

Comparison of Meat Quality Characteristics and Aromatic Substances of Korean Native Black Goat Ribs by Different Sex

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Abstract This study was conducted to compare the meat quality characteristics and aromatic substances in rib cut of Korean native black goat (KNBG) based on gender. Comparison of the proximate composition, including moisture, crude protein, crude fat, and crude ash content, of the ribs from female and male KNBGs did not show a significant difference. The meat quality characteristics, such as water holding capacity (WHC), cooking loss, and shear force, did not show a significant difference when compared by gender. However, the pH of rib meat from female KNBGs was significantly higher than that of male KNBGs ($p = 0.001$). Meat color characteristics represented by lightness (L^*) and yellowness (b^*) of ribs from female KNBGs were significantly higher than those of male KNBGs. Fatty acid analysis revealed highest amount (44.74-45.93%) of oleic acid (C18:1n9) in ribs regardless of gender, while the amount of saturated fatty acids (C14:0 and C16:0) was significantly higher in ribs from female than male KNBGs ($p < 0.05$). However, the overall ratios of saturated and unsaturated fatty acids in the rib meat were 41.89-44.83% and 55.17-58.11%, respectively, while no significant difference was found based on gender. The aromatic substances in the rib meat differed significantly based on gender (PC1, 99.768%). Particularly, in rib meat from female KNBGs, ethanol content was significantly higher, lending a distinguished aroma to the meat when compared to that from male KNBGs. Further, 2-butane was detected in female KNBG meat alone while Z-3-hezen-1-ol, acetate was detected in male meat. These data indicated that pH and color (L^* and b^*) of the rib meat from male and female KNBGs differed significantly; particularly, 2-butane and Z-3-hezen-1-ol, acetate may be potentially used as biomarkers for gender discrimination of KNBG meat.

Keywords: Korean native black goat, ribs, meat quality, volatile compound, aromatic substance

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1. Introduction

Over 100 million goats (*Capra hircus*) comprising approximately 570 species are reared worldwide and represent one of the most widely distributed types of livestock [1]. The goats of each country have unique morphological characteristics, and their ability to adapt to different climates is better than that of other ruminant species [2].

In Korea, dairy and meat goat breeds were imported and distributed to farmers; since then, the quality of goats used for meat production has been largely improved, and crossbred goats have been reared for meat production. Korean native black goats (KNBGs) are less productive with respect to meat production because they grow slowly, requiring more than 24 months to mature, and are small in

size; owing to their low value, these goats have become endangered [3].

In Korea, KNBG meat is consumed as a medicinal extract rather than as food [4]. In recent years, with the increasing demand for healthy food and livestock products, the consumption of goat meat has transitioned from extract to food (meat roasted or boiled and soup) [3,4]. In fact, the rib cut is the most consumed among these. However, goat meat is less juicy owing to the lower fat mass under the skin and muscle compared to other meats [5]. Moreover, goat meat has a stronger singular odor compared to other meats, which may be unappealing to some consumers, particularly when the meat is grilled [6]. Thus, many recent studies have focused on reducing the smell of burning fat in KNBG; furthermore, to reduce the odor of goat meat, castrated billy goats or female goats are typically produced for the market [7,8].

Despite these limitations, goat meat can be prepared as a variety of dishes and is widely consumed by people from different cultures because unlike beef and pork, it is not prohibited by religious and cultural traditions.

In this study, differences in the quality characteristics and aromatic substances in rib meat from male and female KNBGs were compared.

2. Materials and Methods

2.1. Experimental Animals

The protocols used for animal experiments were approved by the Animal Protection Law and the National Institute of Animal Science Animal Test Ethics Committee (approval no.: 2019-320) in agreement with the Animal Care and Use Protocols of the Rural Development Administration National Institute of Animal Science. The KNBGs used in this study are a long-lived breed of goats preserved as a gene resource in the Livestock Genetic Resources Center, National Institute of Animal Science, Rural Development Administration. The KNBGs were fed concentrated fodder (1.5% of the animal weight each day) and provided with free access to dry grass and water.

2.2. Testing Materials

We randomly selected male and female goats aged 28 months for the study. The mean weights of female and non-castrated male goats were 25.3 ± 2.19 and 62.6 ± 9.8 kg, respectively. Feeding was stopped at 12 h before slaughter. After slaughter, the animals were refrigerated at 5°C for 24 h. The rib meat from male and female goats was collected and used to analyze the meat quality and aromatic substances.

