | 0.001 | 0.802 | 0.415 |
| | 24 | 3.93 | 3.75 | 1.47 | 1.75 | 0.294 | 0.001 | 0.867 | 0.259 |
| | 26 | - | 4.38 | - | 1.75 | 0.520 | 0.001 | - | - |

CM, castration method; SFP, short-term fattening period.

and short-term fattening period ($p > 0.05$). The ultrasound marbling score was significantly higher in the castration groups than in the hemi-castration groups ($p < 0.001$), regardless of the short-term fattening period. The hemi-castration groups showed little change in the marbling score as age increased, but the marbling score of the castration groups increased continuously.

## Carcass characteristics

A comparison of carcass traits according to the short-term fattening period and castration method for Hanwoo cattle is shown in Table 4. Carcass weight was not affected by the castration method ($p = 0.291$) but showed a tendency to increase as the short-term fattening period increased ($p = 0.105$). The rib eye area was not affected by the short-term fattening period ($p = 0.263$) but was found to be wider in the hemi-castration group than in the castration group ($p < 0.002$). In addition, a correlation was observed between the castration method and the short-term fattening period ($p < 0.05$). The back fat thickness was greater in the castration group than in the hemi-castration group because of the effect of the castration method ($p < 0.001$). The yield index was higher in the hemi-castration group than in the castration group ($p < 0.001$), and there was a correlation between the castration method and the short-term fattening period ($p = 0.009$). Marbling and quality grade scores differed according to the castration method and improved in the castration group compared to the hemi-castration group ($p < 0.001$). Conversely, meat color and texture were higher in the hemi-castration group than in the castration group ($p < 0.001$). There was no correlation between the castration method and the short-term fattening period on quality traits. The auction price was higher in the castration group than in the hemi-castration group due to the effect of the castration method ($p < 0.001$).

## Economic analysis

A comparison of the economic analysis according to the short-term fattening period and castration method of Hanwoo cattle is shown in Table 5. Gross receipts increased in the castration group compared to the hemi-castration group ($p < 0.001$). They tended to increase as the short-term


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**Table 4.** Comparison of carcass traits according to short-term fattening period and castration method in Hanwoo

| Item | Castration | | Hemi-castration | | SEM | *p*-value | | |
|---|---|---|---|---|---|---|---|---|
| | 24 months | 26 months | 24 months | 26 months | | CM | SFP | CM × SFP |
| Yield traits | | | | | | | | |
| Carcass weight (kg) | 406.00 | 435.50 | 427.78 | 441.50 | 6.525 | 0.291 | 0.105 | 0.546 |
| Rib eye area ($cm^2$) | 84.14 | 94.00 | 101.22 | 98.50 | 1.864 | 0.002 | 0.263 | 0.050 |
| Back fat thickness (mm) | 16.71 | 14.00 | 6.78 | 7.88 | 0.896 | 0.001 | 0.459 | 0.088 |
| Yield index | 60.26 | 62.46 | 67.58 | 66.77 | 0.594 | 0.001 | 0.207 | 0.009 |
| Yield grade score[1)] | 1.57 | 2.13 | 2.11 | 2.00 | 0.123 | 0.429 | 0.521 | 0.091 |
| Quality traits | | | | | | | | |
| Marbling score | 5.00 | 5.50 | 1.67 | 1.75 | 0.446 | 0.001 | 0.660 | 0.753 |
| Meat color | 4.57 | 4.38 | 5.56 | 5.38 | 0.149 | 0.001 | 0.454 | 0.975 |
| Fat color | 3.14 | 3.25 | 3.33 | 3.38 | 0.081 | 0.354 | 0.660 | 0.846 |
| Texture | 2.29 | 2.00 | 4.00 | 4.25 | 0.239 | 0.001 | 0.958 | 0.431 |
| Maturity | 1.86 | 2.13 | 2.22 | 2.13 | 0.069 | 0.193 | 0.538 | 0.193 |
| Quality grade score[2)] | 3.29 | 3.63 | 1.44 | 1.63 | 0.242 | 0.001 | 0.471 | 0.695 |
| Auction price (won/kg) | 19,464 | 20,609 | 13,923 | 14,609 | 714.452 | 0.001 | 0.374 | 0.823 |

[1)]Yield grade score: Grade A, 3; grade B, 2; grade C, 1.

