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Research article

Effect of ginger extract on Korean black goat *biceps femoris* as a tenderizer

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ABSTRACT

This study investigated the tenderization and quality characteristics of Korean black goat biceps femoris treated with ginger powder extracts (0 %, 3 %, 5 %, and 7 %). The proximate composition, pH, color, shear force, water-holding capacity, sarcomere length, fiber cross-sectional area, and sensory properties were determined and analyzed according to the concentration of the ginger powder extract. The shear force decreased significantly with increasing concentrations of ginger powder extract ($P < 0.05$), whereas the water-holding capacity increased ($P < 0.05$). The sarcomere length of black goat biceps femoris increased with increasing concentrations of ginger powder extract ($P < 0.05$), whereas the fiber cross-sectional area decreased ($P < 0.05$). Sensory evaluation of black goat biceps femoris showed that goatiness decreased with increasing concentrations of ginger powder extract ($P < 0.05$), and the chewiness and overall acceptability were significantly higher ($P < 0.05$). Therefore, 7 % was the optimal concentration for softening black goat biceps femoris with ginger powder extract. In conclusion, it was confirmed that Korean black goat biceps femoris marinated in 7 % ginger extract was softened, and it is judged that this will have a positive effect on the texture of commercial Korean black goat meat.

1. Introduction

The meat industry is growing, with the number of black goats in Korea doubling between 2015 and 2019. Black goat meat has a higher protein content than beef and pork, a lower fat content, is rich in essential amino and fatty acids, and has recently been recognized as a healthy food [1]. However, because of its tough texture and low juiciness, it has been preferably used for medicinal purposes in the form of extracts, cooked, and produced in ways that enhance its flavor, such as soups, stews, and hotpots [1,2]. Considering the tough quality of black goat meat, it is necessary to develop it as an ingredient in various meat products to improve its softness and ease of consumption.

Meat products can be tenderized by physical tenderization, which is an injection technique used to improve texture, or chemical tenderization, which involves the addition of proteolytic enzymes [3,4]. Proteolytic enzymes, such as papain from papaya, actinidin from kiwi, and bromelain from pineapple, are mainly used in the tenderization process [5]. However, fruit-derived proteolytic enzymes have a strong tenderizing effect, which leads to over-tenderization and reduces the commodity value of meat; therefore, they require careful concentration control, and their prices fluctuate depending on the season [6]. In contrast, vegetable-derived proteases, such as radish, bean sprouts, and ginger, which have not yet been commercialized as tenderizers, are less prone to over-degradation

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owing to their proteolytic capacity that increases and then equilibrates; they can be used as natural tenderizers because they can be supplied stably at a lower price than fruits [7,8].

Ginger is a perennial herbaceous plant belonging to the Zingiberaceae family, native to tropical Asian countries such as Malaysia and India, and is mainly consumed as its roots [9]. Known as a highly palatable spice with a distinctive taste and aroma, it is widely used in the food industry and in meat products such as patties, sausages, and jerky [10,11]. In addition, it has been used as a health functional food because it contains various bioactive components, such as 6-gingerol and 6-shogaol, which have anti-inflammatory, antioxidant, blood circulation, and digestion-promoting effects [12,13]. In addition, zingibain, a proteolytic enzyme, has been reported to be a natural tenderizer for meat; however, its commercialization has been limited [14,15].

Therefore, in this study, we investigated the softening process of black goat meat using ginger extract and used it as a basis for its incorporation into meat products.

2. Materials and methods

2.1. Preparation of black goat biceps femoris with ginger extract

Ginger powder was purchased from Hello Green (Seoul, South Korea). The concentration levels of ginger powder extract was modified and set up by the research method of Ruitong et al. [16]. The powder and distilled water were stirred for 48 h at room temperature (25 °C) in the proportions of 0 %, 3 %, 5 %, and 7 %, respectively, and centrifuged at 8694×*g* for 20 min at 4 °C using a centrifuge (Supra R22, Hanil Science, Daejeon, Korea). The extract was then filtered through a Whatman No. 1 filter paper (GE Healthcare, Chicago, IL, USA).

