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ARTICLE

Study on Ways to Improve the Quality of Black Goat Meat Jerky and Reduce Goaty Flavor through Various Spices

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Abstract In this study, we analyzed the physicochemical and sensory properties of black goat jerky marinated with various spices (non-spice, control; rosemary, RO; basil, BA; ginger, GI; turmeric, TU; and garlic, GA). The physicochemical properties of black goat jerky analyzed were pH, water holding capacity, color, cooking yield, shear force, and fatty acid composition. The sensory characteristics were analyzed through the aroma profile (electronic nose), taste profile (electronic tongue), and sensory evaluation. The pH and water holding capacity of the GI showed higher values than the other samples. GI and GA showed similar values of CIE L* and CIE a* to that of the control. The shear force of the GI and TU was significantly lower than that of other samples ($p<0.05$). Regarding fatty acid composition, GI showed high unsaturated and low saturated fatty acid contents compared with that of the other samples except for RO ($p<0.05$). In the aroma profile, the peak area of hexanal, which is responsible for a faintly rancid odor, was lower in all treatment groups than in the control. In the taste profile, the umami of spice samples was higher than that of the control, and among the samples, GI had the highest score. In the sensory evaluation, the GI sample showed significantly higher scores than the control in terms of flavor, aroma, goaty flavor, and overall acceptability ($p<0.05$). Therefore, marinating black goat jerky with ginger powder enhanced the overall flavor and reduced the goat odor.

Keywords black goat, jerky, goaty flavor, volatile compounds, fatty acid composition

Introduction

In the recent meat market, there has been an increase in the number of consumers seeking high-quality meat products with nutritionally superior functions (Manzoor et al., 2022). Goat meat, known for its high protein, trace element, and low-fat contents, is a healthier option than other red meat types (Kawęcka et al., 2022). Furthermore, the absence of religious restrictions, such as those for pork or beef, has contributed to the global rise in goat meat consumption (Qi et al., 2022). The global production of goat meat has grown significantly, increasing from approximately 5.6 million tons in 2015 to approximately 6.2 million tons in 2019, displaying an overall increase of approximately 0.6 million tons in four years (Popescu et al., 2021). Accordingly, in order to maximize the consumption of goat meat, the development of new meat products using goat meat is in progress (Teixeira et al., 2020).

Smoking, drying, and curing are among the oldest methods used for meat preservation, and jerkies are a processed meat product with a long history (Cheng et al., 2023). Moreover, it is a globally high-demand snack food as a ready-to-eat meat product that can be stored at room temperature (Gaikwad et al., 2020). There are two main types of jerkies: whole muscle jerkies produced by curing and drying thin slices of whole muscle and restructured jerkies made by grinding raw meat, followed by curing, molding, and drying (Lemma et al., 2022). The drying process in jerkies extends the meat storage period by controlling water activity and inhibiting microbial growth (Kim et al., 2021). Moreover, the hydrolysis and oxidation of fat during drying are responsible for the distinctive flavor development in jerkies (Han et al., 2020).

Flavor, a sensory attribute of food detected through taste and smell, is an important factor influencing consumers' decision to purchase meat (Khan et al., 2015). The flavor of cooked meat arises from aromatic volatile organic compounds (VOCs) and non-VOCs generated through heat in the matrix of muscle fibers, connective tissues, and fat depots (Sgarro et al., 2022). However, depending on the type of livestock animal and the storage and cooking methods after slaughter, an off-flavor instead of the desired flavor may occur (Gómez et al., 2020). The unique goaty flavor can influence consumer preference, and various processing techniques, such as spice addition, thermal processing, and irradiation, are required to enhance preference (Jia et al., 2021; Jia et al., 2022; Qi et al., 2022). Spices are natural additives derived from extracting or drying the seeds, flowers, roots, or leaves of various plants (Ağaoğlu et al., 2007). Spices impart a unique taste and aroma based on their main ingredients and are usually added in small amounts to food, effectively reducing off-flavors and enhancing overall flavors (Sachan et al., 2018).

The primary objective of this study is to investigate methods for reducing the goaty flavor by analyzing the physicochemical and sensory characteristics of black goat jerky based on different spice treatments (rosemary, basil, ginger, turmeric, and garlic) commonly used to remove food odors.

Materials and Methods

Prepared to black goat meat and various spice powder

The raw meat used for jerky production was purchased from Gaon (Gangjin, Korea). It was sourced from the front and hind whole legs of black goats (Boer×black Korean goat; female; 12 months old), obtained 24 hours after slaughter. Before use, excess connective tissues were removed from the meat. The powders in this study were purchased online in 100% form without additives. These included ginger, turmeric, and garlic powders (Gomine, Uijeongbu, Korea), basil powder (Sun-jae Food, Icheon, Korea), and rosemary powder (Garunara, Seoul, Korea). The pH and color characteristics of each spice were as follows: rosemary (pH: 5.73; CIE L*: 61.35, CIE a*: 4.29, CIE b*: 22.54), basil (pH: 5.98; CIE L*: 55.34, CIE a*: 3.70, CIE b*: 18.39), ginger (pH: 7.43; CIE L*: 70.70, CIE a*: 8.20, CIE b*: 28.90), turmeric (pH: 6.55; CIE L*: 55.48, CIE a*: 19.49, CIE b*: 35.38), and garlic (pH: 6.21; CIE L*: 81.33, CIE a*: 8.25, CIE b*: 24.68). A curing agent was prepared by mixing 1.5% salt, 1.5% sugar, and 0.2% spice based on 100% meat (Table 1).

