INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
19–0731/2019/22–5–1087–1092
DOI: 10.17957/IJAB/15.1173
http://www.fspublishers.org

Full Length Article

Effects of Seasonal Castration on Elk Deer Venison Quality

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Abstract

Deer meat quality and carcass weight vary during breeding season and may be influenced by castration timing. We investigated the effect of castration time using elk deer (*Cervus canadensis*) castrated at four times (n = 3/group). Weight changes during the breeding season (September–October) varied among the groups (T1 > T2 > T3 > T4), with a sharp decline (-23.30 kg) for T4. Fat percentage significantly differed among the groups ($P < 0.05$), with lower levels measured in T4. Crude fat percentage was significantly higher ($P < 0.05$) in T1–T3 than in T4, with no significant difference ($P < 0.05$) in crude protein percentages. The highest mineral concentrations corresponded to K > P > Na > Mg; the lowest concentrations to Cu, Ca, Fe, and Zn. Similar patterns were observed in Mg, Na, and P concentrations among the groups. Shear force in T4 compared with that in T1–T3 was significantly higher. Thus, castration improved venison quality and reduced carcass weight loss regardless of the breeding season, but did not improve other features. We anticipate that these findings will contribute to the development of optimal management strategies for deer, leading to increased production and quality of the meat. Further, interest in deer farming, wildlife conservation, and preservation of the genetic diversity of elk deer species may be promoted.

Keywords: Breeding season; Castration; Elk deer; Minerals; Venison

Introduction

Deer are seasonal breeders and their weight gain or loss fluctuates remarkably across seasons. Unfortunately, deer farming has been decreasing worldwide because venison is commonly produced on a small scale by local residents. Venison is considered a valuable meat product, containing high protein and mineral levels (Miao *et al*., 2001) and less fat and cholesterol than traditional red meats do (Drew *et al*., 1991; Shin *et al*., 2000). Seasonal castration can affect the level of muscle glycogen and pH of meat and, consequently, its quality. pH and meat color are the most important indices of meat quality. Standard evaluation of high-quality meat includes a decisive pH range of 5.4–5.6. Meat delicacy decreases at a pH greater than 5.8, along with a risk of declining meat quality with aging. The same quality parameters are considered for evaluating meat and carcasses intended for export (Page *et al*., 2001; Goñi *et al*., 2007). Consumers pay great attention to the color for a visual impression and the marbling (intramuscular fat), as well as the muscle tissue composition and meat structure.

Color and marbling score are important determinants of meat quality. Marbling is the dispersion of fat within the lean muscle tissue. Its degree primarily determines the meat quality grade and can be influenced by timing, type, and relative feed value of feedstuffs. Older elk deer fed a high-energy diet exhibit a higher grade based on quality scores than those fed other diets, but have a much lower percentage of carcass fat. Feeding deer a high amount of cereal grains such as corn or barley modifies the fat color of the carcass from yellowish to white and increases the chance of obtaining a higher meat quality grade, according to the USDA (Wheeler *et al*., 1994). Meat from castrated animals has increased juiciness, amount of connective tissue, myofibrillar tenderness, and tenderness, compared with that from non-castrated animals, but no differences in flavor. Dikeman *et al*. (1986) reported that tenderness and juiciness, but not flavor, were superior with castrated animals.

Castration affects meat composition by decreasing the water content and increasing fat content. A significant increase in intramuscular fat after castration affects the muscle collagen content, likely due to the effects of testosterone (Boccard and Bordes, 1986). An increase in

To cite this paper: Kim, K.W., M.M.R. Chowdhury, S.S. Lee, J. Lee, D.Y. Jeon, S.W. Kim, S. Kim, D.Y. Jeon, S.W. Kim and S.H. Lee, 2019. Effects of seasonal castration on elk deer venison quality. *Intl. J. Agric. Biol*., 22: 1087–1092

growth rate and carcass weight are common. Fat content changes the most during weight decrease in males. Venison meat is highly valued by consumers because it is very rich in protein and iron, while very low in fat, energy, and cholesterol (Drew *et al*., 1991; Shin *et al*., 2000). Currently, worldwide demand for venison from domestically reared deer has increased, boosting its market value and generating a considerable renewed interest in deer farming, particularly among commercial farmers. Consequently, attention has been focused on improving the meat quality; therefore, deer farms aim to produce high-quality venison. To contribute to these efforts, we conducted this study to provide a distinctive management strategy to increase venison production by revealing the potential correlation between castration timing and carcass production and venison quality of elk deer. Our results may lead to a substantial interest in the deer-farming industry, thereby promoting wildlife conservation programs.

