

The Quality Characteristics and Antioxidant Properties of Sun-dried Venison Jerky with Green Tea Powder during Storage

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Abstract

This study was conducted to compare the physicochemical, microbiological and antioxidant activities of sun-dried venison amended with green tea powder (T1-3: 0, 0.5, and 1%) and Hanwoo beef jerky. Sliced beef and venison shank were marinated and sun-dried at 28-30°C and 30-35% RH for 3.5 h. The venison jerky had a higher ash and protein content, and lower moisture and fat content than the control ($p < 0.05$). T3 (venison+green tea powder 1%) showed a lower a_w than all other samples during storage for 10 and 20 d ($p < 0.05$). Hunter's color a^* and b^* values of T2 and T3 were lower than those of T1 and the control at day 0 ($p < 0.05$). Saturated fatty acid was significantly higher in T1, while PUFA was higher in T2 and T3 ($p < 0.05$). Overall sensory scores of venison jerky were lower than those of the control, except for T2, which had a similar color, flavor, saltiness and acceptability as the control. T2 and T3 showed a significant decrease in TPCs after storage for 20 d ($p < 0.05$). The TBARS values of T3 jerky were lower than those of other jerky samples ($p < 0.05$).

Keywords: sun-dried venison jerky, green tea powder, physicochemical properties, TPC, TBARS

Received January 2, 2016; Revised August 30, 2016; Accepted August 31, 2016

Introduction

Drying meat in the sun, which is one of the oldest methods of food preservation, is still a popular method of preservation in many developing countries, particularly in areas where no cold chain is available. Most nutritional properties of meat, in particular protein content, remain unchanged through drying (Heinz and Hautzinger, 2007). However, traditional the sun-drying process can be very time-consuming, and it is difficult to control moisture content when using this method (Konieczny *et al.*, 2007). However, there have been few attempts to assess the quality and microbiological aspects of jerky produced under sun-drying conditions to date. Although jerky can be made from a variety of animal species, more than 70% is produced from beef. In general, venison is tender and has very low fat concentrations of 0.07-1%, while it has relatively high levels of proteins and minerals (Banout *et al.*, 2012; Wiklund *et al.*, 2010). Consumers are increasingly becoming concerned about the health aspects and

safety of products; therefore, demand for such products is increasing. Accordingly, demand for venison is increasing because it is considered a healthy food (Hoffman and Wiklund, 2006). Previous investigations of venison have mainly included evaluation of carcass composition, handling and transport (Delanty and Dichter, 2000; Youdim and Joseph, 2001); however, no studies of the physicochemical properties of venison jerky have been conducted to date.

Lipid oxidation can have negative effects on meat quality, causing changes in sensory attributes (color, texture, odor, and flavor) and nutritional quality. Tea catechins are polyphenolic antioxidants found in green tea that possess a range of health promoting properties (Katiyar and Mukhtar, 1997) and inhibit lipid oxidation in edible oil (Wang and Zhao, 1997). Consumer preferences for natural products have resulted in increased interest in the use of natural antioxidants because of their lower toxicities relative to synthetic antioxidants (Kim *et al.*, 2012). Because of concerns about the toxicological safety of synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) (Branen, 1975), naturally derived antioxidants are perceived by consumers as better and safer than synthetics (Dorko, 1994). Therefore, meat products containing natural antioxidants are more

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desirable than those containing synthetic derivatives from a consumer viewpoint. However, it is not known if the addition of tea catechins to meat products is as effective at maintaining meat quality as synthetic antioxidants. Although the effects of natural antioxidants on meats such as beef, pork and chicken have been reported (Tang *et al.*, 2001), their effects on venison have not. Moreover, few studies have investigated the physicochemical traits of sun-dried venison jerky amended with green tea powder. Therefore, this study was conducted to investigate the effects of green tea powder on the physicochemical quality and antioxidant properties of sun-dried venison jerky in comparison to beef jerky during storage.