Preparation of black goat jerky

Jerkies were produced using the methods outlined in Kim et al. (2008) with certain modifications. The front and hind leg

Table 1. Formulation of black goat jerky marinated with various spices

Ingredients (%)		Control	RO	BA	GI	TU	GA
Meat		100.0	100.0	100.0	100.0	100.0	100.0
Additive	Salt	1.5	1.5	1.5	1.5	1.5	1.5
	Sugar	1.5	1.5	1.5	1.5	1.5	1.5
	Spices	-	0.2	0.2	0.2	0.2	0.2

Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

meat of black goats were sliced to a thickness of 7–8 mm in the same direction as the muscle fibers. Random sampling of the meat slices was performed to minimize deviations in different muscle parts. The sliced raw meat was evenly coated with the curing agent without spice or with 0.2% rosemary, basil, ginger, turmeric, or garlic, followed by 1 min of hand massaging. After applying the curing agent, the cured black goat meats were vacuum-packed and stored (cured) for 18 h at 4℃. After curing, the black goat meat was cooked and dried in a chamber (10.10 ESI/sk, Alto Shaam, Menomonee Falls, WI, USA) using the following temperature method: 90 min at 72℃, 60 min at 65℃, and 60 min at 55℃. The final jerkies were obtained after 1 h of cooling at 20℃ (room temperature).

The samples before cooking were utilized to measure the pH, water holding capacity (WHC), and color, while those after cooking were used to measure the cooking yield, shear force, and fatty acid composition and to perform electronic nose (E-nose) and electronic tongue (E-tongue) analyses and sensory evaluations.

At this time, the moisture content and water activity (a_w) of the cooked black goat jerky are as follows: control (non-spice; moisture contents – 35.58%; a_w – 0.72), black goat jerky marinated with rosemary (RO; moisture contents – 37.69%; a_w – 0.74), black goat jerky marinated with basil (BA; moisture contents – 39.69%; a_w – 0.75), black goat jerky marinated with ginger (GI; moisture contents – 31.96%; a_w – 0.71), black goat jerky marinated with turmeric (TU; moisture contents – 34.90%; a_w – 0.73), black goat jerky marinated with garlic (GA; moisture contents – 30.25%; a_w – 0.69).

pH

To measure the pH of samples, 3 g of the sample was added to 12 mL of distilled water, and the solution was homogenized for 1 min at 6,451×g using an ultraturrax (HMZ-20DN, Poonglim Tech, Seongnam, Korea). Homogeneous samples were measured using a glass electrode pH meter (Model S220, Mettler-Toledo, Schwerzenbach, Switzerland). The pH meter was calibrated with pH 4.01, pH 7.00, and pH 10.00 buffer solutions (Suntex Instruments, Taipei, Taiwan).

Color

The color was measured using a colorimeter (CR-10, Minolta, Tokyo, Japan) equipped with a pulsed xenon lamp, 2° standard observer, aperture of 8 mm, and illuminant D65. The CIE L*, CIE a*, and CIE b* of the sample surface were recorded; the spice on the sample surface was not removed, and the samples bloomed at 25℃ for 30 min, then the color was measured. The device was calibrated using a white standard plate (CIE L*: +97.83, CIE a*: –0.43, CIE b*: –1.98).

Water-holding capacity

The WHC of the black goat jerky sample was measured using the filter paper press method (Go et al., 2023). First, 0.3 g of the sample inner part was placed in the center of the filter paper (Whatman No. 1, GE Healthcare, Chicago, IL, USA) and compressed for 3 min at a constant pressure using a Plexiglass plate device. The pressed sample surface and the exudation areas were measured using a Digitizing Area-lines Sensor (MT-10S, MT Precision, Tokyo, Japan). WHC was calculated as a percentage by substituting the following formula:

$$\mathrm{WHC}\ (\%) = \frac{\mathrm{Meat\ area\ (mm^2)}}{\mathrm{Exudation\ area\ (mm^2)}} \times 100 \tag{1}$$

Cooking yield

The cooking conditions were the same as the jerky manufacturing conditions. The cooking yield was determined by measuring the weight of the sample before and after cooking. Subsequently, the measured value was calculated as a percentage by substituting the following formula.

$$\mathrm{Cooking\ yield}\ (\%) = \frac{\mathrm{Sample\ weight\ after\ cooking\ (g)}}{\mathrm{Sample\ weight\ before\ cooking\ (g)}} \times 100 \tag{2}$$

Shear force

The shear force was measured using a Texture Analyzer (TA1, Lloyd, Largo, FL, USA) with a V-blade attached. The black goat jerky (1.0×3.0×0.3 cm; length×width×height), which had been molded parallel to the muscle fiber direction, was cut perpendicular to the muscle fiber direction. Then, the analysis conditions were as follows: a test speed of 2 mm/s, distance of 22 mm, force of 5.6 N, and the measured values were expressed in Newtons (N).