Materials and Methods

Experimental Animals and Castration Timing

Twelve elk deer (*Cervus canadensis*) of the same age (6 years) and size (average weight: 310 kg) were used as the experimental animals. They were evaluated over a period of 8 months from the non-breeding to the breeding season in February to October. The animals were fed concentrated feed and roughage (1.8%) twice a day according to each animal's weight, with free access to water and the coarse fodder for voluntary intake until the conclusion of this study (Table 1). We compared the effects of castration period on the gross weight changes and carcass characteristics of elk deer castrated at four different stages. The animals were randomly allocated to four treatment groups (Table 2).

Weight Measurement and Carcass Characteristics

Initial weights were measured on March 1 and September 1 to determine the weight changes during the velvet antler growth period and again before feeding on September 1 during the breeding season and on October 10. At the end of the experimental period, the animals were slaughtered to analyze their carcass composition and venison characteristics. Temperature and weight were measured at the half-carcass state, and then the carcass was stored in a refrigerator for 24 h. Cold carcass weights were measured the following day, and the left halves of the carcasses were deboned to measure the contents of fat, bones, and meat cuts.

Meat Color

Meat color was analyzed using fresh longissimus muscle (cross-section of the longissimus thoracis) 48 h after slaughter using a Minolta Chroma Meter CR-310 (Minolta Co., Ltd., Japan), with a color measuring area of 50 mm in diameter according to the CIE color system $L^*a^*b^*$. L^* designates lightness ranging from 0 (for black) to 100 (for ideal white), a^* and b^* indicate the color ($+a^*$ = redness, $-a^*$ = green, $+b^*$ = yellow, and $-b^*$ = blue), the b/a ratio represents the type, and the $\sqrt{a^2+b^2}$ value represents the color. The standard color plate used was (L* = 94.5, a^* = 0.3136, and b^* = 0.3203), consistent with the manufacturer protocol, and the mean values were derived after measuring three sections of the sample once. The color intensity/saturation (C^*) and h^* indices were calculated as follows:

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

$$h^* = \arctan\left(\frac{b^*}{a^*}\right)$$

Analysis of Shear Force, Cooking Loss, Color, and pH of Elk Venison

Shear force was measured using an Instron 3343 analyzer (US/MX50, A&D Co., U.S.A.), with a load cell of 10 kg and an adapter area of 30 mm^2. Fresh venison was cut into horizontal sections in the muscle fiber direction to 0.65 × 2.00 cm and then cut perpendicularly to the muscle direction using a knife-type plunger, followed by 10 repeated measurements.

To measure the cooking loss, the venison was cored into 25-g parts, enclosed in polyvinyl iodine chloride film, and heated for 30 min after the core temperature reached 70°C. Moisture loss was measured following a cooling period of 1 h at optimal temperature, which was then used in the following equation to calculate cooking loss:

$$\text{Cooking Loss (\%)} = \frac{\text{Moisture Loss (g)}}{\text{Sample Weight (g)}} \times 100$$

The pH of the loin muscle was measured 48 h after slaughter using a pH meter (8603; Metrohm, Switzerland). After removing the fascia and fat, 10 g of sample meat was minced with 90 mL distilled water for 20 s using a homogenizer at 13,500 rpm (T25B; IKA Sdn. Bhd., Malaysia).

Mineral Contents of Elk Deer Venison

Three grams of the venison sample was placed in a Kjeldahl flask and decomposed in 10 mL of each strong H_2SO_4 and HNO_3 on a hotplate until the solution became colorless. The solution was filtered in 100 mL of a solvent using filter paper (Whatman No. 6), and the mineral content was analyzed using inductively coupled plasma spectrometry (Aton Scan 25; Thermo Jorell Ash Co., France) under analytical conditions of: RF power, 1150 W; pump rate, 100 rpm; nebulizer pressure, 30 psi; and observation height, 15 mm. The mineral content (mg/kg) was determined using the following formula:

$$= \frac{(\text{Absorbance of Sample Solution}/\text{Absorbance per ppm}) \times \text{Dilution Factor}}{\text{Sample Weight (g)} \times 10^6} \times 100$$