2.3. Proximate Composition

We determined the moisture, crude fat, crude ash, and crude protein contents in accordance with AOAC methods [9]. Moisture was analyzed using the normal pressure drying method by heating at 105°C. The crude fat content was determined using the Soxhlet extraction method, crude ash was determined using the dry ashing method at 550°C, and crude protein content was quantified using the Kjeldahl method.

2.4. Meat pH and Color

For pH analysis, 10-g sample was homogenized in 90 mL of distilled water and the pH was measured using a pH meter (Orion Star A211, Thermo Fisher Scientific, Waltham, MA, USA). Meat color was determined using a color-difference meter (Colormeter CR-300, Minolta Co., Osaka, Japan). We determined the lightness (L^*), redness (a^*), and yellowness (b^*) values repeatedly in the same manner and obtained the mean values. For standardization, we used a standard white plate where the Y value was 93.60 (x 0.3134, y 0.3194).

2.5. Water-Holding Capacity

For water-holding capacity analysis, approximately 0.5-g sample was heated in a water tank for 20 min at a constant temperature of 80°C. The sample was then cooled at room temperature for 10 min and centrifuged at $2,000 \times g$ for 20 min, prior to weight measurement. The water-holding capacity was calculated using the following formula:

$$\text{Water-holding capacity (\%)} = [(\text{total moisture} - \text{free moisture})/\text{total moisture}] \times 100$$

$$\text{Free moisture} = [(\text{weight before centrifugation} - \text{weight after centrifugation})/(\text{specimen} \times \text{fat factor})] \times 100$$

$$\text{Fat factor} = 1 - (\text{fat content})/100$$

2.6. Cooking Loss and Shear Force

For cooking loss analysis, the sample was placed in a polyethylene bag and heated in a water tank at a constant temperature until the core temperature of the meat reached $75 \pm 2^\circ\text{C}$. We then calculated heat loss by converting the difference in weight before and after heating into percentage.

For shear force analysis, the sample was heated as described above. We then cut the sample into $2 \times 1 \times 1\text{-cm}^3$ pieces perpendicularly in the direction of the muscle fiber. We used a Texture Analyzer TA 1 (LLOYD Instruments, Fareham, UK) and measured with a V blade. The measurement conditions comprised a test speed of 50 mm/min and load cell of 500 N.

2.7. Fatty Acid Composition

The fatty acid composition was analyzed as described by Kim et al. [9]. We used Folch solution (2:1 chloroform:methanol) for fat extraction. The sample was placed in a test tube containing 1.5 mL 0.5 N NaOH-methanol solution, mixed by vortexing, and heated at 100°C for 5 min. The sample was cooled in cold water, mixed with 2 mL 10% BF_3 -methanol solution (Supelco, Bellefonte, PA, USA) by vortexing, heated again at 100°C for 2 min, and then cooled. We added 2 mL of iso-octane and mixed the sample by vortexing for 1 min to extract fatty acid methyl esters. Saturated 1 mL NaCl solution was added and mixed thoroughly by vortexing for 1 min. The organic layer was separated using a centrifugal separator (2,000 rpm, 3 min, 15°C), and the supernatant was used for gas chromatography (GC) analysis. The details of the conditions for GC analysis are given in Table 1.

Table 1. GC Conditions for Fatty Acid Analysis

Item	Condition
Instrument	6890N, Agilent Technologies, Santa Clara, CA, USA
Column	Omegawax 250 (30 m \times 0.25 mm id, 0.25 μm film thickness; Supelco, Bellefonte, PA, USA)
Detector	Flame ionization detector
Carrier gas	Helium (99.99%, research purity)
Column flow rate	1.0 mL/min
Split ratio	100:1, 1 μL (injection volume)
Injection port temperature	250°C
Detection port temperature	260°C
Oven temperature	150°C, hold for 2 min 4°C/min up to 220°C, hold for 30 min

2.8. Aromatic Substances

To analyze aromatic substances in the rib meat samples, we used the electronic nose system HERACLES II (Alpha MOS, Toulouse, France). We placed the sample (2 g) in a 10-mL vial and collected the headspace at 40°C for analysis with flame ionization detectors in a system with two columns (MXT-5, MXT-1701) mounted in parallel. The collection time was 5 min and the analysis was conducted when the adsorption and desorption temperatures at the trap were 40°C and 270°C, respectively. The data were analyzed using the AlphaSoft software (AlphaSoft, Alpha MOS).

2.9. Statistical Analysis

For statistical analysis, the mean values of each test were evaluated at the level of $p < 0.05$ by t -test using the SAS version 9.1 software (Statistical Analysis System, Cary, NC, USA).