Fatty acid composition

For fatty acid composition, lipids were extracted using the method previously described by Folch et al. (1957). The sample and chloroform-methanol (2:1) were mixed and homogenized for 1 min at 1,296×g with a homogenizer (AM-5, Nihonseiki Kaisha, Tokyo, Japan). Subsequently, 0.88% KCl was added and centrifuged for 10 min at 3,000×g using a centrifuge (Supra R22, Hanil Science, Gimpo, Korea) at 2℃. The supernatant was removed, and the lower layer was filtered using a filter paper (Whatman No. 1, GE Healthcare). Then, it was concentrated using an N_2 gas blow concentrator (MGS-2200, Eyela Tokyo Rikakikai, Tokyo, Japan) at 38℃. The concentrated lipids were methylated with 0.5 N NaOH (in methanol) and 14% boron trifluoride (in methanol) according to the method previously described by David et al. (2003). Subsequently, 5 mL of distilled water and 2 mL of hexane were mixed and centrifuged for 10 min at 2℃ and 3,000×g. Then, 1 μL was injected into a gas chromatography equipped with an HP-Innowax column (100 m length×0.32 mm id×0.25 μm film thickness; Agilent Technologies, Palo Alto, CA, USA) for analysis. The analysis conditions were inlet temperature: 225℃, split ratio: 1/10, carrier: heat 1 mL/min, oven program: 150℃ for 1 min, 150℃–200℃ at 15/min, 200℃–250℃ at 2/min, 250℃ for 10 min; FID temperature: 280℃. Each fatty acid peak analyzed was calculated as a percentage (%) of the total fatty acid peak area after comparison and identification with the retention time of the standard material (47015-U, PUFA No. 2 Animal Source, Supelco, Bellefonte, PA, USA).

Electronic nose

E-nose was used by referring to the method of Xie et al. (2023). Each cooked sample was homogenized, and 5 g was weighed into a 20 mL headspace vial. The analyses were performed using an E-nose system (Heracles-II-e-nose, Alpha MOS, Toulouse, France) under the conditions of injection speed 125 μL/s, injection temperature 200℃, trap absorption temperature 80℃, trap desorption temperature 250℃, and acquisition time 110 s. The MXT-5 and MXT-1701 columns were used. Classified data were reported as primary component values (PC1) and secondary component values (PC2).

Electronic tongue

Taste evaluation was performed using a taste sensor E-tongue (Astree V, Alpha MOS) by referring to the method of Zhu et al. (2022). First, 4 g of black goat jerky sample was homogenized for 1 min at 6,451×g using 16 mL of distilled water and a homogenizer (AM-5, Nihonseiki Kaisha). The homogenized sample was filtered using the Whatman No.1 filter paper (GE Healthcare). Then, the filtrate was diluted 1,000-fold in distilled water and measured using a taste sensor E-tongue. The analysis measured the signal intensity at each sensor using taste sensors: NMS (umami), AHS (sourness), and CTS (saltiness), along with auxiliary sensors SCS and CPS, and standard sensors PKS and ANS.

Sensory evaluation

The sensory evaluation was performed with approval from the Kongju National University Institutional Bioethics Committee (Authorization Number: KNU_IRB_2021-75). Samples were prepared by cutting them into blocks of 1.0 cm×1.0 cm and then distributed randomly for evaluation. The sensory panelists (15 people) conducted the evaluation and were sufficiently educated on samples and evaluation criteria. Based on the control jerky, spice-added jerky was evaluated. The mouth was rinsed with water every time the treatment was changed. The color, flavor, texture, aroma, and overall acceptability of the cooked black goat jerky samples were evaluated on a scale of 10, with 10 being the “best” and 1 being the “worst” score. In the case of goaty flavor, the treatment group with less goat odor received a higher score in the evaluation.

Statistical analysis

For all data in this study, at least three experiments were repeated to obtain the results, expressed as mean±SD. To minimize the deviation across the raw meat samples used in the experiments, pre-curing samples of black goat meat were randomized for the experiments. One-way analysis of variance (ANOVA) was performed on the results obtained through the procedures of the generalized linear model (GLM). Tukey’s studentized range test was used to test the significance at $p<0.05$. All statistical analyses were performed using the SAS software (Version 9.3 for Windows, SAS Institute, Cary, NC, USA).

Results and Discussion

pH and color

pH is a critical factor affecting the taste and overall quality of meat (Ribeiro et al., 2021). Table 2 presents the pH and color of cured black goat meat according to the treatment with various spice marinades. The GI and RO exhibited the highest and lowest pH, respectively, with significance ($p<0.05$). The pH of the ginger and rosemary powders used in this study were 7.43 and 5.73, respectively, and it was judged that the pH of the powder affected the pH of the jerky. Vişan et al. (2021) reported that the pH of Black Angus sirloin was influenced by the composition of the spice the meat was marinated with, consistent with the findings of this study. The pH of the meat is negatively correlated with drip loss and may affect the quality characteristics of meat products, such as color, flavor, and shelf-life (Vergara et al., 2020; Xu et al., 2020). Therefore, various

Table 2. pH and color of cured black goat meat marinated in various spices

Traits		Treatments					
		Control	RO	BA	GI	TU	GA
pH		6.24±0.03[b]	5.96±0.01[e]	6.10±0.01[d]	6.55±0.02[a]	6.15±0.01[c]	6.14±0.01[cd]
Color	CIE L*	34.25±0.26[b]	33.25±0.60[c]	33.35±0.22[c]	34.05±0.32[bc]	36.98±0.45[a]	34.50±0.68[b]
	CIE a*	7.53±0.08[a]	5.17±0.44[b]	5.58±0.13[b]	7.58±0.26[a]	5.47±0.28[b]	7.32±0.51[a]
	CIE b*	6.37±0.29[c]	5.88±0.34[cd]	5.65±0.12[d]	7.02±0.37[b]	12.18±0.33[a]	7.30±0.32[b]

All values are mean±SD.
[a–e] Mean values in the same row with different letters are significantly different ($p<0.05$).
Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

spice treatments of jerkies could impact qualities such as WHC and cooking yield.