Statistical Analysis

Data analysis was performed using S.P.S.S. 12.0 for Windows (S.P.S.S. Inc., U.S.A.). Continuous variables are presented as the mean ± standard error, and differences were verified with Duncan's multiple range test. For inter-group comparisons, data from all replicates of each treatment were analyzed using two-way analysis of variance (Control-T4, and T1, T2, and T3 as the independent variable) followed by multiple pairwise comparisons (Duncan's test). In all cases, 95% confidence levels were considered significant, and experimental group results with $P < 0.05$ were considered statistically significant.

Results

Effects of Castration Time on Body Weight during Antler Growth

The T4 group, which including non-castrated elk deer, showed a significant decrease in body weight of 23.30 kg (Table 3). Body weight was also decreased in the castration groups, but to a lower degree; T1, T2, and T3 showed decreases of 1.53 kg, 4.40 kg, and 9.67 kg, respectively.

Effects of Castration Time on Deer Meat Quality and Color

Table 4 shows the analysis of general components of venison during different castration periods. There was a significant difference in the moisture and crude fat between the castrated groups and non-castrated group. The moisture was lower in the castrated groups, at 73.1, 73.8% and 73.6% in T1, T2, and T3, respectively, compared with 75.7% in T4 ($P < 0.05$). However, crude fat was higher in the castrated groups at 3.00, 2.20 and 2.01% in T1, T2 and T3, respectively, compared with 1.09% in T4.

In order to evaluate the effects of different castration periods on the color parameters of meat samples, lightness (L^*), redness (a^*), and yellowness (b^*) were assessed (Table 5). No significant differences were observed for L^*, a^*, and b^* among the four groups ($P < 0.05$). However, overall, the non-castrated group (T4) showed a slight decrease in color values compared with those of the castrated groups (T1, T2, and T3).

Effects of Castration Time on Shear Force, Cooking Loss, and pH

Our results demonstrated that the time of castration had no remarkable effect on the shear force of the venison (Table 6). Nonetheless, the difference in shear force between the non-castrated group (T4) compared with the three castrated groups (T1–T3) was significant, with a higher shear force in T4 ($P < 0.05$). In addition, there were no significant differences in cooking loss or pH among the groups, although a slight decrease in pH was observed in the castrated groups compared with the non-castrated group.

Table 1: Ingredients and composition of the basal diet provided during the experiments

Item	Concentrate	Hay
Dry matter (%)	85.9	30.1
Crude protein (% in DM)	18.8	15.2
Ash (% in DM)	3.87	8.4
Crude fiber (% in DM)	7.65	31.3
Neutral detergent fiber (% in DM)	38.2	64.0
Acid detergent fiber (% in DM)	19.9	33.5

DM: dry matter

Table 2: Experimental design

Group	Castration time	No. of elk deer
T1	Casting	3
T2	Velvet growth; day 50	3
T3	Velvet antler; day 85	3
T4	Hard antler (non-castration)	3

Table 3: Variation in body weight according to castration timing during the breeding season (September to October)

Group	Initial weight (kg)	Final weight (kg)	Total gain (kg)	ADG (kg/day)
T1	347.3 ± 39.6	345.7 ± 39.4	-1.5 ± 14.5	-0.04 ± 0.4
T2	362.7 ± 21.9	358.7 ± 14.2	-4.4 ± 11.3	-0.11 ± 0.3
T3	334.7 ± 44.0	324.3 ± 53.56	-9.7 ± 9.8	-0.25 ± 0.3
T4	340.0 ± 19.8	317.0 ± 14.1	-23.3 ± 5.2	-0.60 ± 0.1

T1: Casting (March), T2: Velvet growth (April), T3: Velvet antler (June), T4: Hard antler, not castrated (October). ADG: Average daily gains. The data are expressed as the mean ± standard error of the mean (SEM)

Table 4: Variation in deer meat quality in different castration periods

Group	Moisture (%)	Crude protein (%)	Crude fat (%)	Crude ash (%)
T1	73.1 ± 0.2^b	22.2 ± 0.1	3.0 ± 0.2^a	0.8 ± 0.0^b
T2	73.8 ± 0.4^b	22.2 ± 0.3	2.2 ± 0.1^b	0.9 ± 0.0^a
T3	73.6 ± 0.2^b	22.8 ± 0.3	2.0 ± 0.2^b	0.9 ± 0.0^a
T4	75.8 ± 0.1^a	22.0 ± 0.1	1.1 ± 0.1^c	0.9 ± 0.0^a