3. Results and Discussion

3.1. Proximate Composition of KNBG Ribs Segregated by Sex

The comparison of the composition of ribs from male and female KNBGs is presented in Table 2. The moisture, crude protein, crude fat, and crude ash contents in ribs from female KNBGs were 77.53%, 18.02%, 6.15%, and 1.01%, respectively; these values for ribs from male KNBGs were 73.27%, 19.54%, 7.07%, and 1.03%, respectively. The composition did not significantly differ between ribs from male and female goats.

Kim et al. [11] reported that for KNBG meat, the moisture was 70.40%, crude protein was 21.33%, and crude fat was 8.67%, similar to the results of this study. Joo et al. [12] reported that depending on the region, the crude fat content in KNBG meat was approximately 1.5%, whereas we found a high crude fat content of 6.15-7.07%. The moisture, crude protein, crude fat, and crude ash contents of black goat meat were reported to be 75.00-75.49%, 21.30-21.60%, 1.40-1.46%, and 1.25-1.46%, respectively, depending on the region [13].

Table 2. Proximate Composition of KNBG Ribs by Sex

Item (%)	Female	Male	<i>p</i> -value
Moisture	75.53 ± 3.54	73.27 ± 2.66	0.2405
Crude protein	18.02 ± 1.07	19.54 ± 1.89	0.1196
Crude fat	6.15 ± 3.86	7.07 ± 5.52	0.7446
Crude ash	1.01 ± 0.09	1.03 ± 0.05	0.6401

3.2. Meat Quality of KNBGs Ribs Segregated based on Sex

The meat quality characteristics of KNBG ribs based on sex are shown in Table 3. The pH of female KNBG ribs was 6.46, which was significantly higher than that of male ribs ($p = 0.001$). pH is closely related to the quality of meat, and parameters such as the water-holding capacity

and age are instrumental for evaluating meat quality [14]. Kim et al. [10] reported that the pH of the KNBG loin is 5.5. In the present study, the pH of ribs was 6.21-6.46, which is higher than that of the loin.

For the meat color, the L^* and b^* values of ribs from female KNBGs were significantly higher than those of male ribs ($p < 0.05$), whereas the a^* value did not significantly differ. However, Lee et al. [15] reported that beef loin samples from female goats had lower L^* and b^* values than samples from male and castrated goats, suggesting that the meat color depends on the species.

Studies have shown that the water-holding capacity is influenced by the pH, sarcomere length, and protein denaturation, and can influence the appearance of meat.

Table 3. Meat Quality Characteristics of Korean Native Black Goat Ribs Based on Sex

Item	Female	Male	<i>p</i> -value	
pH	6.46 ± 0.13	6.21 ± 0.03	0.0010	
Meat color	L^*	38.68 ± 0.66	33.81 ± 3.46	0.0069
	a^*	22.92 ± 1.06	21.22 ± 1.70	0.0641
	b^*	9.88 ± 0.76	8.70 ± 0.98	0.0435
WHC (%)	44.96 ± 1.78	46.26 ± 1.91	0.2504	
Cooking loss (%)	29.79 ± 2.88	29.00 ± 3.24	0.6612	
Shear force (N)	35.87 ± 3.42	34.78 ± 2.65	0.5517	

3.3. Fatty Acid Composition of KNBG Ribs Segregated by Sex

Table 4. Fatty Acid Composition of KNBG Ribs Segregated by Sex

Fatty acid (%)	Female	Male	<i>p</i> -value
C14:0(myristic acid)	2.36 ± 0.17	3.63 ± 0.35	<0.001
C16:0(palmitic acid)	22.79 ± 0.32	24.77 ± 1.32	0.0052
C16:1n7(palmitoleic acid)	2.31 ± 0.80	2.16 ± 0.26	0.6726
C18:0(stearic acid)	16.73 ± 3.67	16.43 ± 0.39	0.8463
C18:1n9(oleic acid)	45.93 ± 8.38	44.74 ± 3.97	0.7600
C18:1n7(vaccenic acid)	1.32 ± 0.20	1.35 ± 0.12	0.7469
C18:2n6(linoleic acid)	4.38 ± 2.45	4.91 ± 1.82	0.6768
C18:3n6(<i>r</i> -linolenic acid)	0.00 ± 0.00	0.00 ± 0.00	-
C18:3n3(<i>a</i> -linolenic acid)	0.35 ± 0.15	0.32 ± 0.04	0.6308
C20:1n9(eicosenoic acid)	0.32 ± 0.02	0.33 ± 0.03	0.2049
C20:4n6(arachidonic acid)	3.04 ± 2.61	1.21 ± 0.43	0.1205
C20:5n3(eicosapentaenoic acid, EPA)	0.13 ± 0.15	0.00 ± 0.00	0.0545
C22:4n6(adrenic acid)	0.34 ± 0.22	0.14 ± 0.02	0.0539
C22:6n3(docosahexaenoic acid, DHA)	0.00 ± 0.00	0.00 ± 0.00	-
SFA	41.89 ± 3.81	44.83 ± 2.03	0.1259
UFA	58.11 ± 3.81	55.17 ± 2.03	0.1259
MUFA	49.88 ± 9.37	48.59 ± 4.33	0.7646
PUFA	8.24 ± 5.57	6.58 ± 2.30	0.5176
MUFA/SFA	1.22 ± 0.33	1.09 ± 0.15	0.4101
PUFA/SFA	0.19 ± 0.12	0.15 ± 0.04	0.4288

