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ARTICLE

Physicochemical Properties of Restructured Black Goat Jerky with Various Types of Ultra-Ground Seaweed Powders

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Abstract This study investigated the effects of ultra-ground seaweed powders (USP) on the physicochemical properties (proximate composition, mineral contents, pH, color, shear force, sensory evaluation, electronic nose, and electronic tongue) of restructured black goat jerky. Restructured black goat jerky was prepared using three different treatments, i.e., 3% (w/w) each of ultra-ground sea tangle (ST; *Undaria pinnatifida*), sea mustard (SM; *Saccharina japonica*), and sea string (SS; *Gracilaria verrucosa*) powders. Moisture and ash contents were significantly higher in the USP-treated group than in the control ($p<0.05$). Potassium, calcium, and zinc contents were significantly higher in the SM than in the other USP-treated groups ($p<0.05$). In contrast, pH values were significantly higher in the ST and SM than in the control and SS ($p<0.05$). CIE L*, CIE a*, CIE b*, and shear force were significantly lower in the USP-treated groups than in the control ($p<0.05$). Sensory evaluation revealed no significant difference in taste, texture, seaweed-like odor, and goaty flavor ($p<0.05$). Principal component analysis (PCA) and peak graph analysis of the electronic nose showed that the SS differed the most from the control compared with the other USP-treated groups, owing to the seaweed odor of ultra-ground SS powder. The PCA and ranking analysis of the electronic tongue showed that the umami taste of the SM was higher than that of the control and other USP-treated groups. Therefore, the potassium, calcium, zinc contents, and umami taste of reconstituted black goat jerky were significantly higher in the SM than in the control and other USP-treated groups.

Keywords physicochemical properties, black goat, restructured jerky, ultra-ground seaweed powder

Introduction

Black goat (*Capra hircus*) meat is a high-protein, low-fat food with high nutritional value due to its high vitamin E, essential amino acid, and unsaturated fat content (Park et al., 2020). Recently, along with a rise in domestic meat consumption, the number of black goats being reared has rapidly increased by 36%, from 284,000 to 443,000 animals between 2015 and 2021 (Korea Agricultural Statistics Service, 2021). However, Korean consumers still perceive black goats as mostly being for medicinal use rather than edible (Kim et al., 2020). There is a high barrier to entry for goat meat because it is mostly sold directly from farms or at specialist restaurants, and people have preconceptions about the unique goaty smell. Consequently, there is a need for research on various types of processed food products to change consumers' perceptions regarding black goats and increase consumption (Choi et al., 2022). Recently, there has been much research overseas to develop processed goat meat products, including nuggets with added enoki mushrooms, patties with added chrysanthemum extract, and jerky with added raising (Banerjee et al., 2020; Khan et al., 2020; Lemma et al., 2022). The development of high-protein meat products is also being considered in Korea.

Recently, with the growth of leisure, drinking alone, and camping cuslture, consumers are increasingly seeking convenience, leading to greater interest in and consumption of jerky owing to its portability and high nutritional value relative to weight (Food Information Statistics System, 2023). Among various methods of preparing jerky, flat jerky is a traditional method in which the meat is cut and dried as it is, preserving the shape of the muscle (Kim et al., 2021). Flat jerky tends to be tough and chewy, as its shape resembles the shape of the muscle (Yu, 2017). In contrast, restructured jerky is prepared by processing ground meat, rendering it relatively more tender than flat jerky (Hong et al., 2020). Restructured jerky is simpler to use in the development of health functional foods than flat jerky, as during the grinding and restructuring process, the meat can be combined in a smooth mixture with various additional ingredients, e.g., chili pepper seeds or black rice (Lee and Kim, 2016; Park and Kim, 2016).