The raw meat used for marination was provided as the *biceps femoris* muscle (Female, Korean native black goat × Boer goat, 12 months old, 28 goats, slaughtered on December 5th, 2023) from Gaon Agricultural Corporation (Gangjin, Korea). The black goat *biceps femoris* used in this study was slaughtered at a nationally certified black goat specialized slaughterhouse (Jeollanam-do No. 2019-0506003), in the Republic of Korea. For animal ethical considerations, the black goats were provided with a stress-minimized environment by being kept in a quiet, dark area prior to slaughter. To further reduce animal suffering, an electric stunning method was employed to render the animals unconscious immediately before slaughter. The black goat meat, 24 h after slaughter, was transported frozen for 2 h and used in the laboratory. After removing excess subcutaneous fat and connective tissue, 600 g of the *biceps femoris* was collected from each individual, totaling approximately 16.8 kg. Collected *biceps femoris* were randomly divided into 200 g and frozen in the −80 °C deep freezer (Thermo, Fisher Scientific, USA), and each was thawed in a 4 °C refrigerator for overnight before being used in the experiment. For the marinated method, 200 g of black goat *biceps femoris* muscle was cutted into cube shape size of 5 × 5 cm^2. And each 200 g of cube shape *biceps femoris* was mixed with ginger powder extract concentration (0 %, 3 %, 5 %, and 7 %) and sealed in a polyethylene bag (prepared 7 polyethylene bags for each concentration). Each mixing ratio was set at a 1:1 ratio of black goat *biceps femoris* and ginger powder extract (200 g:200 mL) and curing in a refrigerator at 4 °C for 48 h. After curing, the *biceps femoris* were dried at room temperature (21°C–23 °C) for 30 min before use.

2.2. Proximate composition

The moisture, fat, protein, and collagen contents of the *biceps femoris* according to the ginger powder extract content, were determined by homogenizing the samples using a homogenizer (AM-5, Nihonseiki Kaisha LTD, Tokyo, Japan) before measurement. Then, 150 g of each sample was weighed into a sample dish at a depth of 14 mm and measured using a food scanner (DA 6200; PerkinElmer, Waltham, MA, USA). The ash content was analyzed by direct ashing method (AOAC 920.153) in an ashing furnace (DMF-5T; Ultech, Suwon, Korea) at 550 °C for 1 g of sample, and all contents were expressed as percentages.

2.3. pH

The pH was determined using a pH meter (Model S220, Mettler-Toledo International, Greifensee, Switzerland) calibrated with pH 4.01, 7.0, and 10.0 buffer solutions (Suntex Instruments Co., Ltd., Taipei, Taiwan). The sample and distilled water were mixed in a 1:4 ratio and homogenized at 6,451×*g* for 1 min before the pH was measured using a glass electrode pH meter (Model S220, Mettler-Toledo, Schwerzenbach, Switzerland).

2.4. Color

The chromaticity of the work performed over 72 h was measured and blooming was performed for 30 min. Measured using a colorimeter (CR-10, Minolta, Tokyo, Japan) equipped with an 8-mm reading surface area, a standard light source D65, 2° standard observers, and a pulsed xenon lamp. After marinated, the internal cross section was measured for *CIE L** (lightness), *CIE a** (redness), and *CIE b** (yellowness) under fluorescent light (1500 lux). The standard colors before the measurement were: *CIE L**: +97.83 for the white standard version, *CIE a**: −0.43, and *CIE b**: +1.98. Seven measurements were taken for each sample and the figures averaged for statistical analysis.

2.5. Shear force

Shear force was measured using the method described by Park and Kim [17]. Each sample was heated in a chamber (10.10ESI/SK, Alto-Shaam Inc., Menomonee Falls, WI, USA) until the center temperature was maintained at 75 °C for 3 min. The heated samples were allowed to cool to room temperature for 30 min and cut horizontally in the direction of the myofibrils using a circular core with a diameter of 1.27 cm. The average weight of the samples was 4.2 ± 0.58 g, then measured using a texture analyzer with a V-blade, seven repetitions were performed per treatment group (analysis conditions: test speed, 5.6 mm/s; distance, 20 mm; force, 21 g; TA 1; Ametek, Largo, FL, USA).