In this study, the cured black goat meats were experimented without rinsing off the curing agent, and it is presumed that the unique color of the spice remaining on the surface had an impact on the color of the jerkies. The TU showed significantly higher CIE L* than the other spice treatment groups for the raw black goat jerkies ($p<0.05$). The RO and BA exhibited lower CIE L* than the other treatment groups. It is known that meat marinades containing green-colored additives can reduce the CIE L* of meat before cooking (Kim et al., 2019). The GI and GA showed similar CIE L* to the control, which agrees with Cózar et al. (2018) and Singh et al. (2014), reporting that marinades containing yellow-colored additives have little impact on meat CIE L*. Regarding CIE a*, the control, GI, and GA did not vary significantly, whereas the RO, BA, and TU exhibited significantly lower CIE a* than the other treatment groups ($p<0.05$). As green and red are complementary colors, green-colored additives reduce the meat products' CIE a* (Lim et al., 2013). Hence, the green-colored rosemary (CIE a*: 4.29) and basil (CIE a*: 3.70) powders with low CIE a* likely reduced the CIE a* of the marinated meat. In the case of CIE b*, the TU displayed a significantly higher value than other treatment groups ($p<0.05$), and the BA showed the lowest value. Turmeric contains a large amount of curcumin, which is yellowish-orange (Duda et al., 2020). The CIE b* of basil powder was the lowest among the various powders used in this study, at approximately 18.39, leading to the low CIE b* of the BA. The color analysis of black goat jerkies revealed that the GI and GA had the most similar color to the control. Thus, the treatment with garlic powder has been determined not to affect the color of the product in the manufacture of black goat jerkies.

Water-holding capacity, cooking yield, and shear force

Table 3 presents the WHC, cooking yield, and shear force of cured black goat meat/cooked black goat jerkies according to the treatment with various spice marinades. The GI showed the highest WHC. This shows a similar result to the pH of black goat jerky and is consistent with the results of Ali et al. (2021), which reported that an increase in anions in muscle fibers produces electrostatic repulsions to expand muscle fibers and improve the WHC. The improved WHC increases the heat transfer efficiency in muscles, and when heated, heat is not only evenly transferred to the whole muscle but also a large amount of Maillard reaction products that cause flavor can be generated by maintaining the surface temperature of the muscle high (Kerth and Miller, 2015). However, the RO showed the lowest WHC. Sun et al. (2018) reported that a fall in pH could reduce WHC and cause the denaturation of certain muscle proteins. Thus, the low WHC of the RO is likely to reduce the quality of black goat jerkies.

Cooking yield is an important production indicator of the economic values of meat (Zhang et al., 2023). An increase in WHC results in an increase in immobilized water bound to the proteins in muscles, thereby increasing the cooking yield

Table 3. Water holding capacity (WHC), cooking yield, and shear force of black goat jerky marinated in various spices

Traits	Treatments					
	Control	RO	BA	GI	TU	GA
WHC (%)	40.49±2.19[ab]	31.57±2.49[bc]	33.95±1.03[bc]	45.46±5.09[a]	35.96±2.13[bc]	38.73±2.02[abc]
Cooking yield (%)	40.07±1.06	39.51±1.59	40.51±1.54	42.54±1.19	41.13±1.32	40.67±1.32
Shear force (N)	78.48±1.97[bc]	86.56±2.79[a]	84.60±1.03[ab]	75.16±4.40[d]	77.43±0.67[d]	79.99±1.69[bc]

All values are mean±SD.
[a–d] Mean values in the same row with different letters are significantly different ($p<0.05$).
Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

(Yang et al., 2022). Although the cooking yield displayed a similar trend to the WHC, no significant variation was found across the spice treatment groups ($p>0.05$).

The shear force of black goat jerkies was the lowest in the GI compared with that of all other treatment groups. The water content of meat products increases as the WHC of meat increases, and the increased moisture leads to softer and tender meat tissues, thus reducing the shear force (Hughes et al., 2014). However, the RO showed significantly higher shear force than all the other treatment groups except the BA ($p<0.05$). Kim et al. (2020a) reported that WHC and shear force were negatively correlated in aged Korean beef, consistent with the finding of this study. The low WHC is also presumed to have caused the high shear force of the RO and BA in this study. Yang et al. (2009) performed a sensory evaluation of pork jerkies according to the drying temperature and time and reported that the shear force at 70–80 N indicated the maximum hardness of jerkies that consumers could accept. In this study, the GI and TU showed 75.16 N and 77.43 N of shear force, respectively, which is predicted to offer a favorable texture to consumers.

Fatty acid composition

Fatty acids are involved in producing various VOCs, and the fatty acid composition is a key factor in the final sensory quality of meat and meat products (Ba et al., 2019). Table 4 presents the fatty acid composition of black goat jerkies according to the treatment with various spice marinades. This study revealed varying fatty acid compositions based on the type of spices used in the preparation of black goat jerky. The main fatty acids in black goat jerkies were palmitic acid (C16:0), stearic acid (C18:0), and oleic acid (C18:1n9), in agreement with Lee et al. (2017), reporting the same compounds as the main fatty acids in black goat jerkies. Spices possess their own fatty acid compositions, and when incorporated into meat processing, they influence the fatty acid composition of the resulting product (Muzolf-Panek and Kaczmarek, 2021). Unsaturated fatty acids (UFAs) and polyunsaturated fatty acids (PUFAs) contents were significantly higher in the RO and GI than in the other treatment groups ($p<0.05$). Xia et al. (2021) reported that various aroma and flavor compounds, including aldehydes, ketones, alcohols, esters, and aliphatic series, were produced via the oxidation of UFAs. Various hydroperoxides were produced to form flavor compounds as PUFAs, such as linoleic acid, arachidonic acid, and eicosapentaenoic acid, were degraded (Al-Dalali et al., 2022). Additionally, Dinh et al. (2021) reported that UFAs undergo the oxidation reaction more readily than saturated fatty acids (SFAs) as they have at least one double bond in their structure, facilitating the conversion into flavor compounds. Hence, the RO and GI enriched with UFAs led to an abundance of flavor compounds compared with that by the other treatment groups, positively affecting the sensory properties of jerkies. The GA and BA showed significantly higher contents of SFAs than the other treatment groups ($p<0.05$). SFAs are generally known to have a negative impact on VOCs in meat and meat products (Morrill et al., 2017). Analyzing the fatty acid composition revealed that spice marinades influenced