Health functional foods are foods that contain ingredients or extracts that have positive effects on health (Jeon et al., 2022). Seaweeds have been receiving much attention as ingredients for health functional foods owing to their abundant antioxidant, dietary fiber, and mineral contents (Yuan et al., 2023). Seaweeds are used as a functional ingredient in various meat products owing to the antioxidant properties of carotenoids and the excellent moisture retention properties of polysaccharides such as fucoidan and alginate (Cofrades et al., 2017; Ilyas et al., 2023). The zinc in seaweed not only helps to activate nearly 200 enzymes in the body but also helps with taste perception and appetite maintenance by promoting the growth, proliferation, and sensitivity of sensory stem cells responsible for taste perception (Peñalver et al., 2020; Singh and Dubey, 2019). There has been persistent research on meat products with added seaweed or physiologically active substances from seaweed, and several functional foods are still being studied (Gullón et al., 2020). For example, there have been studies on functional foods such as pork sausages, reduced salt chicken patties, and beef meatballs with sodium polyphosphate replaced by seaweed (Mohammed et al., 2022; Pindi et al., 2023; Widati et al., 2021). Studies in which seaweed is added to these products mostly use a powdered form of seaweed. Ultra-ground refers to the process of pulverizing particles from 3 mm to 10–25 μm. This has the advantage of improved solubility, thereby increasing bioavailability and performance (Park et al., 2019). In particular, when seaweed powder is finely ground to the micrometer scale, the smaller particle size than that in intact seaweed results in an increased surface area, which can improve absorption and bioavailability (Han and Youn, 2009). However, there is still a lack of research focusing on the development of meat products with improved flavor by adding ultra-ground seaweed powder (USP).

We prepared restructured black goat jerky in a control group with 0% added USP and in USP-treated groups with 3% (w/w) ultra-ground sea tangle (ST; *Undaria pinnatifida*), sea mustard (SM; *Saccharina japonica*), or sea string (SS; *Gracilaria verrucosa*), and we compared their physicochemical characteristics.

Materials and Methods

Preparation of seaweed powders

The seaweeds ST, SM, and SS were obtained from a shopping mall selling local specialties from Wando-gun (Wando-gun Eshop, Wando, Korea). The seaweed was hydrated for 24 h to eliminate any remaining salinity, washed, and dried in a chamber (10.10ESI/SK, Alto Shaam, Menomonee Falls, WI, USA) for 48 h at 35℃. The dried seaweed was ultraground to 300 mesh size in a blender (DP-5800BL, Guangdong Xinbao Electrical Appliances Holdings, Foshan, China). The pH values, colors, and mineral contents of the three USP are listed in Table 1.

Preparation of restructured black goat jerky

For black goats (Agricultural Corporation GAON, Gangjin, Korea), sirloin parts 24 h after slaughter were used. The number of goats used was 6, and the samples were stored at 4℃. After removing excessive fat and connective tissue, the black goat meat was ground using a grinder fitted with a 3 mm plate (PA-82, Mainca, Barcelona, Spain), and this ground meat was used as the meat for jerky. The base brine solution was made by mixing water (10% of the weight of the meat), soy sauce (9%, v/v), nitrite pickling salt (NPS; 0.7%, w/v), starch syrup (5%, v/v), sugar (2%, w/v), black pepper (0.2%, w/v), garlic powder (0.2%, w/v), and onion powder (0.2%, w/v). An additional 3% (w/w) ST, SM, or SS powder was added to the brine solution for the USP-treated groups. The meat and brine solution were mixed in a ball cutter (RM-20, Mainca) at 30 rpm for 1 min before adding ice water and mixing for another 1 min to make an emulsion. The core temperature of the emulsion was kept under 10℃. The mix was formed into 1×8×0.2 cm (W×L×H) cuboids, dried in a chamber (10.10ESI/SK, Alto Shaam) for 90 min at 80℃, and then cooled for 30 min at 25℃. The jerky was then stored in a refrigerator at 4℃ until the experiment.

Proximate composition

Proximate composition analysis was performed according to the AOAC Official methods of Analysis (AOAC, 2019). Moisture content was measured using the commercial drying method (950.46, AOAC) in a drier set to 105℃ (C-F03, Vision Scientific, Daejeon, Korea). Crude protein content was measured using the Kjeldahl method (992.15, AOAC). Crude fat

Table 1. Physical properties and mineral contents of various types of ultra-ground seaweed powder

Traits		Sea tangle	Sea mustard	Sea string
pH		8.83±0.29^{a}	7.81±0.15^{b}	6.31±0.10^{c}
Color	CIE L*	44.23±1.11^{b}	55.50±1.62^{a}	38.30±0.25^{c}
	CIE a*	–0.91±0.12^{c}	4.37±0.25^{a}	1.33±0.07^{b}
	CIE b*	10.24±0.91^{b}	19.18±1.07^{a}	2.36±0.09^{c}
Mineral (ppm)	P	57.14	28.50	43.47
	Na	466.25	161.02	26.30
	Mg	78.23	75.89	15.52
	K	21.46	428.84	330.87
	Ca	226.79	206.39	22.24

All values are mean±SD.
$^{a–c}$ Means with different letters within a same row are significantly different ($p<0.05$).

content was measured using the Soxhlet method (960.39, AOAC). Crude ash was measured using the direct burning method (AOAC 920.153) in an ashing furnace at 550°C (DMF-5T, U1tech, Suwon, Korea).