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

The comparison of the fatty acid composition of KNBG ribs by sex are presented in Table 4. The predominant fatty acid in KNBG ribs was oleic acid (C18:1n9) with an abundance of 44.74-45.93%, followed by palmitic acid (C16:0; 22.79-24.77%), stearic acid (C18:0), and linoleic

acid (C18:2n6). These results are consistent with the previously reported fatty acid composition of KNBG and black goat meat [11,13,17]. The ribs of female KNBGs showed a significantly higher content of the saturated fatty acids C14:0 and C16:0 compared to those from male KNBGs ($p < 0.05$). However, the overall saturated fatty acid and unsaturated fatty acid ratio was 41.89-44.83% and 55.17-58.11%, respectively, revealing no significant difference between the sexes. The content of oleic acid in beef is positively correlated with flavor; a high marbling score is associated with a high ratio [18]. In the present study, the crude fat and oleic acid contents did not significantly differ by sex.

3.4. Aromatic Substances in KNBG Ribs Segregated by Sex

Principal component analysis of aromatic substances in KNBG ribs by sex and from the radar plot using the electronic nose are presented in Figure 1. The peaks of the main aromatic substances were classified by considering reproducibility (% regular standard deviation ≤ 25) and discrimination power (discrimination index ≥ 0.98) before the analysis. The results of principal component analysis showed that the difference in relative aromatic substances in KNBG ribs by sex for principal component 1 (PC1) was 99.768% and principal component 2 (PC2) was 0.2285%, giving a total of 99.9965%, indicating the high

reliability of the results. Particularly, for PC1, the odor components by sex were distinctly separated (Figure 1A).

Comparison of the odor patterns using radar plots showed that the difference in odor of KNBG ribs by sex was due to the differences in the types of components but not due to the differences in intensity (Figure 1B).

The differences in aromatic substances in KNBG ribs segregated by sex were examined using the HERACLES II Electronic Nose. The results are presented in Table 5. The differences in aromatic substances by sex were evaluated using MXT-5—non-polar column—and MXT-1701—slightly polarized column—which revealed six in MXT-5 and four in MXT-1701. Among these, ethanol was found in both MXT-5 and MXT-1701 and showed approximately 1.8-fold higher levels in ribs from female KNBGs than those in ribs from male KNBGs ($p = 0.0083$). Ethanol is a pungent alcohol with a sweet scent. In contrast, aromatic substances such as 1-propanol, 1-hydroxy-2-propanone, 1,1-dichloropropene, acetic acid, 1-octene, and 2,4-octadiene were more abundant in ribs from male KNBGs ($p < 0.05$). These substances are sensual, as they are alcoholic, fruity, plastic, vinegar-like, caramelized, and pungent. 2-Butanol is an aromatic substance that was found only in ribs from female KNBGs that is sweet and pleasant scented. In contrast, the aromatic substances Z-3-hezen-1-ol, acetate were found only in ribs from male KNBGs and are characterized as smelling like apple, banana, grassy, and fruity.