2.6. Water holding capacity (WHC)

Water retention was determined using the filter paper press method Park et al. [18] by placing filter papers (Whatman No. 1, GE Healthcare) in the center of a specially designed plexiglass plate and weighing 0.3 g of each sample. One plexiglass plate was superimposed on top of it, and two sheets of plexiglass were tightened with bolts and nuts and pressed under constant pressure for 3 min. After pressing, the filter paper was removed, and the calculated moisture area and the area covered by the meat pieces were measured using a planimeter (MT-10S, MT Precision Co. Ltd., Tokyo, Japan). The water retention force was calculated as follows equation (1).

$$\mathrm{WHC}(\%) = \frac{\text{Meat area}(mm^2)}{\text{Total area}(mm^2)} \times 100 \quad (1)$$

2.7. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE)

SDS-PAGE was performed in 10 mL of 3 mM phosphate buffer, and 2.5 g of each sample was aliquoted and homogenized in a homogenizer (Nihon Seiki) at 10,000×*g* for 3 min. The homogenate was centrifuged (CF-10 DAIHAN Scientific, Korea) at 109×*g* for 3 min, and 109×*g* 5 min, and the supernatant was extracted using a filter paper (Whatman No. 1; GE Healthcare, Chicago, IL, USA). Each supernatant was mixed with 5 × sample buffer and 3 mM phosphate buffer, stored frozen, and used for experiments. A 15-μL aliquot of the sample was applied to the top of the gel and electrophoresed for 120 min using a power supplier (PowerPacTM HC, BIO-RAD, CA, USA) with a voltage of 120 V. The gel was removed, and the fixative was applied. The gel was removed, fixed with a fixing solution for at least 16 h, and stained for proteins using Coomassie brilliant blue solution for 20 min. The residual dye in the fully stained gel was removed with a destaining solution for 1 h, stored in the storage solution, and scanned.

2.8. Sarcomere length, fiber cross-sectional area

Samples were cut into cubes of 1 × 1 × 1 cm and frozen in a −80 °C deep freezer (Thermo, Fisher Scientific). The frozen samples were sectioned at 5 μm using a Microtome (CM3050S, LEICA, Germany) set at −25 °C. The samples were then attached to glass slides, and cross-sections of the tissues were observed under a stereomicroscope (Eclipse Ci-L, Nikon, Tokyo, Japan).

2.9. Sensory evaluation

Sensory evaluation was conducted in accordance with the Institutional Review Board of Gongju National University (Authority No.: KNU_IRB_2021–54). The treatments were heated in a dry oven at 75 °C in a chamber (10.10ESI/SK, Alto-Shaam Inc., Menomonee Falls) for 5 min to reach a core temperature of 73 °C and cut into 1 × 1 × 1 cm cubes. Fifteen trained panelists rated each treatment for appearance, goatiness, gingery, swallowiness, juiciness, chewiness, and overall acceptability using a 10-point scale (appearance: 1 = pale, 10 = brown; goatiness: 1 = detectable, 10 = undetectable; gingerliness: 1 = not detectable, 10 = detectable; swallowiness: 1 = difficult to swallow, 10 = easy to swallow; juiciness: 1 = very dry, 10 = very jucius; chewiness: 1 = very tough, 10 = very soft; overall acceptability: 1 = inedible, 10 = edible). The sensory evaluation panel comprised individuals with a basic understanding of meat and prior experience in food sensory evaluation. All panelists underwent a 7-day training program, with 1-h sessions each day, using control samples of black goat *biceps femoris* to familiarize themselves with the sensory attributes of black goat meat. All panel consented to participate in the sensory evaluation and agreed to use their information, all treatments distributed across multiple sessions were repeated twice across the same panel.

2.10. Statistical analysis

The concentration of ginger powder extract was considered fixed effects, with repeated experiments treated, the same amount of marinade, marinade time, and slaughter date of individuals as random effects. Each experiment was performed at least three replicates within one month. Values measured using the general linear model in SAS (version 9.3 for window, SAS Institute, Cary, NC, USA) were subjected to one-way analysis of variance, and significant differences between black goat *biceps femoris* treated with ginger powder extract were determined using Duncan's multiple range test ($P < 0.05$). The results in the tables and figures are expressed as mean ± SD (standard deviation) and SE (standard error).