Materials and Methods

Preparation of jerky

Hanwoo shank muscle as a control and venison shank muscles as treatments were obtained from different local meat packers 24 h after slaughter (Korea) and were frozen at -45°C . One day before treatment, samples were allowed to thaw in the refrigerator until the internal temperature reached -1°C . The Hanwoo beef and venison samples were then sliced to 0.5 cm-thick pieces with a meat slicer (HFS 350G, Hankook Fugee, Korea). The sliced samples were cut parallel in direction to muscle fibers, and all subcutaneous and intermuscular fat and visible connective tissue were removed from the muscles. The sliced samples were then submerged for 24 h in a curing liquid that consisted of the extract of dried green tea leaves. Briefly, tea was purchased from the Bosung area in Chonnam, Korea, and 200 g was weighed, transferred to ethanol solution (70%), and extracted overnight. Extraction was performed twice. The formulation for the production of jerky is presented in Table 1. The cured samples were then mixed using a mixer (5K5SS, KitchenAid, USA) for 1 min, after which they were aged for 24 h in refrigerated temperature. All cured muscles samples were placed on a netted tray and sun-dried in an open sunny spot with good air circulation at $30\text{--}32^{\circ}\text{C}$ and 26–28% RH for 3.5 h. The jerky samples were loosely packed in oxygen impermeable plastic bags and displayed at room temperature for up to 20 d for analysis.

Proximate composition

The proximate composition was obtained with a slightly modified method of AOAC (2000). Briefly, the total moisture content of 3 g samples placed in aluminum moisture dishes were determined from their weights before and

after drying in an air oven at 104°C for 24 h and expressed as the percentage of pre-dry weight and grams of water per gram of dry weight. The crude fats were extracted from 5 g of meat with chloroform/methanol (2:1) according to the method described by Folch *et al.* (1957). The crude ash content was measured by heating the sample (2 g) in a furnace at 600°C for 6 h. The crude protein content was measured by the Kjeldahl method (VAPO45, Gerhardt Ltd., Idar-Oberstein, Germany).

Water activity (a_w)

Three pieces of the dried jerky samples from each treatment were selected and cut into small pieces using sharp scissors, then homogenized prior to measurement of a_w . The pieces were put into a_w cups, and their a_w was determined with an a_w meter (BT-RS1, Rotronic, Switzerland) that had been calibrated at ambient temperature (25°C) with distilled water ($a_w = 0.999$).

pH measurement

The pH of the samples was determined using a pH meter (Orion 2 Star, Thermo scientific, USA) after blending a 3 g sample with 27 mL distilled water for 60 s in a homogenizer (Polytron PT 10-35 GT, Kinematica AG, Switzerland). The electrode was calibrated with pH 4.01 and 7.00 standard buffers equilibrated at 25°C for the measurements.

Instrumental measurement of color

The surface color value of samples was measured by the CIE L^* , a^* and b^* system using a Minolta chromameter (Model CR-410, Minolta Co. Ltd., Japan), with measurements standardized with respect to a white calibration plate ($L^* = 89.2$, $a^* = 0.921$, $b^* = 0.783$) after 30 min at room temperature. Color measurement for each sample was conducted in triplicate. Areas having excess fat were avoided during color measurement.

Fatty acid analysis

Total fat for fatty acid analysis was extracted according to the method described by Folch *et al.* (1957). After thawing the samples, the lipids in a 5 g sample were extracted in chloroform/methanol (2:1), with BHT as an antioxidant (Bligh and Dyer, 1959). The methyl esters from fatty acids (FAMES) were formed using a KOH solution in methanol. The fatty acid methyl esters (FAME) were extracted with water and hexane. The top hexane layer containing FAME was dehydrated through anhydrous Na_2SO_4 . The extracted and dehydrated hexane was transferred

to a vial for analysis.

Separation and quantification of the fatty acid methyl esters was conducted using a gas chromatograph (GC, Agilent 7890N, Agilent Technologies Seoul, Korea) equipped with a flame ionization detector automatic sample injector HP 7693, and using a DB-WAX fused silica capillary column (30 m, 0.25 mm i.d., 0.2 μ film thickness, Agilent Technologies Seoul, Korea). Helium was applied as a carrier gas at a 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, where it was held 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 (Catalogue number H3500, Sigma-Aldrich Inc., USA). The FAME in the total lipids was identified by comparison of the retention times with those of a standard FAME mixture (Supleco™ 37 Component FAME Mix, Catalogue number 47885-UP, Lot number, LB-85684, Sigma-Aldrich Inc., USA). Fatty acids were expressed as a percentage of total fatty acids identified and grouped as follows: SFA, MUFA and PUFA. The PUFA/SFA and n-6/n-3 ratios were calculated.

