



Effects of Different Feeding Regimes on Deer Meat (Venison) Quality Following Chilled Storage Condition

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Abstract

This study was conducted to investigate the effect of different feeding regimes on the quality of deer meat (venison) following storage at 4°C for various durations. Twelve 5-year-old elk stags about 350 kg were stratified by weight and randomly assigned to one of four dietary treatments (three elk stags per treatment). The dietary treatments consisted of a feeding concentrate of 1.5% of body weight (T1), feeding concentrate of 1.8% of body weight (T2), feeding concentrate *ad libitum* (T3), or a home-mixed ration *ad libitum* (T4). The pH values of deer meat were not significantly different among treatment groups but were affected by duration of storage. Cooking loss increased under T4 treatment with increasing storage time at 4°C ($p < 0.05$). Increased storage time also resulted in significant decreases in shear force under T2 and T3 treatment compared to that under other dietary treatments ($p < 0.05$). Lightness (L*), redness (a*), and yellowness (b*) parameters were not significantly different among treatment groups, but lower values of a* and b* were observed under T1 and T4 treatment with increasing durations of storage ($p < 0.05$). The chemical and fatty acid composition had no significantly different among treatments. Therefore, meat quality was most affected by increased storage time at 4°C. These results may serve as the basis for further study of deer meat (venison) from Korea.

Keywords deer meat, pH, cooking loss, shear force, meat color

Introduction

The elk (*Cervus canadensis*) is one of the largest species of the Cervidae or deer family in the world and one of the largest land mammals in North America and Eastern Asia (Pitra *et al.*, 2004). In Korea, deer and elk were imported from New Zealand and North America about 50 years ago and have been raised locally since then (Kim *et al.*, 2016).

The primary food products produced from deer are venison and velvet antlers. Velvet antlers are soft, bony organs that are shed and fully regenerate every year (Li, 2003). They are mostly consumed in Asian countries including Korea as an ingredient in traditional oriental medicines (Miao *et al.*, 2001). Venison is considered a valuable meat product that contains high levels of protein and minerals. It also contains less fat and cholesterol than traditional red meats (Drew *et al.*, 1991; Shin *et al.*, 2000). Nonetheless, deer farming has been decreasing in Korea since

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2001 (Ministry of Agriculture Food and Rural Affairs, 2015) because venison is commonly harvested on small-scale farms in Korea. Moreover, there is a lack of studies on efficient feeding management techniques.

Farmed deer are frequently fed concentrates over the winter, resulting in pastoral feed deficiency (Flesch *et al.*, 2002; Tuckwell, 2003). However, little is known regarding the relationship between concentrate supplementation and meat production in farmed deer. Therefore, the aim of the present study was to investigate the effect of different feeding regimes on the physicochemical qualities of deer meat (venison) from elk grown in Korea and maintained at 4°C storage.

Materials and Methods

Animal feeding and sample preparation

All animal-based procedures were performed in accordance with the standard guidelines for the Care and Use of Experimental Animals provided by the National Institute of Animal Science, RDA, Republic of Korea. Twelve elk stags were raised for 4 months at the Animal Genetic Resources Research Center, National Institute of Animal Science (NIAS), Namwon, Republic of Korea.

Twelve 5-year-old elk stags were stratified by weight and randomly assigned to one of four treatments (three elks per treatment): concentrate at 1.5% of body weight (T1), concentrate at 1.8% of body weight (T2), concentrate *ad libitum* (T3), and home-mixed ration *ad libitum* (T4).

The ingredients and chemical compositions of the experimental diets are presented in Table 1. Concentrate feed was provided twice a day in equal amounts, and animals were provided free access to freshwater and mineralized salt blocks. A portion of each diet samples was collected for proximate analysis using the modified methods of the Association of Official Analytical Chemists (AOAC, 2005).

Upon reaching an average live weight of about 350 kg,

elks were slaughtered at the NIAS slaughterhouse using standard NIAS procedures. Carcasses were then held in cold storage (4°C) for 24 h prior to carcass dissection. After boning, excised loin muscle samples were vacuum-packed and stored at 4°C until further analysis.