[a–c] Different superscript letters indicate statistically significant differences ($P < 0.05$)
T1: Casting (March), T2: Velvet growth (April), T3: Velvet antler (June), T4: Hard antler, not castrated (October)

Table 5: Changes in venison color according to elk deer castration time

Group	Meat color		
	Lightness (CIE L)	Redness (CIE a)	Yellowness (CIE b)
T1	33.5 ± 0.4^a	19.3 ± 0.0^a	7.7 ± 0.0^a
T2	33.8 ± 0.9^a	19.5 ± 0.7^a	7.5 ± 0.6^a
T3	34.1 ± 0.8^a	19.1 ± 0.4^a	7.5 ± 0.2^a
T4	31.1 ± 0.6^b	16.0 ± 1.0^b	5.0 ± 0.6^b

[a–c] Different superscript letters indicate statistically significant differences ($P < 0.05$)
T1: Casting (March), T2: Velvet growth (April), T3: Velvet antler (June), T4: Hard antler, not castrated (October). The data are expressed as the mean ± standard error of the mean (SEM)

Mineral Contents

Differences in mineral contents were observed between the T1–T3 and T4 groups (Table 7). The highest concentrations

Table 6: Shear force, cooking loss, and pH of venison according to elk deer castration time

Group	Shear force (kg/0.5 inch^2)	Cooking loss (%)	pH
T1	2.9 ± 3.1^{c}	28.8 ± 0.6	5.7 ± 0.0^{b}
T2	4.4 ± 0.3^{b}	29.6 ± 0.8	5.7 ± 0.1^{b}
T3	1.5 ± 0.1^{b}	29.1 ± 0.8	5.6 ± 0.4^{b}
T4	6.8 ± 0.2^{a}	29.8 ± 0.7	6.2 ± 0.2^{a}

$^{a-c}$ Different superscript letters indicate statistically significant differences ($P < 0.05$)
T1: Casting (March), T2: Velvet growth (April), T3: Velvet antler (June), T4: Hard antler, not castrated (October). The data are expressed as the mean ± standard error of the mean (SEM)

Table 7: Mineral concentrations in venison according to the elk deer castration time

Group	Ca (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	K (mg/kg)	Mg (mg/kg)	Na (mg/kg)	P (mg/kg)	Zn (mg/kg)
T1	101.2 ± 2.9^{ab}	3.5 ± 0.1^{ab}	68.4 ± 2.2^{b}	6922.3 ± 49.9	480.2 ± 5.0	1143.5 ± 18.5	4275.5 ± 20.2^{ab}	109.3 ± 4.6^{ab}
T2	105.0 ± 4.1^{a}	3.4 ± 0.3^{b}	75.6 ± 7.6^{ab}	6834.4 ± 251.7	483.3 ± 2.8	1190.6 ± 0.2	4290.2 ± 55.9^{ab}	115.3 ± 9.2^{ab}
T3	101.8 ± 1.7^{ab}	4.3 ± 0.2^{a}	72.4 ± 4.0^{ab}	6901.2 ± 195.3	500.7 ± 25.8	1178.1 ± 52.5	4385.8 ± 79.3^{a}	91.2 ± 16.3^{b}
T4	93.0 ± 4.4^{b}	3.8 ± 0.3^{ab}	86.2 ± 4.5^{a}	6729.7 ± 164.2	465.1 ± 2.8	1135.5 ± 13.7	4203.7 ± 13.8^{b}	132.9 ± 3.6^{a}

$^{a-b}$ Different superscript letters indicate statistically significant differences ($P < 0.05$)
T1: Casting (March), T2: Velvet growth (April), T3: Velvet antler (June), T4: Hard antler, not castrated (October)

were observed for K, followed by P, Na, and Mg, and the lowest concentrations were observed for Cu, Ca, and Fe. Ca content was the highest in T3 (105.04 mg/kg) and the lowest in T1 (92.98 mg/kg). No significant difference in the concentrations of Cu, K, Mg, Na, and P ($P < 0.05$) among the groups was observed. However, the castrated elk deer meat contained a lower amount of Cu (3.42–3.82 mg/kg) compared with the non-castrated elk deer meat (4.25 mg/kg). In contrast, Fe content was relatively lower in T4 (72.42 mg/kg) than in T1–T3 (68.37–86.23 mg/kg). T1 deer had the highest Zn content (132.84 mg/kg) among the four groups.