Sensory evaluations

The samples were cut into 20 × 20 × 20 mm thick slices and cooked on an electrical grill (Nova EMG-533, 1,400 W, Evergreen Enterprise, Korea) at 100°C for 1 min. During the sensory training sessions, there was both discussion and sensory assessment of representative samples. The attributes color, flavor, juiciness, tenderness and acceptability were assessed. The sensory scores were evaluated independently by 20 trained sensory panelists using random cubes of each sample after making sun-dried jerky using a nine-point quantitative descriptive method ranging from dislike/weak extremely (score 1) to like/strong extremely (score 9). The mean values of three repeated measurements were determined.

Microbiological analysis

The jerky samples (1 g) were placed in 9 mL sterilized peptone water (1% sterile peptone, w/v) in a sterile stomacher bag. Samples were then homogenized using a stomacher (Interscience Bag Mixers, Hanover, USA) for 2 min and diluted with peptone water for the microbial count. Stomached samples were 10-fold serially diluted with saline solution, after which total aerobic bacteria were enumerated by plating the diluted samples on plate count agar petrifilms (3M, USA) in triplicate and incubating the pla-

tes at 35°C for 48 h. Each microbial count was the mean of three determinations. Microbial colonies were counted and expressed as colony forming units per gram of sample (CFU/g).

TBARS (2-thiobarbituric acid reactive substance)

TBARS values were determined after various storage times. The TBARS of samples were analyzed using a modified version of the method described by Ahn *et al.* (1998). Briefly, a 5 g sample was homogenized with 15 mL of distilled water using a homogenizer (Polytron PT 10-35 GT, Kinematica Co., Switzerland) for 2 min, then transferred to a 100 mL falcon tube. Next, 1 mL of solution was placed in test tubes and 50 mL buylated hydroxytoluene (7.2% in ethanol, w/v) and 2 mL thiobarbituric acid/trichloroacetic acid solution (20 mM TBA/15%, w/v) were added. The mixture was then vortexed and incubated in a 90°C boiling water bath for 15 min to develop color. The sample was cooled in cold water for 10 min, after which it was centrifuged for 15 min at 3,000 *g*. The absorbance of the resulting supernatant solution was determined at 531 nm against a blank containing all reagents minus the sample. Next, 1 mL of distilled water was added to a test tube and mixed with 2 mL of TBA/TCA solution as a blank sample. The TBARS value of each product was determined in triplicate. The amount of color was measured in a UV spectrophotometer (T60 U., Karaltay Scientific Instruments Co., China). The results were expressed as mg malonaldehyde/kg sample.

Statistical methods

All data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the SAS statistical package (SAS, 2002). Duncan's multiple range test ($p < 0.05$) was used to identify significant differences among treatment means.

Results and Discussion

Physicochemical characteristics, fatty acid composition and sensory evaluations

The proximate composition of beef and venison jerky amended with green tea powder is shown in Table 1. The proximate composition of jerky differed significantly between beef and venison. However, there were no significant differences in proximate compositions of venison among treatments. The moisture content in venison ranged from 21.00% to 25.11%. These findings are in agreement with those of Chen *et al.* (2002), stated that jerky is

Table 1. Formula for the preparation of beef and venison jerky added with green tea powder

Ingredient	Treatment (g)			
	Control	T1	T2	T3
Beef	400 (100%)			
Venison		400 (100%)	400 (100%)	400 (100%)
Water	48 (12%)	48 (12%)	48 (12%)	48 (12%)
Sodium chloride	8 (2%)	8 (2%)	8 (2%)	8 (2%)
Brown sugar	8 (2%)	8 (2%)	8 (2%)	8 (2%)
Sodium nitrite	0.02 (0.005%)	0.02 (0.005%)	0.02 (0.005%)	0.02 (0.005%)
Phosphate	0.4 (0.1%)	0.4 (0.1%)	0.4 (0.1%)	0.4 (0.1%)
Ascorbic acid	2 (0.5%)	2 (0.5%)	2 (0.5%)	2 (0.5%)
Ginger powder	4.8 (1.2%)	4.8 (1.2%)	4.8 (1.2%)	4.8 (1.2%)
Onion powder	4.8 (1.2%)	4.8 (1.2%)	4.8 (1.2%)	4.8 (1.2%)
Garlic powder	4.8 (1.2%)	4.8 (1.2%)	4.8 (1.2%)	4.8 (1.2%)
Black pepper	0.64 (0.16%)	0.64 (0.16%)	0.64 (0.16%)	0.64 (0.16%)
Green tea powder			2 (0.5%)	4 (1%)