Physicochemical analysis

After slaughter, samples were stored at 4°C for 2, 7, 11, 15, 18, or 21 days post mortem, and quality characteristics were then measured. All determinations were carried out on homogenized samples in triplicate.

The pH of each sample was determined using a pH meter (Model 520A, Orion, USA). The pH values of samples were measured by blending a 10-g sample with 90 mL distilled water for 60 s in a homogenizer [T25-B, IKA Works (Asia) Sdn. Bhd., Malaysia].

For assessment of cooking loss, samples in vacuum-sealed plastic bags were weighed and cooked for 1 h at 80°C in a water bath (SB-1000, EYELA, Japan). Cooked samples were cooled at 24°C for 30 min, and then they were dried and re-weighed. Cooking loss percentage was calculated based on the difference between the raw and final cooked weights.

Shear force values were analyzed using the method described by Wheeler *et al.* (2000). Shear force values per core were obtained for each animal from 30-mm-thick steaks that had been cooked to an internal temperature of 70°C and then cooled rapidly in cold water. The cooled samples (cylinders 0.5 inches in diameter) were cut perpendicular to the muscle fiber and assessed with a texture analyzer (Waner-Bratzler shear meter, G-R Elec. Mfg. Co., USA).

Color measurements were taken with a Minolta chromameter (Model CR-301, Japan), and the Commission Internationale de l'Eclairage color values for L*, a*, and b* were measured. The chromameter was standardized using a white calibration plate ($Y=92.4$, $x=0.3136$, $y=0.3196$) after 30 min of blooming at room temperature. Color measurements were recorded for three replicates of each sample.

Chemical composition and fatty acid analysis

All determinations were carried out on the homogenized sample. The chemical composition was determined on samples using a slightly modified method of AOAC (AOAC, 2000).

Total fat for fatty acid analysis was extracted according to the method of Folch *et al.* (1957). After thawing the samples, the lipids in a 5 g sample were extracted in chlo-

Table 1. Chemical compositions of experimental diets

Chemical composition, %	Concentrates	Home mixed ration
Dry matter	89.76	81.42
Crude protein	20.51	13.94
Ether extract	4.45	4.34
Ash	10.06	6.80
Crude fiber	9.29	7.06
Calcium	1.65	0.70
Phosphorus	0.79	0.52
Total digestible nutrients	69.99	65.07

roform/methanol (2:1), with 10% dibutyl hydroxyl toluene as an antioxidant. The fatty acid methyl esters (FAMES) were formed using a KOH solution in methanol and extracted with water and hexane. The top hexane layer containing FAME was dehydrated through anhydrous NaSO₄. The extracted and dehydrated hexane was transferred to a vial to be analyzed. Separation and quantification of the fatty acid methyl esters was carried out using a gas chromatograph (GC, Aglient 7890N, Aglient Technologies Seoul, Korea) equipped with a flame ionization detector, automatic sample injector (HP 7693). The column was unadsorbed DB-WAX fused silica capillary column (30 m, 0.25 mm i.d., 0.2 μm film thickness, Agilent Technologies, Seoul, Korea). Helium was used as carrier gas at linear flow of 1 mL/min and the injection volume was 1 mL. The oven temperature was initially held at 180°C for 1 min then increased at 2.5°C/min to 230°C for 12 min. The injector (split mode) and detector temperatures were maintained at 280°C. Linoleic acid (C18:2) was used as an internal standard (H3500, Sigma-Aldrich Inc., USA). The FAMES in the total lipids were identified by comparison of the retention times with those of a standard FAME mixture (Supelco TM 37 component FAME mix, Sigma-Aldrich Inc., USA). Fatty acid were expressed as a percentage of total fatty acids (MUFA) and polyunsaturated fatty acid (PUFA). PUFA/SFA ratios were calculated.