Discussion

Venison is considered a valuable meat product with high protein and mineral content. Worldwide demand for deer meat has increased, and the interest in market value and deer farming has risen, particularly among commercial farmers. In the current market, improving the quality of venison is of high interest, and deer farms accordingly aim to 1produce high-quality venison. Therefore, in this study, we aimed to provide a distinctive management strategy to increase venison production by revealing the potential correlations between castration time and deer meat quality.

The amount of food consumed by deer differs between seasons, and their required nutrition should be ensured seasonally rather than daily, in contrast to bovine species. In our study, the carcass weight of elk deer changed significantly during the antler growth period according to the different castration times. In terms of weight variation by season, T2 showed the highest total weight gain from the previous season (T1), which was significantly higher than that of the other three groups ($P < 0.05$), confirming that the highest daily growth occurred during this period ($P < 0.05$). The rate of weight gain was highest from spring to summer and lowest from autumn to winter until 2 years after birth. Body weight of adult males decreased sharply after the breeding season. Drew (1985) proposed that the prime time to slaughter deer to produce the most amount of venison is between 15 and 27 months after birth. However, the food consumption upsurges, and an increase in weight between spring and summer should also be considered when determining its economic feasibility.

In our study, the moisture, crude protein, fat, and crude ash contents were 74–75%, 22–23%, 1–3%, and 0.83–0.90%, respectively, which was in line with the findings of Kim *et al.* (2017). The high protein and low fat contents in the meat of T1 also corroborated the findings of Kim *et al.* (2017). Previous studies reported that the increased fat content in meat and melting of the fat by heat protected against moisture loss (Hoffman and Wiklund, 2006). Low fat content with a desirable fatty acid composition and high levels of protein (Hoffman and Wiklund, 2006) encourage consumers to pay higher prices for more tender meat (Miller *et al*., 2001). Additionally, changes in deer meat quality occur following storage, and time might have an additional effect on the physicochemical composition of the fatty acids (Piaskowska *et al*., 2016).

In this study, the color parameters *a** and *b** increased slightly in T1 and T2 ($P < 0.05$). Slightly higher *L** values were found in T3 than in the other three groups. In addition, higher values for redness (*a**) and yellow (*b**) were observed in T2 and T1, respectively, than in the other groups, but the difference was not statistically significant ($P < 0.05$). Consistent values were reported for *L**, *a**, and *b** evaluated during different slaughter seasons by Kadim *et al.* (2004). The color variations observed following different castration periods among the groups might be mediated by testosterone and estradiol-17β, which cause the most pronounced hormonal changes in male gonads (McCarty *et al*., 1979). The testicles produce androgens and estrogens that coordinate with growth hormone to promote meat production by increasing nitrogen retention (Malo *et al*., 2009). When the testes are removed, the production of estrogen and the natural male anabolic steroid testosterone is

reduced. Testosterone is involved in muscle-collagen synthesis, accumulation, and maturation, which are responsible for some of the differences in tenderness between intact males and castrates (Unruh, 1986). Further studies are needed to clearly demonstrate the association between castration periods and color variations.

Shear force is related to the intramuscular connective tissue contents that determine the toughness of cooked meat, and it affects meat flavor and juiciness (Savell *et al*., 1987). The results indicate that the shear force was significantly higher in the non-castrated group compared with the castrated groups ($P < 0.05$). In general, castration decreases the aggressive tendency of males and increases the amount of anabolic hormones secreted by the testes, thereby lowering the final pH at slaughter (Morgan *et al*., 1993) and increasing muscle fat content (Field, 1971), while increasing backfat thickness (Knight *et al*., 1999; Purchas *et al*., 2002) and improving tenderness of the meat (Morgan *et al*., 1993). The results of this study showed no significant differences in cooking loss or pH among the groups, although the pH decreased in the castration groups. This finding is consistent with a previous report showing a reduction in the pH of meat due to increased secretion of anabolic hormones in castrated animals (Morgan *et al*., 1993). In addition, our results corroborated those of Reagan *et al*. (1971) who reported no differences in cooking loss in bull and steer meat. However, Purchas (1990) reported higher cooking losses in bull meat than in that from castrated steers. Further, other authors have observed lower cooking loss in castrated animals (Riley *et al*., 1983; Dikeman *et al*., 1986).