Table 2. Proximate composition of venison jerky added with green tea powder

Treatment ¹	Moisture	Crude fat	Crude ash	Crude protein
Control	34.11 ^a	13.51 ^a	6.66 ^b	44.24 ^b
T1	25.11 ^b	5.51 ^b	9.10 ^a	54.42 ^a
T2	22.00 ^b	4.24 ^b	8.39 ^a	56.82 ^a
T3	21.00 ^b	4.29 ^b	8.80 ^a	58.22 ^a
SEM ²	1.78	1.19	0.33	1.70

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=15).

^{a,b}Figures with different letters within the same column differ significantly ($p < 0.05$).

Table 3. Water activity and pH of venison jerky added with green tea powder during storage

Treatment	Storage (d)			SEM
	0	10	20	
Water activity				
Control	0.82 ^{ax}	0.81 ^{ay}	0.77 ^{az}	0.22
T1	0.70 ^b	0.72 ^b	0.73 ^b	1.49
T2	0.65 ^{cy}	0.73 ^{bx}	0.72 ^{bx}	0.95
T3	0.62 ^{cy}	0.68 ^{cx}	0.66 ^{cx}	0.72
SEM ²	2.37	1.41	1.23	
pH				
Control	5.82 ^{ax}	5.66 ^y	5.66 ^{aby}	0.00
T1	5.78 ^{bx}	5.68 ^y	5.65 ^{abz}	0.01
T2	5.79 ^{abx}	5.65 ^y	5.67 ^{az}	0.01
T3	5.79 ^{abx}	5.69 ^y	5.64 ^{by}	0.01
SEM	0.01	0.01	0.00	

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=15).

^{a-c}Figures with different letters within the same column differ significantly ($p < 0.05$).

^{x-z}Figures with different letters within the same row differ significantly ($p < 0.05$).

classified as an intermediate moisture (IM) meat product, with moisture contents of 20% to 25%. The crude fat content in venison ranged from 5.51% to 4.24%, which was similar to the results reported by Yang (2009), who reported that the crude fat content of venison jerky ranged from 4.14% to 5.11%. The moisture and crude fat contents were lower in venison than beef, while the crude ash and protein contents were higher in venison ($p < 0.05$). Mois-

ture content in jerky determines both their texture and shelf life (Konieczny *et al.*, 2007). The changes in water activity (a_w) and pH of beef and venison jerky amended with green tea powder during storage are shown in Table 3. The a_w of jerky samples varied from 0.82 to 0.62 with storage, and all jerky samples showed significant changes among treatments during storage ($p < 0.05$). Moreover, there were significant differences in a_w between beef and

venison jerky ($p < 0.05$). This might have been due to differences between beef and venison muscles. The T3 (venison + green tea 1%) samples showed a lower a_w than all other samples ($p < 0.05$). Jerky should have a stable a_w to avoid changes in meat quality during storage (Yamaguchi *et al.*, 1986). Our results indicate that venison jerky would be better than beef jerky owing to the lower moisture content and a_w during storage. The pH values in venison jerky ranged from 5.64 to 5.82, which were lower than those in beef jerky at day 0. Spoilage of various dried meat products by mold growth can be inhibited or delayed by reducing the pH (Leistner, 1987).

The color values of beef and venison jerky amended with green tea powder during storage are presented in Table 4. Beef jerky (control) samples showed significantly higher L^* , a^* and b^* values than all other jerky samples at day 0 ($p < 0.05$). Moreover, the T2 and T3 (green tea addition) groups showed significantly lower a^* and b^* values than the other groups at day 0 ($p < 0.05$). The color stability of venison was poor, suggesting the meat is prone to oxidative deterioration (Stevenson-Barry *et al.*, 1999).