Table 4. Fatty acid composition of black goat jerky marinated in various spice

Trait (%)	Treatments					
	Control	RO	BA	GI	TU	GA
Myristic acid (C14:0)	4.46±0.04[c]	4.72±0.04[b]	4.80±0.02[d]	5.23±0.04[a]	4.29±0.01[d]	4.23±0.01[d]
Palmitic acid (C16:0)	37.54±0.06[b]	36.73±0.19[c]	36.69±0.19[c]	38.46±0.09[a]	36.56±0.12[c]	38.34±0.07[a]
Palmitoleic acid (C16:1n7)	1.40±0.01[a]	1.29±0.01[c]	1.18±0.01[e]	1.34±0.01[b]	1.31±0.01[bc]	1.26±0.01[d]
Stearic acid (C18:0)	27.28±0.19[c]	26.75±0.11[d]	29.06±0.01[a]	24.39±0.09[e]	27.88±0.07[b]	28.08±0.08[b]
Oleic acid (C18:1n9)	18.75±0.26[a]	17.09±0.06[c]	16.47±0.14[d]	17.22±0.03[c]	16.96±0.06[c]	17.70±0.04[b]
Vaccenic acid (C18:1n7)	0.76±0.03[a]	0.73±0.04[ab]	0.72±0.02[ab]	0.76±0.04[a]	0.76±0.01[a]	0.67±0.01[b]
Linoleic acid (C18:2n6)	6.99±0.02[e]	8.96±0.06[a]	8.48±0.05[c]	8.58±0.02[b]	8.63±0.02[b]	7.15±0.01[d]
γ-Linolenic acid (C18:3n6)	0.04±0.02[b]	0.05±0.01[ab]	0.04±0.01[ab]	0.06±0.01[a]	0.05±0.01[ab]	0.04±0.01[b]
α-Linolenic acid (C18:3n3)	0.28±0.01[d]	0.37±0.01[b]	0.34±0.01[c]	0.40±0.01[a]	0.36±0.01[b]	0.26±0.01[e]
Gondoic acid (C20:1n9)	0.09±0.01[a]	0.07±0.01[b]	0.10±0.01[a]	0.10±0.01[a]	0.09±0.01[a]	0.08±0.01[b]
Arachidonic acid (C20:4n6)	2.10±0.03[e]	2.81±0.03[b]	2.30±0.03[d]	2.98±0.01[a]	2.70±0.03[c]	1.93±0.01[f]
Eicosapentaenoic acid (C20:5n3)	0.08±0.01[c]	0.09±0.01[b]	0.08±0.01[c]	0.14±0.01[a]	0.10±0.01[b]	0.07±0.01[c]
Docosatetraenoate acid (C22:4n6)	0.24±0.01[d]	0.31±0.01[b]	0.27±0.01[c]	0.33±0.01[a]	0.30±0.01[b]	0.20±0.01[e]
Docosahexaenoic acid (C22:6n3)	0.01±0.01[b]	0.02±0.01[ab]	0.01±0.01[ab]	0.02±0.01[ab]	0.02±0.01[a]	0.01±0.01[ab]
SFA	69.28±0.24[c]	68.21±0.12[e]	70.03±0.19[b]	68.07±0.07[e]	68.72±0.08[d]	70.65±0.04[a]
UFA	30.72±0.24[c]	31.79±0.12[a]	29.97±0.19[d]	31.91±0.07[a]	31.28±0.08[b]	29.35±0.04[e]
MUFA	20.99±0.29[a]	19.19±0.02[c]	18.46±0.13[d]	19.41±0.07[bc]	19.11±0.06[c]	19.0±0.05[b]
PUFA	9.73±0.05[d]	12.60±0.01[a]	11.51±0.08[c]	12.51±0.03[a]	12.17±0.02[b]	9.65±0.01[d]
n3	0.37±0.01[d]	0.48±0.01[b]	0.42±0.01[c]	0.57±0.01[a]	0.49±0.01[b]	0.33±0.01[e]
n6	9.36±0.05[e]	12.12±0.09[a]	11.08±0.07[d]	11.95±0.03[b]	11.68±0.02[c]	9.32±0.01[e]
UFA/SFA	0.44±0.01[c]	0.47±0.01[a]	0.43±0.01[d]	0.47±0.01[a]	0.46±0.01[b]	0.42±0.01[e]
MUFA/SFA	0.30±0.01[a]	0.28±0.01[bc]	0.26±0.01[d]	0.29±0.01[b]	0.28±0.01[c]	0.28±0.01[bc]
PUFA/SFA	0.14±0.01[c]	0.18±0.01[a]	0.16±0.01[b]	0.18±0.01[a]	0.18±0.01[a]	0.14±0.01[c]
n6/n3	25.48±0.40[b]	25.26±0.50[b]	26.12±0.07[b]	21.13±0.47[d]	23.98±0.32[c]	27.82±0.46[a]

[a–f] Mean values in the same row with different letters are significantly different ($p<0.05$).
Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic; SFA, saturated fatty acid; UFA, unsaturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

the fatty acid composition of black goat jerkies, while the RO and GI were effective in enhancing flavor and reducing the goaty flavor of black goat jerkies.