Statistical analysis

An analysis of variance for all variables was performed using the GLM procedure in the SAS 9.1 statistical package (SAS Institute Inc., USA). Differences among treatment means were identified using Duncan's multiple range tests.

Results and Discussion

pH value

Changes in the pH values of meat samples following various durations of storage at 4°C are presented in Table 2. There was no difference in average pH value among treatments. However, there were significant increases in the average pH values of T1 and T4 samples with an increasing duration of cold storage ($p < 0.05$), consistent with previous reports (Tesanovic *et al.*, 2011). It is well documented that meat pH values influence the color, tenderness, water-holding capacity, and packaging processes of meat (Boles *et al.*, 1993; Hofmann, 1986). A previous study reported that an increase in pH during maturation was associated with proteolytic changes in muscle proteins (Wiklund *et al.*, 1995). It was also associated with an increase in the content of alkaline compounds formed during autolysis (Feidt *et al.*, 1998).

Table 2. Change in pH of deer meat during storage at 4°C for various durations

Storage period	Treatments ¹				
	T1	T2	T3	T4	
pH	2 d	5.66 ± 0.02 ^C	5.86 ± 0.27	5.87 ± 0.25	5.69 ± 0.03 ^{CD}
	7 d	5.64 ± 0.03 ^C	5.85 ± 0.28	5.85 ± 0.33	5.65 ± 0.01 ^D
	11 d	5.83 ± 0.04 ^B	6.03 ± 0.32	6.01 ± 0.33	5.82 ± 0.02 ^{BC}
	15 d	5.85 ± 0.02 ^B	6.10 ± 0.38	5.97 ± 0.20	5.91 ± 0.01 ^{AB}
	18 d	5.94 ± 0.02 ^{AB}	6.15 ± 0.34	6.02 ± 0.05	5.93 ± 0.12 ^{AB}
	21 d	6.02 ± 0.17 ^A	6.17 ± 0.33	6.11 ± 0.11	6.00 ± 0.17 ^A

¹Concentrate feed level/body weight: T1=1.5%, T2=1.8%, T3=ad libitum, T4=home mixed ration.

^{A-D}Mean±SD with different superscripts in the same column indicating significant differences at $p < 0.05$.

Table 3. Change in cooking loss of deer meat during storage at 4°C for various durations

Storage period	Treatments ¹				
	T1	T2	T3	T4	
Cooking loss (%)	2 d	29.33 ± 2.47	27.06 ± 3.54	24.40 ± 3.20	23.93 ± 1.47 ^C
	7 d	31.14 ± 2.95	28.96 ± 3.80	26.72 ± 4.32	27.27 ± 1.28 ^{BC}
	11 d	34.54 ± 0.85	33.73 ± 1.92	28.25 ± 6.47	31.05 ± 4.34 ^{AB}
	15 d	32.85 ± 2.68	30.10 ± 2.95	31.57 ± 1.47	32.31 ± 0.82 ^A
	18 d	31.51 ± 1.62	30.40 ± 3.66	31.85 ± 1.27	33.97 ± 1.75 ^A
	21 d	33.10 ± 2.92	28.25 ± 2.04	31.87 ± 2.31	33.34 ± 0.98 ^A

¹Concentrate feed level/body weight: T1=1.5%, T2=1.8%, T3=ad libitum, T4=home mixed ration.

^{A-C}Mean±SD with different superscripts in the same column indicating significant differences at $p < 0.05$.

Cooking loss

Different feeding regimes and cold storage durations had no significant effects on the cooking loss of elk meat under T1, T2, or T3 treatment (Table 3). However, in the T4 treatment group, cooking loss increased with increased storage duration. Cooking loss in meat is related to water-holding capacity. Bengtsson *et al.* (1876) reported that loss of water in the form of purge or drip loss attributes to an increase in meat temperature. Cooking loss and water-holding capacity are important factors in the evaluation of meat quality and affect the juiciness of cooked meat (Wiklund *et al.*, 2003).