[2)]Quality grade score: Grade $1^{++}$, 5; grade$1^{+}$, 4; grade 1, 3; grade 2, 2; grade 3, 1.

CM, castration method; SFP, short-term fattening period.

**Table 5.** Comparison of economy analysis according to short-term fattening period and castration method in Hanwoo

| Item (USD/head) | Castration | | Hemi-castration | | SEM | *p*-value | | |
|---|---|---|---|---|---|---|---|---|
| | 24 months | 26 months | 24 months | 26 months | | CM | SFP | CM × SFP |
| Gross receipts[1)] (A) | 6,770 | 7,542 | 5,071 | 5,470 | 270.097 | 0.001 | 0.179 | 0.664 |
| Operating costs (B) | 5,759 | 5,955 | 5,781 | 5,980 | 18.148 | 0.011 | 0.001 | 0.857 |
| Calf[2)] | 3,333 | 3,333 | 3,333 | 3,333 | - | - | - | - |
| Feed costs[3)] | 1,797 | 1,992 | 1,819 | 2,017 | 18.148 | 0.011 | 0.001 | 0.857 |
| Formula feed | 1,427 | 1,608 | 1,442 | 1,628 | 16.683 | 0.004 | 0.001 | 0.670 |
| Roughage | 370 | 385 | 377 | 390 | 3.771 | 0.428 | 0.084 | 0.911 |
| Others[4)] | 629 | 629 | 629 | 628 | - | - | - | - |
| Net income (C=A−B) | 1,011 | 1,587 | −710 | −510 | 268.150 | 0.001 | 0.369 | 0.662 |

[1)]Gross receipts: Selling price of carcass and by product.

[2)]Calf: average auction price of Hanwoo calf in 2020.

[3)]Feed costs: Commercial concentrate (growing formula feed = 0.35 USD/kg + fattening formula feed = 0.36 USD/kg) + roughage (Italian ryegrass 0.31 USD/kg + rice straw: 0.22 USD/kg).

[4)]Others: water, power and fuel cost = 33.38 USD + veterinary and medicine cost = 29.83 USD + automobile cost = 41.03 USD + farm implements cost = 169.99 USD + farm building and facilities cost = 124.29 USD + miscellaneous materials cost = 75.23 USD + interest on borrowed capital = 61.46 USD + land rent = 4.42 USD + hired labor cost = 45.24 USD + excretion disposal cost = 23.31 USD + production management cost = 18.61 USD.

CM, castration method; SFP, short-term fattening period; USD, United States dollar.

fattening period increased, but there was no significant difference ($p$ = 0.179). The castration method and short-term fattening period affected the operating and feed costs. They were higher in the hemi-castration group than in the castration group ($p$ = 0.011), and increased as the fattening period increased ($p$ < 0.001). Net income was higher in the castration group than in the hemi-castration group ($p$ < 0.001), and increased as the short-term fattening period increased. Net income was numerically higher, but not significantly different ($p$ < 0.369).

## DISCUSSION

Testosterone is a representative steroid-based sex hormone of the androgen family, mainly secreted by stromal cells of the testis. It promotes the increase of muscle cells and satellite cells [12], and improves protein synthesis [6]. It has also been reported to improve growth and muscle development by increasing the secretion of growth hormone and insulin-like growth factor-I [13,14]. Sundby et al. [15] reported that higher serum testosterone concentrations improved growth and weight gain, and Zhou et al. [16] reported that the cause of the increased expression of muscle-related genes in bulls compared to steers was the effect of testosterone. In this study, hemi-castration resulted in secreted testosterone even after surgical castration (Fig. 1), which would benefit growth and muscle development. Therefore, the increase in ADG and rib eye area in the hemi-castration group compared to the castration group is probably due to the influence of testosterone. However, the differences in body weight and carcass weight were not significant. Shah et al. [17] reportedc that the final body weight, ADG, and FCR were the highest in the bull group. There was no difference between the uni and bilateral castration, and the testosterone concentration was significantly lower in the uni castration group than in the bull group. Hyun [18] reported that there was no difference in body weight and ADG between bulls and steers until early fattening but was higher in bulls than in steers from middle fattening (22 months of age) to late fattening (32 months of age). It was presumed that testosterone could improve muscle development during the fattening period when growth is reduced, and fat development is increased, compared to the growing period when body growth is active. The small weight difference between the castration method groups in this study is probably the decrease in testosterone due to hemi-castration and the effect of the short fattening period.