Electronic nose

The results of principal component analysis and VOCs of black goat jerkies using the E-nose and the treatment with various spice marinades are shown in Fig. 1 and Table 5. The dispersion of PC1 (X-axis) and PC2 (Y-axis) was 74.165% and 21.093%, respectively, with the data differentiated mainly according to the differences in PC1 across samples (Fig. 1). The

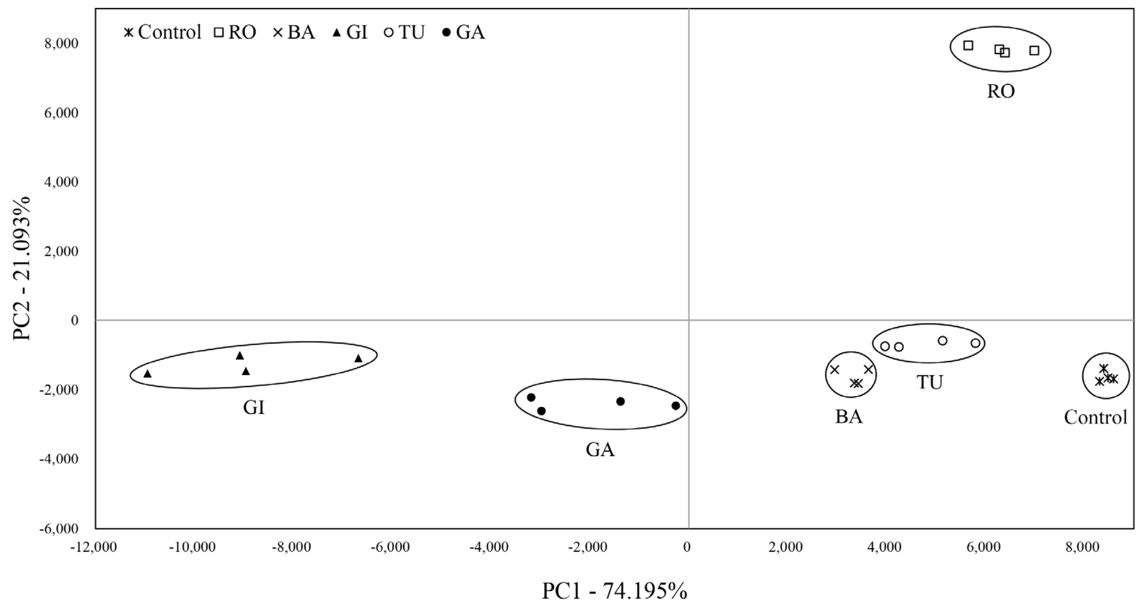

Fig. 1. Principal component analysis of black goat jerky marinated in various spices. Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

Table 5. Volatile compounds of black goat jerky marinated in various spices

Expected volatile compounds	RT	Treatments					
		Control	RO	BA	GI	TU	GA
Ethanol	20.96	5,246.54 ±59.38	6,387.29 ±316.88	8,375.64 ±164.58	16,199.42 ±989.32	7,482.28 ±469.07	11,819.26 ±753.02
Propan-2-one	22.45	1,024.76 ±64.95	896.89 ±53.74	1,151.09 ±44.69	1,746.46 ±26.81	986.66 ±25.02	1,246.84 ±71.85
1-Propanethiol	28.58	572.44 ±233.28	765.40 ±55.04	540.95 ±98.92	298.87 ±23.95	402.53 ±136.13	1,980.82 ±206.18
Hexanal	49.83	2,856.34 ±89.60	1,613.93 ±266.65	1,388.39 ±38.16	1,691.59 ±58.27	2,212.10 ±220.25	2,029.02 ±63.96
3-Methylbutanoic acid	54.06	696.03 ±154.51	762.02 ±58.04	527.09 ±71.84	296.84 ±34.59	344.03 ±97.93	427.45 ±19.63
1,8-Cineole	69.51	1,223.47 ±123.21	6,973.86 ±83.65	1,052.28 ±193.66	1,436.96 ±266.14	1,828.34 ±206	730.58 ±85.749
Skatole	90.24	1,279.38 ±26.84	1,227.48 ±21.37	1,236.67 ±39.38	1,231.90 ±8.09	1,242.78 ±35.12	1,241.83 ±23.98

RT, retention time; Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

control was located on the rightmost area on the X-axis, and to the left of the control were the RO, TU, BA, GA, and GI in the order of proximity, confirming clear distinction of black goat jerkies with different spice marinades. While the RO was found in a positive direction on the Y-axis, the control, BA, GI, TU, and GA were found in a negative direction. It is conjectured that a specific compound in rosemary distinguished the Y-axis.