3. Results and discussion

3.1. Proximate composition

The general composition of black goat *biceps femoris* according to the concentration of ginger powder extract is shown in Table 1. Compared with that in the control, the moisture content increased with an increase in the amount of ginger powder extract added and was significantly higher in the treatment with the highest concentration of 7 % ($P < 0.05$). In a study on the tenderization of water buffalo meat using ginger extract by Naveena et al. [19] the control had a moisture content of 76.51 %, whereas the water buffalo treated with 7 % ginger extract had a moisture content of 78.06 %, which is similar to the results of the present study, in which the moisture content increased with increasing ginger extract concentration. These results were attributed to the improved hydrophilicity of meat due to enzymatic treatment with ginger powder extract [20]. The protein content of black goat *biceps femoris* as a function of ginger powder extract concentration showed a decreasing trend with increasing concentration of ginger powder extract and was significantly lower in the 7 % ginger powder extract treatment than in the control ($P < 0.05$). However, a study on the physicochemical quality of ram and bull meat using ginger extract by Mahmmod et al. [21], showed that protein content increased significantly with increasing concentrations of ginger extract ($P < 0.01$). In this study, the protein content of black goat *biceps femoris* tenderized with ginger powder extract was also quantified, and the protein content tended to increase as the concentration of ginger powder extract increased. The highest values were significantly higher in the 5 % and 7 % ginger powder extract treatments than in the control group ($P < 0.05$). These results may be attributed to the percentage display of the Foodscanner (DA 6200, PerkinElmer, Waltham) used in this experiment, which resulted in a relative decrease in the protein content as the moisture content increased. In contrast, fat and collagen content tended to decrease with increasing concentrations of ginger powder extract. This is consistent with the findings of Li et al. [22], who reported a negative correlation between collagen content and meat tenderness. Cruz et al. [23], reported that the proteolytic enzyme activity of ginger has a greater effect on collagen than that actomyosin, resulting in increased meat tenderness.

3.2. pH, color

Table 2 shows the pH and colorimetric measurements of black goat *biceps femoris* as a function of ginger powder extract content. The pH tended to increase with increasing concentrations of ginger powder extract, and the pH of the treatment with 7 % ginger powder extract was the highest ($P < 0.05$). Naveena and Mendiratta's [24], study of water buffalo meat soaked in ginger extract also reported that the pH increased with increasing ginger extract concentration, which is similar to the results of the present study. This suggests that the pH (6.5) of the ginger powder extract influenced the pH (5.4) of the black goat meat. Ginger extract contains gingerol, a water-soluble phenolic component, and has a high phenolic content when prepared with distilled water. It has been shown that higher concentrations and longer soaking treatment times result in a higher pH of the meat [25].

*CIE L** and *CIE b** tended to increase with increasing concentrations of ginger powder extract, with the treatment marinade in 7 % ginger powder extract showing the highest values ($P < 0.05$). This may be due to curcuminoids, the yellow pigment in ginger itself [26]. Curcuminoids are crystalline compounds that exhibit a bright orange-yellow color, are used as a natural food coloring, and are known for their anti-inflammatory, cancer, dementia prevention, and antioxidant effects owing to their excellent radical scavenging properties [27]. Redness decreased significantly with increasing concentrations of ginger powder extract ($P < 0.05$). A study on the color stability and bacterial growth of ground beef using ginger rhizome extract by Mohammed et al. [28], reported a negative correlation between increased lightness and decreased redness in ground beef treated with ginger rhizome extract, which was similar to our results. These results are likely due to the relative decrease in redness as a function of the brightness and yellowness of the ginger powder extract.

3.3. Shear force, WHC

The shear and holding forces of the *biceps femoris* as a function of the ginger powder extract content are shown in Fig. 1. The shear force decreased with increasing amounts of ginger powder extract and was significantly lower in the highest 7 % treatment than in the control ($P < 0.05$). A study by Zhang et al. [29], comparing the quality characteristics of beef flank steak using ginger extract showed

Table 1
Proximate composition of black goat *biceps femoris* with various levels of ginger extract.