Mineral contents

To measure the mineral contents in restructured black goat jerky with added USP, 0.3 g of jerky was weighed in a vessel, and 7 mL of HNO_3 and 2 mL of H_2O_2 solutions were added. Subsequently, the samples were pretreated for 10 min in a microwave (Titan MPS Microwave, Perkin Elmer, Waltham, MA, USA) to achieve separation. Once separated, 0.5 g of the sample was diluted 100-fold in triple distilled water to adjust the final weight to 50 g. Another 0.2 g of pretreated sample was diluted 100-fold in triple distilled water to make up the final weight to 20 g at a final concentration of 100 ppm. These solutions were used in the experiment. The mineral contents of the samples were determined by measuring ion beam intensity with an inductively coupled plasma mass spectrometer (NEXION-350X, Perkin-Elmer, Shelton, CT, USA).

Measurements of pH

To measure the pH, 3 g of restructured black goat jerky with added USP was measured, mixed with 12 mL of distilled water, and homogenized for 1 min at 10,000 rpm using a homogenizer (AM-5, Nissei, Anjo, Japan). The pH of the homogenized sample was measured using a glass electrode pH meter (Model S220, Mettler-Toledo, Schwerzenbach, Switzerland), calibrated using pH 4.01, pH 7.00, and pH 10.00 buffer solutions (Suntex Instruments, Taipei, Taiwan).

Color measurements

A colorimeter (CR-10, Minolta, Tokyo, Japan) was used to measure Commission Internationale de l'Éclairage CIE L*, CIE a*, and CIE b* values from the inner surface the restructured black goat jerky with added USP. The standard colors of the colorimeter were calibrated using a standard white tile with CIE L* +97.83, CIE a* –0.43, and CIE b* +1.98.

Shear force measurements

For the shear force measurements, a 1.0×5.0×0.2 cm (W×L×H) sample of restructured black goat jerky with added USP was prepared and analyzed using a texture analyzer (TA 1, Lloyd, Largo, FL, USA) fitted with a V-blade. The analysis conditions were set to test speed 2.0 mm/s, distance 2.0 mm, and force 5 g, and measurements were recorded in units of kgf.

Sensory evaluation

Sensory evaluation was conducted with ethical approval from the University Institutional Bioethics Committee. Heat-processed restructured black goat jerky from each treatment group was cut into evenly sized pieces. A panel of 15 trained persons tasted samples from each treatment group and assigned scores out of 10 for different categories, including color, taste, texture, seaweed-like odor, goaty flavor, and overall acceptability, with 10 indicating the best quality and 1 indicating the worst quality. The USP-added group was given a higher score as it was similar to the control group, and the less seaweed and chlorine odors were felt, the higher the score was given. Subsequently, we compared the mean scores of the three USP-treated groups.

Electronic nose

For flavor analysis, 5 g of restructured black goat jerky with added USP was placed in a 20 mL sample vial and analyzed at

80℃ using an electronic nose (HERACLES-2E-NOSE, Alpha MOS, Toulouse, France). The two columns used included MXT-5 (Restek, Bellefonte, PA, USA) and MXT-1701 (Restek). The analysis conditions were set to reaction time 20 min, injection volume 2 mL, injection rate 250 µL/s, inlet temperature 200℃, and detector temperature 260℃. To investigate the differences in volatile organic compounds between the control group and USP-treated groups, principal component analysis (PCA) was performed, and the peaks were analyzed using the Alpha soft program (version 14.1 for Windows, Alpha MOS).

Electronic tongue

To analyze taste components, 4 g of restructured black goat jerky with added USP was measured, mixed with 32 mL of distilled water, and homogenized for 1 min at 10,000 rpm using a homogenizer (AM-5, Nissei). The homogenized sample was filtered using filter paper (Whatman No. 1, Whatman, Maidstone, UK), and the supernatant was collected in a 15 mL conical tube. The supernatant was dissolved 1,000-fold in distilled water and poured into a 150 mL tall beaker before analysis using an electronic tongue (Astree 5, Alpha MOS). Moreover, SCS and CPS sensors were used as indicator sensors alongside the taste sensors CTS (salt), AHS (sour), and NMS (umami). For determining the differences between the control and USP-treated groups, multivariate statistical analysis was used to derive objective, numerical values for the extent of each taste component, and the Alpha soft program (version 14.1 for Windows, Alpha MOS) was used to display the results in terms of PCA and rankings.