Black goat jerkies are classified based on the spice and seven expected goat-related VOCs in Table 5. The VOC with the highest value in the control and spice treatment groups was deduced to be ethanol, with the GI exhibiting the highest value of ethanol. As one of the VOCs abundantly detected in meat, ethanol adds an alcoholic, pungent, and sweet aroma and flavor (Kim et al., 2020b). Aldehydes contribute significantly to the aroma profile of meat due to their low threshold of odor and specific aroma (Zhang et al., 2020). Among the aldehydes, hexanal displayed the highest peak area in the control compared with the treatment groups. Hexanal is a product of lipid oxidation associated with an unpleasant odor, acting as the main odor compound of goat meat (Jia et al., 2023). Ivanović et al. (2020) reported that a high hexanal concentration in mung beans could induce an unsavory and rotting smell. In this study, the intensity of hexanal expression was low in the RO, BA, and GI, indicating that the treatment with rosemary, basil, or ginger reduced the goaty flavor in black goat jerkies. In addition, 3-methylbutanoic acid is a carboxylic acid whose level was high in the RO and control. Moreover, 3-methylbutanoic acid is responsible for rancid, cheesy, and animal smells as it is derived from leucine in the Maillard reaction via the activities of rumen microorganisms (Pisinov et al., 2021). The content of 3-methylbutanoic acid, which potentially contributes to the goaty flavor, was low in the GI and TU, indicating that the treatment with ginger and turmeric reduced the goaty flavor. Depending on the spice used in marinating black goat jerkies, the level of reduction of goaty flavor varied, and overall, the GI was more effective in reducing goaty flavor than other treatment groups.

Electronic tongue

The results of E-tongue analysis of black goat jerkies according to the treatment with various spice marinades are presented in Fig. 2. Umami is detected in the presence of compounds such as monosodium glutamate, inosine monophosphate, and guanosine monophosphate and is distinguishable by human senses (Wang et al., 2020). The GI showed the highest score of umami at 8.5, whereas the lowest score at 3.2 was found in the control. Umami positively affects food acceptability and enhances meat flavor by inhibiting bitterness (Zhu et al., 2022). Sourness was low in the control compared with the spice treatment groups, with the highest score of sourness found in the GI. Sourness can increase in meat products with increased ethanol content (Xu et al., 2021). Hence, the GI with the highest peak area of ethanol at 16,199.42 in the E-nose analysis is presumed to have scored the highest in sourness. In contrast, saltiness was the lowest at 3.2 in the GI and the highest at 9.2 in the control. This decrease in saltiness is presumed to be due to the gingerol compound in ginger inhibiting the saltiness receptor epithelial sodium channel (Alipour et al., 2022; Vinitha et al., 2022). The E-tongue analysis confirmed that the spice treatment groups had a higher level of umami than the control. The GI, in particular, inhibited saltiness and was more effective in enhancing umami than the other treatment groups.

Sensory evaluation

Table 6 presents the sensory evaluation results of the treatment with various spice marinades. The flavor is a highly complex sensation that humans can detect. Flavor perception involves the interactions across olfactory and taste senses that detect the basic taste and aroma (Liu et al., 2022). The lowest flavor score was found in the control compared with the spice treatment groups, and the GI exhibited a significantly higher score than the control ($p<0.05$). Hexanal was shown to be responsible for the goaty flavor in the E-nose analysis, and its level was the highest in the control. Among the spice treatment groups, the BA, RO, and GI exhibited low scores. This finding implies that the differences in the contents of off-flavor compounds across the control and spice treatment groups had an impact on the sensory evaluation. Additionally, the fatty acid composition of the GI had high contents of UFAs and low contents of SFAs, which affected the flavor score. Regarding the aroma, the lowest score was found in the control compared with the spice treatment groups, while the GI and GA