The dynamics of the relationship between various mineral concentrations and castration period in elk deer venison have not been examined to date. This study presents detailed analysis of mineral contents of venison and comparison of the mineral contents between T1–T3 castrated and T4 non-castrated animal groups. The highest concentrations were observed for K, followed by P, Na, and Mg, and the lowest concentrations were observed for Cu, Ca, and Fe. The content of Fe, a vital mineral element of hemoglobin and numerous other proteins, including enzymes, was significantly lower ($P < 0.05$) in T4 than in T1–T3 groups. Significantly higher ($P < 0.05$) Ca content was found in T3 and the lowest in T1. However, T1 deer had the highest ($P < 0.05$) Zn content. Zn is a crucial structural component of more than 200 biotic enzymes involved in the synthesis of nucleic acids, regulating the metabolism and synthesis of proteins to enhance wound healing and promote growth and immune functions (Choi, 2003). Zn deficiency leads to delayed growth and muscle development, hair loss, and reduced reproductive and immune functions, consequently deteriorating the body functions and causing effects such as decreased appetite, decline in gustatory and olfactory senses, and adaptation of eyes to darkness. K concentration was highest among other minerals in all experimental groups, but the differences among the groups were not statistically significant ($P < 0.05$). K plays an important role in transmitting electrical impulses during muscle contractions.

In our study, we did not directly compare the findings with those of other deer species because of the limited elk deer population and species-specific genetic variation between breeds. Thus, the correlations between seasonal effects of castration and the elk deer venison quality require further investigation with larger populations.

Conclusion

We demonstrated the effect of castration timing in elk deer on venison properties and the importance of castration in producing good-quality venison. As castrated elk deer tend to exhibit less weight loss during the breeding season than non-castrated elks do, castration is expected to increase venison productivity. In seasonally bred deer, castration of male elks does not significantly affect the production of venison during the breeding season. Thus, castration improved venison production quality and reduced carcass weight loss. Therefore, to slaughter the non-castrated male elk deer is recommended immediately before the autumn, owing to a decrease in feeding during the breeding season. Castration affected the meat composition likely by limiting testosterone production, which might improve the meat quality but no other features. These findings will help to develop optimal management strategies for castration timing to produce high-quality venison and increase productivity. Such efforts will contribute to expanding the elk deer market, thereby generating interest in deer farming and promoting wildlife conservation programs as well as preservation of the genetic diversity of elk deer species.

Acknowledgments

This work was supported by the Cooperative Research Program for Agriculture Science & Technology Development (Project No. PJ01431501) and Fellowship Program of National Institute of Animal Science, Rural Development Administration, Republic of Korea.

References

Boccard, R. and P. Bordes, 1986. Caracteristiques qualitatives et technologiques des viandes bovines: influence des facteurs de production. *In: Production de Viande Bovines*, pp: 61–84. Micol, D. (Ed.). Paris, France

Choi, M.H., 2003. *Nutritional Science in 21st Century*. Kyo Moon Sa, Seoul, South Korea

Dikeman, M.E., G.B. Reddy, V.H. Arthaud, H.J. Tuma, R.M. Koch, R.W. Mandigo and J.B. Axe, 1986. Longissimus muscle quality, palatability and connective tissue histological characteristics of bulls and steers fed different energy levels and slaughtered at four ages. *J. Anim. Sci.*, 63: 92–101

Drew, K.R., 1985. Meat production from farmed deer. *In: Biology of Deer Production*. pp: 285–290. P.F. Fennessy and K.R. Drew (Eds.). The Royal Society of New Zealand Bulletin, Wellington, New Zealand

Drew, K.R., J.M. Stevenson and P.F. Fennessy, 1991. Venison – a marketable product. *In: Proceedings of a Deer Course for Veterinarians*, pp: 31–35. Deer Branch of the New Zealand Veterinary Association, Wellington, New Zealand

Goñi, M.V., M.J. Beriain, G. Indurain and K. Insausti, 2007. Predicting longissimus dorsi texture characteristics in beef based on early post-mortem colour measurements. *Meat Sci.*, 76: 38–45