Traits	Ginger extract (%)			
	0 (Control)	3	5	7
Moisture (%)	74.12 ± 0.03^{c}	74.29 ± 0.08^{c}	74.69 ± 0.05^{b}	74.92 ± 0.09^{a}
Protein (%)	19.42 ± 0.05^{a}	19.28 ± 0.10^{a}	18.90 ± 0.04^{b}	18.63 ± 0.03^{c}
Fat (%)	4.41 ± 0.08^{a}	4.36 ± 0.11^{a}	4.35 ± 0.02^{a}	4.30 ± 0.04^{a}
Collagen (%)	1.41 ± 0.01^{a}	1.37 ± 0.01^{b}	1.29 ± 0.00^{c}	1.29 ± 0.00^{c}
Ash (%)	0.65 ± 0.07^{a}	0.69 ± 0.07^{a}	0.77 ± 0.09^{a}	0.86 ± 0.09^{a}
Protein quantity (mg/mL)	1.32 ± 0.15^{b}	1.41 ± 0.06^{b}	2.33 ± 0.35^{a}	2.42 ± 0.30^{a}

All values are mean ± SE.
Means in the same row with different letters (a-c) are significantly different ($P < 0.05$).

Table 2
pH and Color of black goat *biceps femoris* with various levels of ginger extract.

Traits		Ginger extract (%)			
		0 (Control)	3	5	7
pH		6.24 ± 0.06^{c}	6.32 ± 0.01^{b}	6.35 ± 0.01^{b}	6.40 ± 0.01^{a}
Color	CIE L*	40.7 ± 0.90^{c}	47.4 ± 0.57^{b}	47.8 ± 0.53^{b}	50.4 ± 0.86^{a}
	CIE a*	10.8 ± 0.91^{a}	7.0 ± 0.82^{b}	6.7 ± 0.89^{b}	3.4 ± 0.85^{c}
	CIE b*	11.2 ± 0.82^{c}	11.3 ± 0.72^{c}	13.0 ± 0.79^{b}	14.2 ± 0.89^{a}

All values are mean ± SD.
Means in the same row with different letters (a-c) are significantly different ($P < 0.05$).

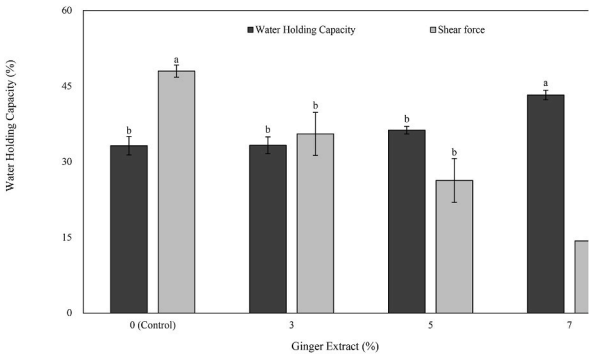

Fig. 1. Predicted means ± standard error for water holding capacity (%) and shear force (N) of black goat *biceps femoris* with various levels of ginger extract. Means in the same color bars with different letters (a–c) are significantly different ($P < 0.05$).

similar results to the present study, in which the shear force decreased with increasing concentrations of ginger powder extract. This is believed to be due to the proteolytic enzyme zingibain in ginger, which breaks down protein-peptide bonds and hydrolyzes them into amino acid components, resulting in a reduced shear force [30]. Choi and Laursen [31], identified the amino acid sequence of a cysteine protease in ginger rhizomes, confirming the mechanism of proteolysis.

Water retention tended to increase with increasing concentrations of ginger powder extract and was significantly higher in the 7 % ginger powder extract treatment than in the control ($P < 0.05$). Naveena et al. [24], in their study on the tenderization of buffalo meat using ginger rhizome extract, also showed an increase in water retention after treatment with ginger rhizome extract, which was similar to the results of this study. Rostamani et al. [32], in their study on beef marinade, showed an increase in water retention using proteolytic enzymes from ginger, similar to the results of this study. Ruitong et al. [16], reported that increasing the concentration of ginger powder extract beyond 7 % did not significantly enhance water retention capacity. This is believed to be due to the pH shifts away from the isoelectric point, the increase in anions is thought to widen the gap between muscle fibers, thereby increasing the space available for water retention [3]. This study also showed that ginger powder extract increased the water retention of meat by moving the pH away from the isoelectric point (5.2–5.3) of black goat *biceps femoris*.