A previous study reported that cooking loss changes associated with increased storage times could be due to physical factors, including changes in muscle structure, rather than biochemical factors (Huff-Lonergan and Lonergan, 2005). Manipulation of the physical properties of meat by altering muscle fiber and fiber bundle alignment results in meat with high drip losses in the raw and cooked states (Farouk *et al.*, 2007), which did occur in our study. Thus, the observed increase in cooking loss with longer storage times in the T4 treatment may be related to changes in muscle structure with different sources of feed and feed intake.

Shearing force

The shearing forces of elk meat resulting from the different feeding regimes and storage durations are presented in Table 4. Shear force is associated with the connective tissue contribution to cooked meat toughness and also affects meat flavor and preference (Beilken *et al.*, 1986; Savell *et al.*, 1987). In the present study, increased storage times resulted in significantly decreased shear forces under T2 and T3 treatment ($p < 0.05$). This is consistent with numerous studies that have reported that increased storage periods are associated with decreases in shear for-

ces and juiciness of deer meat due to increasing proteolytic degradation of myofibrillar protein within muscles (Bouton *et al.*, 1972; Bureš *et al.*, 2015). The activity of proteolytic enzymes (μ -calpain and m-calpain) leads to the degradation of cytoskeletal proteins responsible for maintaining the structural integrity of the muscle fibers (Farouk *et al.*, 2007; Koochmaraie, 1996). It has also been reported that the degradation of muscle fibers increases the tenderness of deer meat during aging (Piaskowska *et al.*, 2016).

In our study, the significant decrease in the shear force value of deer meat stored at 4°C for 18 d following T4 treatment compared with that following T1 treatment may result from differences in feed and energy level intake. However, further study is required to determine the relationship between concentrate feed intake and shearing force with increasing aging periods.

Meat color

Different feeding regimes had no significant effect on the color parameters of deer meat samples (Table 5). Maintaining color stability is a major challenge in the optimization of meat storage conditions and is affected by the myoglobin content within the meat (Anchía *et al.*, 1992; Kang *et al.*, 1999). In the present study, significant increases in the color parameters a^* and b^* were observed under T1 and T4 treatments with increasing storage periods ($p < 0.05$). This may be related to residual oxygen levels within packaged meat samples. A previous study reported that use of a vacuum with an anaerobic gas mixture prevented changes in the color of red meat during aging and storage periods. Nonetheless, under industrial conditions, oxygen is incompletely eliminated and low partial pressures of residual oxygen exist within meat, contributing to oxidation of meat myoglobin (Mancini and Hunt, 2005; Piaskowska *et al.*, 2016).

Table 4. Change in shear force of deer meat during storage at 4°C for various durations

Storage period	Treatments ¹				
	T1	T2	T3	T4	
Shear force (kg/0.5 inch ²)	2 d	6.38 ± 0.64	6.82 ± 1.72 ^A	7.99 ± 1.78 ^A	7.10 ± 1.44
	7 d	5.81 ± 1.95	6.98 ± 2.61 ^A	6.03 ± 1.51 ^B	5.98 ± 2.80
	11 d	5.35 ± 1.84	5.44 ± 0.92 ^{AB}	4.65 ± 0.77 ^B	5.05 ± 1.69
	15 d	4.29 ± 1.93	3.71 ± 0.84 ^B	4.20 ± 0.68 ^B	4.77 ± 0.65
	18 d	3.28 ± 0.64 ^b	4.08 ± 0.41 ^{Bab}	4.22 ± 0.28 ^{Bab}	5.37 ± 1.16 ^a
	21 d	3.80 ± 0.58	3.79 ± 0.59 ^B	4.11 ± 0.84 ^B	5.11 ± 0.61

¹Concentrate feed level/body weight: T1=1.5%, T2=1.8%, T3=ad libitum, T4=home mixed ration.

^{A,B}Mean±SD with different superscripts in the same column indicating significant differences at $p < 0.05$.

^{a,b}Mean±SD with different superscripts in the same row indicating significant differences at $p < 0.05$.