Statistical analyses

All experiments were performed in triplicate, at least. Each variable was analyzed using a one-way analysis of variance, and significant differences between groups ($p<0.05$) were tested using Duncan's multiple-range test. The statistics program SAS (version 9.4 for Windows, SAS Institute, Cary, NC, USA) was used to present the results in terms of mean and SD.

Results and Discussion

Proximate composition

Table 2 shows the results of the proximate composition analysis of restructured black goat jerky with different types of added USP. Moisture content was significantly higher in the USP-treated groups than in the control group ($p<0.05$), consistent with the results of a previous study where Sipahutar et al. (2020) reported higher moisture content in fish sausages with added seaweed powder than that in a control group. This difference in moisture content between the control and USP-treated groups is considered to be due to high water absorption by sulfate groups in seaweed dietary fiber, which consists of complex polysaccharides (Wang et al., 2013). The sulfate groups on the seaweed polysaccharides show affinity for monovalent and bivalent positive ions, and at temperatures less than 30℃–40℃, molecular interactions result in gelatinization of the three-dimensional structure, increasing water absorption (Qureshi et al., 2019). Ash content was significantly higher in the ST and SM compared to the control and SS ($p<0.05$). Kim et al. (2010a) reported higher ash content with increasing dietary fiber in pork sausages with added seaweed powder than in those without this seaweed powder. Likewise, in our study, the high fiber contents of the USP are considered to have affected the ash contents. Crude protein and crude fat contents were significantly higher in the control group than in the USP-treated groups ($p<0.05$). Choi et al. (2012) also observed that adding seaweed powder to pork patties resulted in higher moisture and ash and lower protein and fat contents than those in pork patties without added seaweed powder, consistent with our findings. The USPs added in our study are considered to have

Table 2. Proximate composition of restructured black goat jerky with various types of ultra-ground seaweed powder

Traits (%)	Control	Sea tangle	Sea mustard	Sea string
Moisture	36.23±0.51[c]	37.36±0.87[b]	39.12±0.81[a]	37.51±0.49[b]
Protein	38.03±0.86[a]	36.15±0.22[b]	35.34±0.31[c]	36.36±0.58[b]
Fat	14.42±0.61[a]	13.05±0.13[c]	14.18±0.66[b]	13.86±0.81[c]
Ash	5.86±0.04[b]	6.21±0.05[a]	6.15±0.05[a]	5.89±0.08[b]

All values are mean±SD.
[a–c] Means with different letters within a same row are significantly different (p<0.05).

contributed to a rise in moisture and ash contents and a decline in protein and fat contents.

Mineral contents

Table 3 shows the results for the mineral content of restructured black goat jerky with different types of USP added. Phosphorus (P) content was significantly higher in the control group than in the USP-treated groups ($p<0.05$). It is considered that higher moisture content in the USP-treated groups than that in the control group, due to the high water-retaining properties of seaweed polysaccharides, resulted in relatively lower P content than that in the control group. Although P is essential for bone formation and maintenance, excessive intake can antagonistically affect calcium (Ca) absorption, leading to osteoporosis and hypertension; therefore, restricted P intake is recommended (Lee et al., 2020). According to the 2020 Dietary Reference Intakes for Koreans, published by the Ministry of Health and Welfare (2020), the recommended daily P intake for adults (19–64 years old) is 700 mg. The P content in the USP-treated groups did not exceed the recommended levels (Jeon and Choi, 2012); therefore, it can be believed safe. Iron (Fe) content was significantly higher in the ST than in the other groups ($p<0.05$). Potassium (K), Ca, and zinc (Zn) contents were significantly higher in the SM than in the control group and the other groups with added USPs ($p<0.05$). As a component of hemoglobin, myoglobin, and mitochondrial enzymes, Fe is essential for adenosine triphosphate (ATP) production via oxygen transport and oxidase formation (Kim et al., 2010b). Potassium inhibits sections of the hormone renin, regulating blood pressure by reducing sodium (Na) reabsorption. In addition, when ATP-sensitive Ca channels in the cell membrane close, resulting in depolarization, K causes the opening of voltage-gated Ca channels, causing a rapid influx of Ca and stimulating insulin secretion; thus, K also plays a crucial role in regulating blood glucose (Kang, 2020). Ca is involved in neurotransmission, intracellular signaling, enzyme activity, and the contraction and relaxation of muscles (Marriott et al., 2020). Zn affects the synthesis of the protein gustin, which is involved in taste bud production, increases salivary Ca concentration, helps with Ca receptor activity in the taste buds, and also acts as