3.4. Fiber cross-sectional area, sarcomere length

Fig. 3 shows the root length and cross-sectional area of black goat *biceps femoris* as a function of ginger powder extract concentration. As the concentration of ginger powder extract increased, the root length and cross-sectional area of black goat *biceps femoris* decreased significantly ($P < 0.05$). This is similar to the study of structural changes in camel meat treated with ginger extract and papain powder by Abdel-Naeem et al. [34], who also showed a decrease in muscle cross-sectional area with increasing ginger extract content, suggesting that the ginger powder extract extensively degrades the muscle fibers of black goat *biceps femoris*. In their study evaluating the antioxidant activity of various plant extracts and their application to beef patties, Mansour and Khalil [35], reported that proteolytic enzymes in ginger promoted the degradation of intramyometrial collagen and sarcolemma surrounding the muscle fibers, resulting in cracks in the muscle fibers of the meat and changes in the connective tissue with an increase in the space between the fibers. A study by Ertbjerg and Puolanne [36], on the Muscle structure, sarcomere length and influences on meat quality showed a negative correlation between muscle cross-sectional area and meat tenderness, which is consistent with the results of this study.

There was a significant increase in the root length of black goat *biceps femoris* with increasing concentrations of ginger powder extract, with the highest value at 7 %, and the highest concentration of ginger powder extract was significantly higher than that of the control ($P < 0.05$). A study by Naqvi et al. [37], on softening and improving the quality of *biceps femoris* in aged cattle using ginger proteolytic enzymes also showed similar results, showing an increase in root length with an increasing concentration of ginger extract. Tenderness characterization studies on beef muscle by Roy and Bruce [38], and Holman et al. [39], on the structure and tenderness of muscle also showed that longer root lengths had lower shear force values, and there was a positive correlation between root length and

meat tenderness. These results suggest that plant-derived proteolytic enzymes accelerate the degradation of beef myofibrils and collagen proteins, which has a positive effect on meat tenderization [40]. In addition, shorter myofibril lengths increase the overlap of filaments, resulting in higher shear force values and increased degradation of small-molecule proteins [41].

3.5. SDS-PAGE

Fig. 2 shows the SDS-PAGE results for black goat *biceps femoris* as a function of ginger powder extract concentration, and the pixel size is shown in Table 3. Zheng et al. [42], reported that proteolytic enzymes in ginger have higher protein solubility than other plant proteolytic enzymes, and ginger extract has a high protein hydrolysis effect. In this study, we found that increasing concentrations of ginger powder extract resulted in an overall increase in the degradation of high molecular weight proteins to low molecular weight proteins. Tropomyosin α chain is a regulatory protein that influences and regulates the interaction between actin and muscle and is an important protein for meat tenderization [42,43]. Myosin light chain 1 (MLC 1) can be 25 kDa in weight and is used as an indicator of proteolysis and tenderness in meat [44]. Myosin light chain 2 (MLC 2), at 15 kDa, is responsible for muscle contraction and has calcium-binding sites that lead to phosphorylation of the protein [45]. Phosphorylated MLC 2 and shear force are positively correlated, and proteolytic enzymes inhibit kinase, a phosphatase that binds to MLC 2 [46]. In this study, the pixel size of MLC 2 tended to decrease as the concentration of ginger powder extract increased. These results suggested that the decrease in MLC 2 resulted in the overall hydrolysis of the protein into small-molecule proteins below 15 kDa.