Table 5. Change in color of deer meat during storage at 4°C for various durations

Storage period	Treatments ¹				
	T1	T2	T3	T4	
L*	2 d	33.41 ± 1.15	31.54 ± 3.14	30.80 ± 2.54	32.21 ± 0.34
	7 d	34.49 ± 2.24	31.91 ± 3.21	31.88 ± 3.73	32.72 ± 0.63
	11 d	35.39 ± 1.62	32.52 ± 3.16	32.14 ± 2.49	34.57 ± 0.14
	15 d	35.25 ± 1.63	32.50 ± 4.15	32.59 ± 2.78	33.99 ± 0.69
	18 d	34.44 ± 1.76	31.68 ± 3.63	32.31 ± 2.86	34.40 ± 1.31
	21 d	33.05 ± 3.35	30.26 ± 3.29	32.31 ± 3.00	33.42 ± 1.64
a*	2 d	16.81 ± 1.44 ^B	13.75 ± 3.23	14.01 ± 2.46	15.04 ± 0.80 ^C
	7 d	18.02 ± 1.67 ^{AB}	14.67 ± 4.24	15.17 ± 4.01	17.10 ± 0.71 ^B
	11 d	18.03 ± 1.80 ^{AB}	14.56 ± 3.17	15.78 ± 4.00	19.76 ± 0.42 ^A
	15 d	20.05 ± 0.86 ^A	17.39 ± 3.01	17.34 ± 4.51	19.01 ± 0.87 ^{AB}
	18 d	20.70 ± 0.54 ^A	15.58 ± 3.86	16.99 ± 2.14	18.66 ± 0.72 ^{AB}
	21 d	19.05 ± 1.51 ^{AB}	14.96 ± 2.22	18.57 ± 5.43	18.25 ± 1.95 ^{AB}
b*	2 d	6.33 ± 0.84 ^B	4.54 ± 1.48	4.93 ± 1.23	5.64 ± 0.53 ^B
	7 d	7.26 ± 1.71 ^{AB}	5.45 ± 2.73	5.68 ± 2.23	6.85 ± 0.65 ^{AB}
	11 d	7.23 ± 1.01 ^{AB}	4.94 ± 1.91	5.82 ± 2.54	8.45 ± 0.17 ^A
	15 d	8.53 ± 0.75 ^A	6.69 ± 2.47	7.03 ± 2.92	8.15 ± 0.46 ^A
	18 d	9.20 ± 0.39 ^A	5.96 ± 2.40	7.08 ± 1.19	7.56 ± 0.89 ^A
	21 d	8.55 ± 1.01 ^A	6.27 ± 1.07	7.97 ± 3.22	8.03 ± 2.06 ^A

¹Concentrate feed level/body weight: T1=1.5%, T2=1.8%, T3=ad libitum, T4=home mixed ration.

^{A-C}Mean±SD with different superscripts in the same column indicating significant differences at $p < 0.05$.

Chemical and fatty acid composition

There were no significant differences in chemical composition of deer meat on different feeding regimes (Table 6). Moisture, Crude protein and fat contents were in the range of 74% to 75%, 22% to 23% and 1% to 2%, respectively. The above finding is consistent with Kim *et al.* (2016), who found that the moisture, protein and fat content of elk was 73 to 75%, 22% and 1 to 2%, respectively. Previous study venison could fulfill the expectations and dietary requirements of the modern consumer, due to a low content of fat with a desirable fatty acid composition and high levels of protein (Hoffman and Wiklund, 2006). In our study, the high protein content and low fat content in the Korean elk meat obtained indicating a similar result to the previous findings.