The fatty acid composition of beef and venison jerky amended with green tea powder is shown in Table 5. The most abundant compound in beef jerky is C18:1, followed by C16:0, C16:1 and C18:0, while that in venison was C16:0, followed by C18:1, C18:2 and C16:1. It can be assumed that the lower percentage of C18:1 (oleic

acid) present in venison jerky was due to differences in the animal's diet or to ruminal hydrogenation phenomena (Ekeren *et al.*, 1992). Significant differences in most fatty acids were found among jerky samples. Consequently, significant changes in the percentage of SFA (saturated fatty acid), UFA (unsaturated fatty acid), MUFA (mono-unsaturated fatty acid) and PUFA (polyunsaturated fatty acid) in jerky samples were observed. SFA (%) in T1 samples was significantly higher than in the control (beef). However, SFA in T2 and T3 were lower than in T1 ($p < 0.05$). UFA levels, especially, PUFA in the control, were significantly higher than in T1. However, PUFA contents were higher in T2 and T3 amended with green tea powder, which showed the highest percentages of linoleic acid (C18:2) and linolenic acid (C18:3). The polyunsaturated/saturated fatty acid (PUFA/SFA) ratio is used to assess the nutritional quality of the lipid fraction in foods. Consequently, nutritional guidelines have recommended that the PUFA/SFA ratio should be above 0.4-0.5 (Wood *et al.*, 2008). Banskalieva *et al.* (2000) reported PUFA/SFA ratios for different muscles that ranged from 0.16 to 0.49 in goat meat. In this study, the PUFA/SFA ratios of T2 and T3 were higher than those of the control and T1. In the present experiment, the fatty acid composition of venison jerky amended with green tea powder was superior to that of unamended jerky.

Sensory evaluation of beef and venison jerky amended

Table 4. CIE color of venison jerky added with green tea powder during storage

Treatment ¹	Storage (days)			SEM ²
	0	10	20	
L*(Lightness)				
Control	32.14 ^{ay}	35.98 ^x	27.91 ^z	0.29
T1	30.43 ^{by}	36.59 ^x	28.62 ^z	0.38
T2	29.81 ^{by}	36.38 ^x	28.42 ^z	0.28
T3	29.53 ^{by}	36.85 ^x	28.44 ^z	0.28
SEM	0.33	0.21	0.12	
a*(Redness)				
Control	17.55 ^{ax}	4.23 ^y	5.68 ^y	0.47
T1	13.50 ^{bx}	7.19 ^y	2.34 ^z	1.24
T2	6.23 ^{cx}	6.00 ^y	2.98 ^z	0.16
T3	6.33 ^c	5.24	2.55	0.15
SEM	1.47	0.69	0.12	
b*(Yellowness)				
Control	5.27 ^{ax}	2.67 ^y	1.93 ^{ay}	0.18
T1	2.91 ^{bx}	1.93 ^{xy}	0.67 ^{bz}	0.46
T2	1.13 ^{cx}	1.46 ^x	0.79 ^{by}	0.05
T3	1.54 ^c	1.51	0.74 ^b	0.06
SEM	0.49	0.24	0.16	

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=15).

^{a-c}Figures with different letters within the same column differ significantly ($p < 0.05$).

^{x-z}Figures with different letters within the same row differ significantly ($p < 0.05$).