3.6. Sensory evaluation

The results of the organoleptic evaluation of black goat *biceps femoris* according to the concentration of ginger powder extract are shown in Table 4. The appearance of black goat *biceps femoris* heated in a dry oven showed higher scores with increasing concentrations of ginger powder extract compared with the control, with the highest 7 % treatment showing significantly higher scores ($P < 0.05$). This may be due to the yellow pigment, curcuminoid, in the ginger itself [26], and the chromaticity in this study also showed a significantly higher yellow value in the 7 % treatment with the highest concentration of ginger powder extract ($P < 0.05$). Goatiness and ginger also showed higher scores with increasing concentrations of ginger powder extract and significantly higher scores in the 7 % treatment with the highest amount of ginger powder extract ($P < 0.05$). These results were attributed to the presence of zingerone, gingerol, and shogaol, which are the characteristic flavor components of ginger, decreasing the detection of ginger and increasing the detection of ginger with increasing concentration [47]. The swallowiness and chewiness scores were also significantly higher with increasing concentrations of ginger powder extract ($P < 0.05$). This is believed to be due to the proteolytic enzymes in ginger, which decrease the shear force of black goat *biceps femoris* and increase its softness. Juiciness scores tended to increase with increasing concentrations of ginger powder extract, with the highest concentration (7 %) showing significantly higher scores than the control ($P < 0.05$). These results suggest that the pH of black goat *biceps femoris* was positively shifted away from the isoelectric point (5.2–5.3) due to ginger powder extract, which increased the anions and widened the spacing between muscle fibers. This increased the space for water storage, thus improving the water retention of the meat, which also increased the juiciness score [33]. The overall acceptability scores also increased as the concentration of ginger powder extract increased, with significantly higher scores in the 7 % treatment and the highest amount of ginger powder extract compared with the control ($P < 0.05$). The increased sensory evaluation scores with higher concentrations of ginger powder extract are expected to align with consumer preferences for tender and flavorful meat products. According to a study by Mohd Azmi et al. [30], on the characteristics of plant-based proteolytic enzymes, it was reported that

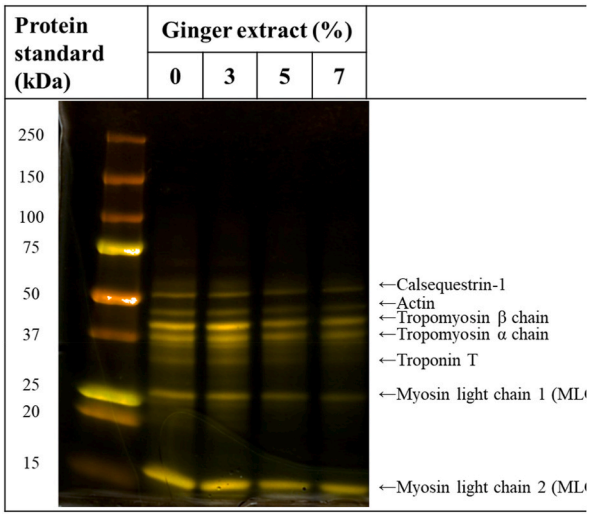

Fig. 2. SDS-PAGE of black goat *biceps femoris* with various levels of ginger extract.

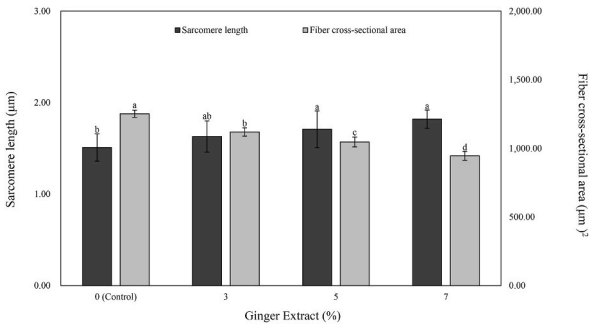

Fig. 3. Sarcomere length and fiber cross-sectional area of black goat *biceps femoris* with various levels of ginger extract. Means in the same color bars with different letters (a–d) are significantly different ($P < 0.05$).

Table 3
Pixel size (px^2) of SDS-PAGE of black goat *biceps femoris* with various levels of ginger extract.

kDa	Ginger extract (%)			
	0 (Control)	3	5	7
37	1322.42	1102.11	1033.26	979.56
20	1425.14	1209.86	919.27	790.21
15	2796.91	2015.36	1801.48	1740.63

Table 4
Sensory evaluation of black goat *biceps femoris* with various levels of ginger extract.