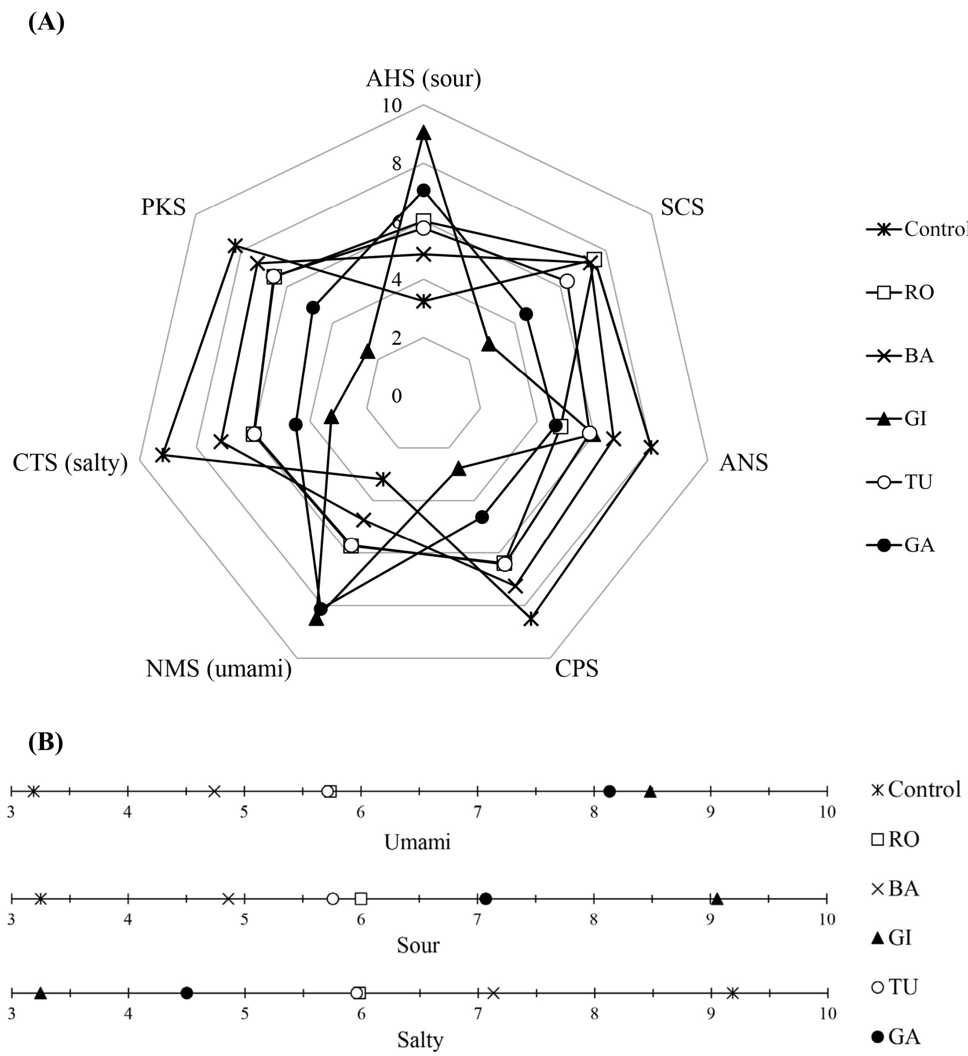

Fig. 2. Electronic tongue of black goat jerky marinated in various spices. (A) Changes in sensory characteristics of black goat jerky marinated in various spices expressed by radar. (B) Changes in sensory characteristics of black goat jerky marinated in various spices expressed in ranking. Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

Table 6. Sensory evaluation of black goat jerky marinated in various spices

Traits	Treatments					
	Control	RO	BA	GI	TU	GA
Color	8.58±0.77	8.53±0.84	8.71±0.82	8.77±0.85	8.09±0.99	8.50±0.89
Flavor	7.54±0.42^{b}	8.09±1.01^{ab}	8.01±1.14^{ab}	8.59±1.07^{a}	7.91±1.04^{ab}	8.24±1.18^{ab}
Texture	8.50±0.89	8.70±0.90	8.53±1.00	8.86±0.90	8.72±0.97	8.86±1.02
Aroma	7.37±0.74^{b}	8.29±0.92^{ab}	8.01±0.91^{ab}	8.49±1.15^{a}	8.19±1.17^{ab}	8.49±1.21^{a}
Goaty-flavor	7.06±0.45^{b}	8.14±1.05^{a}	7.97±1.29^{ab}	8.63±1.03^{a}	8.21±1.03^{a}	8.29±1.05^{a}
Overall acceptability	7.44±0.50^{b}	8.32±1.06^{ab}	8.06±0.92^{ab}	8.66±1.08^{a}	8.34±0.83^{ab}	8.23±1.23^{ab}

The evaluation scores range from 1 to 10, where 10 represents the 'best' and 1 represents the 'worst'.
^{a,b} Mean values in the same row with different letters are significantly different ($p<0.05$).
Control, non-spice; RO, black goat jerky marinated with rosemary; BA, black goat jerky marinated with basil; GI, black goat jerky marinated with ginger; TU, black goat jerky marinated with turmeric; GA, black goat jerky marinated with garlic.

exhibited significantly higher scores than the control ($p<0.05$). Baker et al. (2013) and Javed et al. (2011) reported that, in the manufacture of meat products, the meat taste and flavor were enhanced by adding ginger and garlic, in agreement with the results of this study. Regarding goaty flavor and overall acceptability, the lowest scores were found in the control compared with the spice treatment groups, and the GI exhibited the highest scores. Singh et al. (2014) analyzed the odor scores of chicken meat emulsions according to the storage period and reported that high scores were found in the groups treated with ginger paste compared with those treated with garlic paste. Ultimately, as the GI exhibited higher scores of flavor, aroma, goaty flavor, and overall acceptability than the control, RO, BA, and TU, the treatment with ginger powder in the production of black goat jerkies is anticipated to have positive effects on enhancing flavor and reducing the goaty flavor.

Conclusion

This study investigated the use of rosemary, basil, ginger, turmeric, and garlic powders in curing black goat jerkies, and the resulting physicochemical and sensory properties were analyzed. The E-nose analysis revealed that the intensity of hexanal expression, which affects the goaty flavor, was low with rosemary, basil, and ginger powders, and the 3-methylbutanoic acid content, which induces the goaty flavor, was low in meat treated with ginger or turmeric powder. In the E-tongue analysis, ginger powder increased the sourness and umami of black goat jerkies but decreased the saltiness. In the sensory evaluation, ginger powder improved the flavor, aroma, goaty flavor, and overall acceptability of black goat jerkies. As a result of the study, it was confirmed that various spices reduce the goaty flavor of black goat, and enhance the overall flavor and umami. Among them, ginger powder showed the most outstanding effect. Thus, applying ginger to produce black goat jerkies is predicted to improve the quality and sensory properties.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Choi DM, Lee SH. Data curation: Choi DM, Lee SH. Formal analysis: Choi DM, Lee SH. Methodology: Choi DM, Kim HY, Lee SH. Software: Choi DM. Validation: Choi DM, Kim HY, Lee SH. Investigation: Choi DM, Kim HY, Lee SH. Writing - original draft: Choi DM. Writing - review & editing: Choi DM, Kim HY, Lee SH.

Ethics Approval

The sensory evaluation was performed with approval from the Kongju National University Institutional Bioethics Committee (Authorization Number: KNU_IRB_2021-75).

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