Table 5. Fatty acid composition of venison jerky added with green tea powder

Fatty acid	Treatment ¹	Control	T1	T2	T3	SEM ²
C15:1		0.54 ^d	3.90 ^c	5.78 ^a	4.57 ^b	0.19
C16:0		29.36 ^a	30.29 ^a	26.15 ^c	28.48 ^b	0.49
C16:1		8.33 ^a	7.95 ^a	7.64 ^b	8.44 ^a	0.20
C17:0		0.45 ^a	0.43 ^c	0.33 ^c	0.37 ^b	0.01
C17:1		0.75 ^a	0.24 ^c	0.24 ^c	0.27 ^b	0.01
C18:0		6.87 ^b	11.55 ^a	10.89 ^a	10.80 ^a	0.23
C18:1		44.80 ^a	25.48 ^b	22.24 ^c	23.50 ^c	0.27
C18:1t		1.13 ^a	0.53 ^b	0.44 ^c	0.55 ^b	0.02
C18:2		2.45 ^c	8.75 ^b	11.64 ^a	9.96 ^a	0.30
C18:3		0.11 ^b	0.13 ^b	0.52 ^a	0.66 ^a	0.06
C20:0		0.04 ^a	0.03 ^a	0.00 ^b	0.00 ^b	0.01
C20:1		0.23 ^b	0.32 ^a	0.23 ^b	0.24 ^b	0.02
C20:3		0.31 ^c	0.31 ^c	0.49 ^a	0.38 ^b	0.02
C20:4		0.74 ^d	6.32 ^c	9.50 ^a	7.84 ^b	0.31
SFA ⁴		36.73 ^c	42.30 ^a	37.38 ^c	39.64 ^b	0.59
UFA		59.39 ^a	53.95 ^c	58.68 ^a	56.41 ^b	0.54
PUFA		3.60 ^d	15.52 ^c	22.12 ^a	18.84 ^b	0.60
MUFA		55.79 ^a	38.43 ^b	36.56 ^d	37.57 ^c	0.21
UFA/SFA		1.62 ^a	1.28 ^c	1.57 ^a	1.42 ^b	0.04
P/S		0.10 ^c	0.37 ^b	0.59 ^a	0.48 ^a	0.03

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=15).

^{a-d}Figures with different letters within the same row differ significantly ($p<0.05$).

⁴SFA: saturated fatty acid, UFA: unsaturated fatty acid, MUFA: monounsaturated fatty acid, PUFA: polyunsaturated fatty acid.

Table 6. Sensory evaluation of venison jerky added with green tea powder

Treatment ¹	Color	Flavor	Tenderness	Juiciness	Saltiness	Acceptability
Control	6.75 ^a	6.50 ^a	7.50 ^a	7.50 ^a	5.25 ^a	7.25 ^a
T1	3.50 ^c	3.25 ^b	5.75 ^b	5.75 ^b	3.75 ^b	3.75 ^b
T2	7.00 ^a	6.75 ^a	2.75 ^c	3.00 ^c	4.25 ^a	5.75 ^a
T3	5.25 ^b	4.50 ^b	3.50 ^c	3.25 ^c	2.50 ^b	2.75 ^c
SEM ²	0.40	0.42	0.50	0.50	0.30	0.55

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=20).

^{a-c}Figures with different letters within the same column differ significantly ($p<0.05$).

with green tea powder is presented in Table 6. Overall, the control showed the highest sensory test results. In particular, tenderness and juiciness scored better in the control than other samples, probably because of the high fat content in beef jerky. Green tea powder treatments resulted in significant differences in tenderness and juiciness ($p<0.05$). Sensory scores for color, flavor, saltiness and acceptability in the control were similar to those for T2, indicating that sensory evaluation was affected by the addition of 0.5% green tea powder to venison jerky. The amount and type of fat in meat influence two major components of meat quality, tenderness and flavor (Wood *et al.*, 2008). In general, the intramuscular fat (IMF) content is correlated with meat tenderness (Wood *et al.*, 2003). Lipids are also one of the major flavor precursors in meat (Mottram, 1983). High proportions of PUFA reduce the

oxidative stability of lipids, which could have negative effects on sensory characteristics of fresh meat and meat products (Nawar, 1996). Overall, the results presented herein indicate that further research is required to identify and verify differences in meat quality of beef and venison muscles.

Microbiological test (TPCs) and TBARS values

The changes in total plate counts of beef and venison jerky amended with green tea powder during storage are shown in Table 7. The total plate counts of all jerky samples increased with storage ($p<0.05$). There were no significant differences among control and treatment groups until 10 d of storage, at which time the total plate counts of T2 and T3 were significantly lower than those of other jerky samples at 20 d of storage ($p<0.05$). The low micro-

Table 7. Total plate count (TPC) of venison jerky added with green tea powder during storage

Treatment ¹	Storage (d)			SEM ²
	0	10	20	
TCP (log CFU/g)				
Control	2.74 ^z	3.15 ^y	4.08 ^{ax}	0.38
T1	2.87 ^y	2.65 ^y	3.60 ^{bx}	0.36
T2	2.48 ^y	2.85 ^y	3.30 ^{cx}	0.00
T3	ND	2.30 ^y	3.00 ^{cx}	0.17
SEM	0.40	0.34	0.09	

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=15).