Traits	Ginger extract (%)			
	0 (Control)	3	5	7
Appearance	7.79 ± 0.89^{c}	8.31 ± 0.50^{bc}	8.66 ± 0.62^{ab}	9.04 ± 0.79^{a}
Goatiness	7.25 ± 0.67^{c}	8.70 ± 0.71^{b}	8.83 ± 0.81^{ab}	9.71 ± 0.62^{a}
Ginger	7.25 ± 0.46^{c}	7.60 ± 0.88^{c}	8.60 ± 0.46^{b}	9.36 ± 0.55^{a}
Swallowiness	7.45 ± 0.73^{d}	8.38 ± 0.71^{c}	8.91 ± 0.58^{b}	9.50 ± 0.52^{a}
Juiciness	7.38 ± 0.48^{c}	8.35 ± 0.67^{b}	8.73 ± 0.52^{b}	9.50 ± 0.52^{a}
Chewiness	7.36 ± 0.45^{d}	8.00 ± 0.78^{c}	8.59 ± 0.66^{b}	9.42 ± 0.67^{a}
Overall acceptability	7.32 ± 0.56^{c}	8.04 ± 0.69^{b}	8.58 ± 0.57^{b}	9.38 ± 0.74^{a}

All values are mean ± SD.
Means in the same row with different letters (a-d) are significantly different ($P < 0.05$).

the excessive addition of enzymes not only harmed meat quality but also adversely affected sensory evaluation. Moreover, it was judged that adding more than 7 % ginger powder extract would impair the flavor of the meat. Therefore, it is concluded that tenderization of black goat *biceps femoris* with ginger powder extract at a concentration of 7 % when cooked in a dry oven is likely to be organoleptically superior.

4. Conclusion

In this study, we investigated the effects of ginger powder extract concentrations on the quality characteristics of black goat *biceps femoris*. The moisture and protein contents of B. *biceps femoris* tended to increase with increasing concentrations of ginger powder extract, and the values were significantly higher in the highest 7 % treatment than in the control. The pH tended to increase with increasing concentrations of ginger powder extract, and the values were significantly higher in the highest 7 % treatment than in the control. The CIE L* value of chromaticity was significantly higher in the 7 % treatment with the highest concentration of ginger powder extract compared with the control. The CIE a* value was significantly lower in the 7 % treatment compared with the control. The CIE b* value tended to increase with increasing concentrations of ginger powder extract compared with the control and was significantly higher in the highest 7 % treatment. The shear force tended to decrease with increasing concentrations of ginger powder extract and was significantly lower than that of the control at the highest concentration of 7 %. Water retention force was significantly higher in the 7 % ginger powder extract treatment than in the control. High-molecular weight proteins were degraded to low molecular weight proteins as the concentration of ginger powder extract increased. The root cross-sectional area significantly decreased with increasing concentrations of ginger powder extract, and root length was significantly higher in the 5 % and 7 % ginger powder extract treatments than in the control. Sensory evaluation results showed that all parameters were significantly higher in the 7 % ginger powder extract-treated group. The optimal concentration of ginger powder extract has been identified as 7 %. Ginger is known for its various health

benefits, including anticancer properties, and is expected to have a positive impact on consumers seeking functional health foods. The proteolytic enzymes in ginger powder extract are effective in softening black goat meat's tough texture. In addition, it is suggested that future research should explore the incorporation of black goat meat tenderized with ginger powder extract into processed meat products.

CRediT authorship contribution statement

Jin-Hee An: Writing – original draft, Visualization, Validation, Project administration, Methodology, Formal analysis, Data curation. **Hack-Youn Kim:** Writing – review & editing, Supervision, Software, Resources, Investigation, Funding acquisition, Conceptualization.

Data availability statement

Data will be made available on request.

Ethical approval and consent to participate

The authors declare that this study was approved by the Kongju University Institutional Safety Ethics Committee of South Korea (Authority No.: KNU_IRB_2021-075), and that all participants consented to participate in the sensory evaluation and agreed to the use of their information. All procedures were conducted in accordance with relevant laws and institutional guidelines. Appropriate protocols to protect the rights and privacy of participants were followed throughout the research.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e40736.

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