Hoffman, L.C. and E. Wiklund, 2006. Game and venison–meat for the modern consumer. *Meat Sci.*, 74: 197–208

Kadim, I.T., O. Mahgoub, D.S. Al-Ajmi, R.S. Al-Maqbaly, S.M. Al-Mugheiry and D.Y. Bartolome, 2004. The influence of season on quality characteristics of hot-boned beef of *M. longissimus thoracis*. *Meat Sci.*, 66: 831–836

Kim, K.W., H.S. Park, S.S. Lee, S.H. Yeon, C.Y. Cho, S.W. Kim and J. Lee, 2017. Effects of different feeding regimes on deer meat (venison) quality following chilled storage condition. *Kor. J. Food Sci. Anim. Resour.*, 37: 511–517

Malo, A.F., E.R.S. Roldan, J.J. Garde, A.J. Soler, J. Vicente, C. Gortazar and M. Gomendio, 2009. What does testosterone do for red deer males? *Proc. Roy. Soc. Lond. B Biol. Sci.*, 276: 971–980

McCarty Jr, K.S., T.K. Barton, B.F. Fetter, W.T. Creasman and K.S. McCarty Sr, 1979. Correlation of estrogen and progesterone receptors with histologic differentiation in endometrial adenocarcinoma. *Amer. J. Pathol.*, 96: 171–183

Miao, Z.H., P.C. Glatz, A. English and Y.J. Ru, 2001. Managing fallow deer and red deer for animal house research. *Aust. New Zeal. Counc. Care Anim. Res. Teach. News*, 14: 1–8

Miller, M.F., M.A. Carr, C.B. Ramsey, K.L. Crockett and L.C. Hoover, 2001. Consumer thresholds for establishing the value of beef tenderness. *J. Anim. Sci.*, 79: 3062–3068

Morgan, J.B., T.L. Wheeler, M. Koohmaraie, J.W. Savell and J.D. Crouse, 1993. Meat tenderness and the calpain proteolytic system in longissimus muscle of young bulls and steers. *J. Anim. Sci.*, 71: 1471–1476

Page, J.K., D.M. Wulf and T.R. Schwotzer, 2001. A survey of beef muscle color and pH. *J. Anim. Sci.*, 79: 678–687

Piaskowska, N., T. Daszkiewicz, D. Kubiak and P. Zapotoczny, 2016. Quality of meat (*Longissimus dorsi*) from male fallow deer (*Dama dama*) packaged and stored under vacuum and modified atmosphere conditions. *Asian-Aust. J. Anim. Sci.*, 29: 1782–1789

Purchas, R.W., 1990. An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. *Meat Sci.*, 27: 129–140

Reagan, J.O., Z.L. Carpenter, G.C. Smith and G.T. King, 1971. Comparison of palatability traits of beef produced by young bulls and steers. *J. Anim. Sci.*, 32: 641–646

Riley, R.R., J.W. Savell, C.E. Murphey, G.C. Smith, D.M. Stiffler and H.R. Cross, 1983. Palatability of beef from steer and young bull carcasses as influenced by electrical stimulation, subcutaneous fat thickness and marbling. *J. Anim. Sci.*, 56: 592–597

Savell, J.W., R.E. Branson, H.R. Cross, D.M. Stiffler, J.W. Wise, D.B. Griffin and G.C. Smith, 1987. National consumer retail beef study. Palatability evaluations of beef loin steaks that differed in marbling. *J. Food Sci.*, 52: 517–519

Shin, H.T., R.J. Hudson, X.H. Gao and J.M. Suttie, 2000. Nutritional requirements and management strategies for farmed deer-review. *Asian-Aust. J. Anim. Sci.*, 13: 561–573

Unruh, J.A., 1986. Effects of endogenous and exogenous growth promoting compounds on carcass composition, meat quality and meat nutritional value. *J. Anim. Sci.*, 62: 1441–1448

Wheeler, T.L., L.V. Cundiff and R.M. Koch, 1994. Effect of marbling degree on beef palatability in *Bos taurus* and *Bos indicus* cattle. *J. Anim. Sci.*, 72: 3145–3151

[Received 30 Apr 2019; Accepted 25 Jun 2019; Published (online) 10 Nov 2019]