^{a-c}Figures with different letters within the same column differ significantly ($p < 0.05$).

^{x-z}Figures with different letters within the same row differ significantly ($p < 0.05$).

bial levels in venison jerky amended with green tea powder appear to be related to its low moisture content and a_w . This result supports the finding that microbial growth is inhibited at a low a_w (Gould and Christian, 1988). It is widely accepted that many food spoilage bacteria are unable to multiply at an a_w value below 0.95 and that growth of most microorganisms is retarded or inhibited below a_w at 0.90 (Leistner, 1987). In this study, a_w values of venison jerky samples were 0.73 to 0.62, which were lower than those of jerky samples.

The addition of 0.5% green tea powder to venison was sufficient to delay the growth of total aerobic bacteria during storage. Some authors have suggested that green tea has antimicrobial activity. However, results showing antibacterial activity of tea extract components against bacterial pathogens have been inconsistent because of variability of the methods used (e.g., different varieties of tea, different processing and extraction procedures), and the mechanisms of action described in the literature remain controversial (Si *et al.*, 2006). Further study concerning meat safety is needed to investigate the effects of addition of green tea to meats on controlling microorganism spoilage. Nevertheless, the results presented herein suggest that venison jerky amended with green tea powder may be safer from microbial growth than beef jerky

under the same processing conditions because of a reduction of a_w and the antibacterial activity in green tea.

The changes in TBARS values of beef and venison jerky amended with green tea powder during storage are presented in Table 8. The TBARS value of jerky samples increased significantly during storage, except for that of T3, which showed significantly lower TBARS values than other samples. The control showed the highest TBARS value during storage ($p < 0.05$). These findings indicate that beef jerky is more susceptible to lipid oxidation than venison jerky during storage. This might have been due to differences in lipid stability owing to differences in the fat content and fatty acid composition between species. Green tea treatments (T2 and T3) effectively reduced lipid oxidation in venison jerky compared to the control and T1. Many studies have suggested that the addition of tea catechins inhibited lipid oxidation (Maher *et al.*, 2002; Tang *et al.*, 2001). According to McCarthy *et al.* (2001), the optimum concentration in the antioxidant activities of tea catechins ranged from 0.25% to 1% (2500-10,000 mg/kg) in meat. Our results indicated that concentrations of green tea powder greater than 0.5% had good antioxidant effects.

Therefore, it is conceivable that venison jerky, in comparison to beef jerky, might have less lipid oxidation

Table 8. TBARS values of venison jerky added with green tea powder during storage

Treatment ¹	Storage (d)			SEM ²
	0	10	20	
(mg malonaldehyde/kg)				
Control	0.31 ^{ay}	0.42 ^{ax}	0.42 ^{ax}	0.01
T1	0.29 ^{by}	0.34 ^{bx}	0.34 ^{bx}	0.01
T2	0.25 ^{cy}	0.33 ^{bx}	0.32 ^{cx}	0.01
T3	0.23 ^d	0.29 ^c	0.31 ^c	0.01
SEM	0.01	0.01	0.01	

¹Control: beef, T1: venison, T2: venison + green tea (0.5%), T3: venison + green tea (1%), ²Standard error of the means (n=15).

^{a-d}Figures with different letters within the same column differ significantly ($p < 0.05$).

^{x-y}Figures with different letters within the same row differ significantly ($p < 0.05$).

because of a low a_w during storage. Additionally, venison jerky added with green tea powder was superior to that of unamended samples for lipid oxidation in this study. Our results indicate that venison jerky amended with green tea powder would be better than beef jerky at inhibiting of microbial growth and retarding lipid oxidation because of its lower moisture and fat contents.

Acknowledgements

This study was supported in part by the Economy Cooperation Supporting Business (R005730-1), Ministry of Trade, Industry and Energy.

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