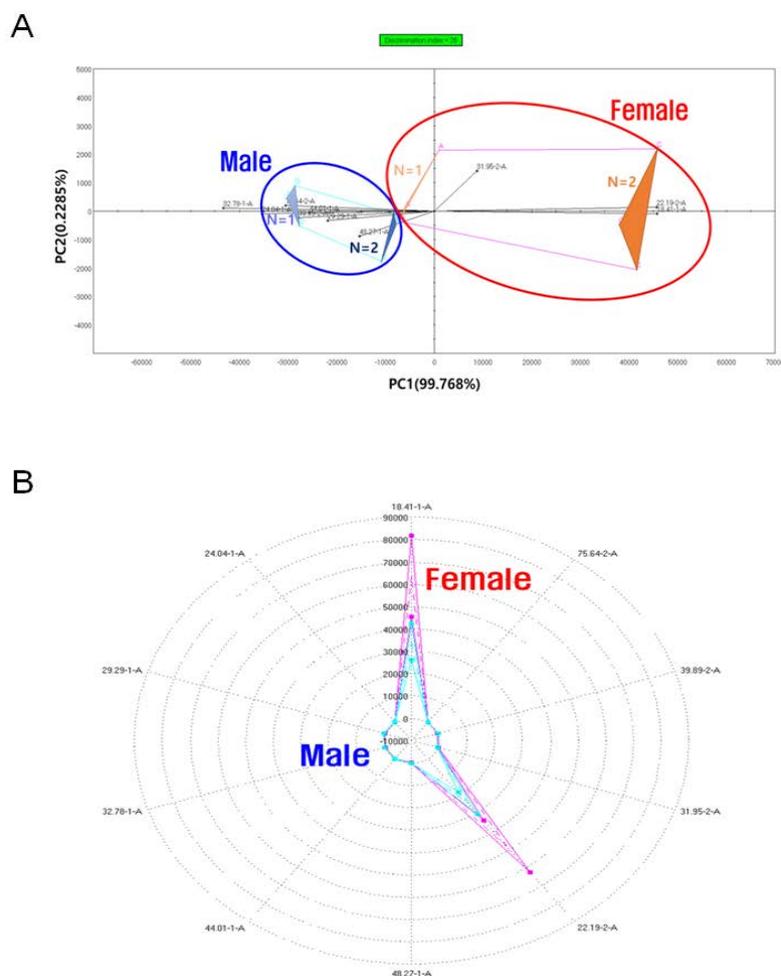


Figure 1. Principal component analysis loading plot (A) and radar plot (B) of volatile compounds of Korean native black goat ribs by sex based on electronic nose signals

Table 5. Volatile Compounds in KNBG Ribs by Sex

Compounds	RT (min)		Sensory descriptors	Peak area x 10 ³					
	MXT-5	MXT-1701		MXT-5		p-value	MXT-1701		p-value
				Female	Male		Female	Male	
Ethanol	18.41	22.19	Alcoholic, Ethanol, Pungent, Sweet	63.40 ± 19.90	34.22 ± 8.90	0.0083	48.69 ± 15.72	24.64 ± 6.46	0.006
1-Propanol	24.04		Alcoholic, Ethanol, Fermented, Fruity, Fusel, Musty, Plastic, Pungent	0.11 ± 0.06	0.29 ± 0.14	0.0165	-	-	-
1-Hydroxy-2-propanone	29.29	-	Caramelized, Pungent, Sweet	0.23 ± 0.06	0.42 ± 0.05	0.0002	-	-	-
1,1-Dichloropropene	32.78	-	-	0.03 ± 0.03	0.09 ± 0.03	0.0168	-	-	-
2-butanol	-	31.95	Pleasant, Sweet, Wine	-	-	-	0.08 ± 0.07	0.00 ± 0.00	0.0161
Acetic acid	-	39.89	Acetic, Acidic, Odorless, Pungent, Sharp, Sour, Vinegar	-	-	-	0.03 ± 0.04	0.14 ± 0.08	0.0125
1-Octene	44.01	-	-	0.04 ± 0.03	0.14 ± 0.08	0.0128	-	-	-
2,4-Octadiene	48.27	-	Glue, Warm	0.02 ± 0.03	0.07 ± 0.02	0.0119	-	-	-
Z-3-Hexen-1-ol, acetate	-	75.59	Apple, Banana, Fresh, Fruity(sweet), Grassy, Green, Sharp, Sweet	-	-	-	0.00 ± 0.00	0.05 ± 0.04	0.0121

RT, retention time (min).

4. Conclusions

Analysis of the meat quality characteristics and aromatic substances in KNBG ribs by sex showed that meat composition and color, water-holding capacity, cooking loss, and shear force did not significantly differ, indicating that male or female goat meat can be consumed. Moreover, the overall saturated/fatty acid and unsaturated fatty acid ratio was not significantly different between sexes. In contrast, the aroma of KNBG ribs clearly differed by sex (PC1, 99.768%); ribs from female KNBGs showed a higher ethanol (alcoholic, pungent, and sweet) level than ribs from male KNBGs, indicating a high odor strength. Particularly 2-butanol (sweet and pleasant) was detected only in ribs from female KNBGs, and Z-3-hexen-1-ol and acetate (apple, banana, and grassy) were specifically detected in male KNBG meat. Each aromatic substance is considered as a sex discriminant for KNBG meat.

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Statement of Competing Interests

The authors have no competing interests.

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