Table 3. Mineral (P, K, Ca, Fe and Zn) contents of restructured black goat jerky with various types of ultra-ground seaweed powder

Traits (ppm)	Control	Sea tangle	Sea mustard	Sea string
P	33.86±0.30[a]	30.30±0.60[c]	33.31±0.36[ab]	32.50±0.65[b]
K	42.47±0.86[c]	47.09±0.29[b]	55.10±0.19[a]	37.24±0.16[d]
Ca	ND	0.84±0.01[c]	3.32±0.03[a]	2.65±0.03[b]
Fe	0.52±0.03[ab]	0.54±0.01[a]	0.51±0.00[b]	0.44±0.00[c]
Zn	0.36±0.00[b]	0.34±0.01[c]	0.43±0.00[a]	0.34±0.01[c]

All values are mean±SD.
[a–d] Means with different letters within a same row are significantly different (p<0.05).
ND, not detected.

a complementary factor for alkaline phosphatase and enzymes in the cell membranes of taste buds (Nagraj et al., 2017). Based on our findings, SM is considered to be beneficial for the production of functional meat products because the SM showed higher levels of minerals that favorably affect various activities in the body than that in the control and other USP-treated groups.

Color and pH

Table 4 shows the outcomes of pH and color analyses of restructured black goat jerky with added USPs. The pH values were significantly higher in the ST and SM groups than in the control and SS groups ($p<0.05$), consistent with the results reported by Pindi et al. (2023) that chicken patties containing seaweed powder showed higher pH than in a control group. The increase in pH in the USP-treated groups is considered to be caused by alkaline minerals in seaweed, such as Fe, Ca, Zn, and manganese (Widati et al., 2021). These alkaline minerals bind to the seaweed polysaccharides, maintaining a positive ionic state and increasing the pH (Robal et al., 2017). The pH of the ingredients used in this experiment was diverse (black goat sirloin: 5.92, SM: 8.83, ST: 7.81, SS: 6.31) and appears to have affected the final pH of black goat jerky.

Regarding color, CIE L*, CIE a*, and CIE b* were significantly higher in the control group than in those containing USP ($p<0.05$). Mohammed et al. (2022) added brown (*Himanthalia elongata* and *Alaria esculenta*) and red algae (*Palmaria palmata* and *Porphyra umbilicalis*) powders to pork sausages and reported higher CIE L*, CIE a*, and CIE b* in the control than in the USP-treated groups, consistent with our findings. In the treatment group, SM showed significantly higher brightness and CIE b* values. This appears to be influenced by the chromaticity of SM powder. As types of brown algae, SM (*U. pinnatifida*) and ST (*S. japonica*) have abundant chlorophyll and show higher chlorophyll recovery rates after cooking compared with those of red algae (Chen and Roca, 2019). Moreover, SS (*G. verrucosa*), a type of red algae, contains carotenoids like phycobilins, which are readily lost owing to oxidation-induced discoloration or isomerization under certain processing conditions, including temperature changes, blending, and drying (Aryee et al., 2018; Lee, 2010). Depending on the color of the USP used in this experiment, CIE L*, CIE a*, and CIE b* varied in the range of 38.30 to 55.50, –0.91 to 4.37, and 2.36 to 10.24, respectively. These differences, along with the various factors discussed above, are believed to have affected the final color of black goat jerky.

Shear force

The results of shear force measurements for restructured black goat jerky with different added USPs are shown in Fig. 1. Shear force was significantly higher in the control group than in the USP-treated groups ($p<0.05$). Choi et al. (2015) reported that pork frankfurters with added seaweed powder (ST, SM, hijiki, and glasswort) showed lower hardness, gumminess, and

Table 4. pH and color of restructured black goat jerky with various types of ultra-ground seaweed powder

Traits		Control	Sea tangle	Sea mustard	Sea string
pH		6.21 ± 0.01^{c}	6.25 ± 0.01^{a}	6.23 ± 0.01^{b}	5.86 ± 0.02^{d}
Color	CIE L*	45.46 ± 0.77^{a}	40.89 ± 0.41^{d}	43.68 ± 0.49^{b}	42.64 ± 0.62^{c}
	CIE a*	9.37 ± 0.52^{a}	2.06 ± 0.17^{c}	5.10 ± 0.19^{b}	5.19 ± 0.58^{b}
	CIE b*	8.79 ± 0.73^{a}	4.70 ± 0.39^{d}	7.50 ± 0.27^{b}	6.07 ± 0.57^{c}

All values are mean±SD.
[a–d] Means with different letters within a same row are significantly different ($p<0.05$).