Previous studies have shown that the changes of deer meat quality during storage time is more commonly affected in physicochemical composition than fatty acid composition (Piaskowska *et al.*, 2016). In our study, predominant saturated fatty acids were palmitic and stearic acid, the predominant MUFA was oleic acid, and the predominant polyunsaturated fatty acid was linoleic acid. These results are consistent with those from previous studies with deer and elk (Purchas *et al.*, 2010; Wiklund *et al.*, 2003). Levels of oleic acid in beef are usually greater than 30% of total fatty acid (Purchas *et al.*, 2010). The elk contains

lower proportions of oleic acid than beef in this study. This may be a reflection of the very low level of intramuscular fat in venison, as the proportion of this oleic acid usually increases as fat levels increase within meat (Purchas *et al.*, 2010). The PUFA/SFA (P/S) ratio is a key indicator of the nutritional value of food products, and its low values contribute to the development of cardiovascular diseases (Daszkiewicz *et al.*, 2012). The normal P/S ratio in ruminant meat is around 0.1 because dietary unsaturated fatty acids are hydrogenated by rumen microorganisms, which did occur present study.

Overall, different feeding regimes had no significant effect on meat quality, which is correlated with consumer appeal, during 4°C storage. In contrast, increased storage duration increased pH values, cooking loss, and the meat color parameters of redness and yellowness, accompanied by a decrease in the shear force value of deer meat (venison). This change in deer meat quality may be associated with protein degradation within the meat muscle. Therefore, further study needed to examine effect of different storage condition on deer meat quality using microbiological analysis.

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Table 6. Chemical and fatty acid composition of deer meat on different feeding regimes

	T1	T2	T3	T4
Chemical composition, %				
Moisture	75.1	75.3	74.7	74.1
Crude fat	0.88	0.76	1.13	1.51
Crude protein	22.5	23.0	23.3	23.6
Crude ash	1.02	1.03	1.02	1
Fatty acid composition, %				
Myristicacid (C14:0)	7.23 ^A ± 0.27	8.43 ^A ± 0.74	7.90 ^A ± 0.23	5.30 ^B ± 1.48
Palmiticacid (C16:0)	35.5 ± 1.56	35.6 ± 1.97	36.0 ± 1.43	33.3 ± 1.51
Palmitoleicacid (C16:1n7)	6.90 ± 1.56	7.28 ± 0.58	9.64 ± 1.53	7.15 ± 1.51
Stearicacid (C18:0)	18.6 ± 4.23	17.9 ± 0.48	18.1 ± 5.70	18.2 ± 2.47
Oleicacid (C18:1n9)	24.2 ± 2.70	22.7 ± 3.43	23.7 ± 3.33	25.9 ± 2.94
Linoleicacid (C18:2n6)	3.04 ± 0.28	4.64 ± 0.62	3.89 ± 1.32	4.33 ± 0.31
γ-Linoleicacid (C18:3n6)	0.15 ± 0.01	0.18 ± 0.06	0.13 ± 0.04	0.12 ± 0.02
Linolenicacid (C18:3n3)	0.24 ± 0.05	0.30 ± 0.08	0.27 ± 0.05	0.19 ± 0.08
Eicosenoicacid (C20:1n9)	0.31 ± 0.06	0.37 ± 0.04	0.28 ± 0.07	0.30 ± 0.05
Arachidonicacid (C20:4n6)	1.07 ± 0.18	1.87 ± 0.12	1.49 ± 0.38	1.07 ± 0.41
SFA	63.3 ± 5.34	62.1 ± 2.92	62.1 ± 6.55	58.8 ± 3.59
UFA	36.7 ± 5.34	37.9 ± 2.92	38.0 ± 6.55	41.2 ± 3.59
MUFA	31.4 ± 4.17	30.3 ± 4.00	32.2 ± 5.95	33.4 ± 4.30
PUFA	4.50 ± 0.15	7.60 ± 1.19	5.78 ± 1.56	5.65 ± 0.74
PUFA/SFA	0.07	0.12	0.10	0.10

SFA, saturated fatty acid; UFA, unsaturated fatty acid; MUFA, monosaturated fatty acid; PUFA, polyunsaturated fatty acid.

¹Concentrate feed level/body weight: T1=1.5%, T2=1.8%, T3=ad libitum, T4=home mixed ration.

^{A-C}Mean±SD with different superscripts in the same column indicating significant differences at $p < 0.05$.

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