Adipose tissue includes visceral fat, subcutaneous fat, and intramuscular fat. It accumulates by increasing the number of cells through the proliferation and differentiation of adipocytes and by increasing the size of adipocytes. Differentiation of adipocytes in cattle is actively performed from the fetal stage to the calf period, after which an increase in size occurs through lipid synthesis rather than differentiation [19]. Although various factors affect fat metabolism, testosterone inhibits fat development. Testosterone suppresses the expression and activity of peroxisome proliferator-activated receptor γ (PPARγ) and reduces mRNA expression of genes related to fat metabolism [20]. Oh et al. [21] reported that the addition of testosterone inhibited the synthesis of triglycerides by decreasing the activity of Glycerol-3-Phosphate dehydrogenase (GPDH) in intramuscular adipocytes of cattle. Singh et al. [12] reported that as testosterone concentration increased, the number of adipocytes and the expression of PPARγ were more severely reduced. In this study, compared to the castration group, back fat thickness and intramuscular fat were decreased (Table 4) in the hemi-castration group, and fat development was slower (Table 3). This could also be attributed to the effect of testosterone, as reported in previous studies [17,22]. In addition, Ahn et al. [22] suggested that the distribution of adipocytes in the *longissimus dorsi* of hemi-castrated cattle was significantly reduced compared to that in steers, suggesting that hemi-castration negatively affects adipocyte proliferation and differentiation. In this study, it can be inferred that the hemi-castration group negatively affected fat development because testosterone concentration continuously increased during the growing period (8–12 months of age) when adipocyte proliferation and differentiation were active. In other words, even after hemi-castration, the testosterone secreted from one testis may be sufficient to inhibit adipose tissue development, suggesting that it may be more sensitive to differentiation than adipocyte hypertrophy.

Intramuscular fat, also called marbling, is the most important meat quality characteristic that affects the meat quality grade and auction price [23]. In the correlation analysis of the auction price


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in the KIAPQE [5] report, the marbling score (r = 0.803) had a strong positive linear relationship, and the color (r = −0.396) and texture (r = −0.617) showed a moderate negative linear relationship. In this study, the auction price of the hemi-castration group was lower than that of the castration group because of lower marbling and higher color and texture. It is also thought that gross receipts and net income decreased in the hemi-castration group due to this difference. Additionally, hemi-castration can negatively affect consumer palatability due to meat's increased color and texture.

The beef cattle industry uses a long fattening period to maximize intramuscular fat synthesis in cattle. However, that is likely to increase production costs and negatively affect weight gain [24], feed efficiency [25] and back fat thickness [26]. Conversely, if the fattening period is too short, the auction price and net income will decrease because intramuscular fat is incomplete. Thus, it is desirable to set an appropriate fattening period. In this study, gross income and net income were higher at 26 months of fattening than at 24 months, regardless of the castration method, which could be explained by the influence of carcass weight and marbling score. Therefore, it may be more effective to set the fattening period to 26 months rather than 24 months, even when considering the feed cost and growth performance.

## CONCLUSION

Hemi-castration is sufficient to reduce marbling by inhibiting the development of fat by male hormones secreted by one testicle. Although it can improve ADG and the rib eye area, it cannot increase net income as much as the difference in marbling could. Thus, general castration, which removes both testicles, is essential for improving profitability through high-quality beef production. In the case of the short-term fattening period, 24 months can reduce the production cost slightly, but 26 months is appropriate for the short-term fattening period at the current level of fattening technology because of the increased net income due to increased carcass weight and marbling. Future studies should investigate new short-term fattening technologies that consider the segmentation of the fattening period and slaughter turnover rate.

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