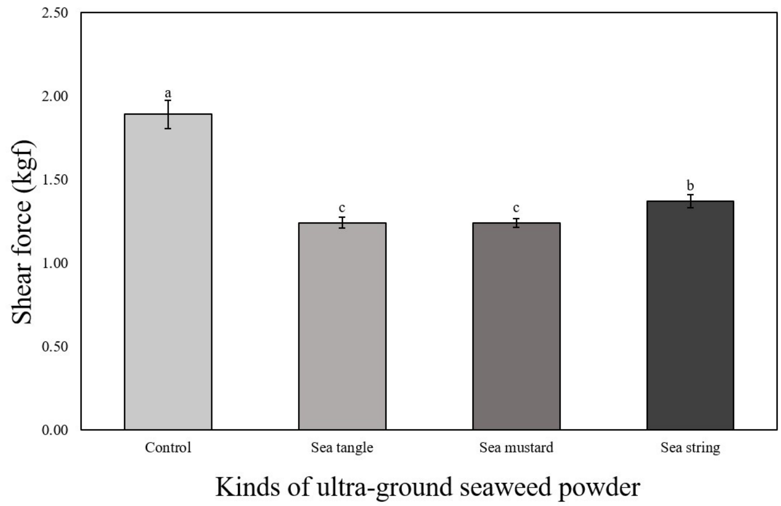

Fig. 1. Shear force of restructured black goat jerky with various types of ultra-ground seaweed powder. [a–c] Means with different letters are significantly different (p<0.05).

chewiness compared to a control group, which was similar to our findings. The increased water-holding capacity of dietary fiber and the internal swelling is considered to have restricted adhesion between constituents. Moreover, as the size of the particles increased beyond that of the previous gel and emulsion particles, this affected the texture of the USP-treated groups (Moroney et al., 2013). In addition, reduced fat content and increased moisture content reduce shear force by increasing water content in the emulsion (Prapasuwannakul, 2018). The proximate composition analysis also showed higher moisture content in the USP-treated groups than in the control group and is believed to have affected the shear force. In summary, adding USP during the preparation of restructured black goat jerky can improve the tenderness of the final product.

Sensory evaluation

Table 5 shows the outcomes of sensory evaluation for restructured black goat jerky with different added USPs. Regarding color, the ST group showed significantly lower scores than those exhibited by the control or other USP-treated groups (p<0.05). The CIE a* of processed meat products has a major effect on consumer preferences, with high CIE a* favored by consumers (Lee et al., 2018). CIE a* positively correlated with the sensory evaluation scores for color (Shin et al., 2022). Similarly, in our study, the SM group with added ultra-ground SM powder showed lower CIE a* and also scored lower in

Table 5. Sensory evaluation of restructured black goat jerky with various types of ultra-ground seaweed powder

Traits	Control	Sea tangle	Sea mustard	Sea string
Color	9.40±0.69[a]	7.70±0.54[b]	8.77±0.68[a]	8.92±0.66[a]
Taste	9.20±0.94	8.80±1.19	9.27±0.41	9.15±0.49
Texture	8.87±0.53	9.10±0.77	9.02±0.50	8.95±0.57
Seaweed-like odour	8.83±0.76	9.00±0.96	8.98±0.38	8.92±0.66
Goaty-flavor	8.82±0.74	9.18±0.68	9.27±0.39	9.02±0.50
Overall acceptability	9.00±0.52	9.22±0.91	9.37±0.36	8.90±0.70

All values are mean±SD.
The evaluation scores range from 1 to 10, where 10 represents the 'best' and 1 represents the 'worst'.
[a,b] Means with different letters within a same row are significantly different (p<0.05).

sensory evaluation compared with these parameters of the control and other USP-treated groups. Taste, texture, seaweed-like odor, goaty flavor, and overall acceptability did not show any significant differences between the control group and the USP-treated groups, suggesting that the addition of seaweed did not have a noticeable negative impact on acceptability. This finding is consistent with that of a previous study by Munsu et al. (2021), who reported no significant differences in flavor, taste, texture, or overall acceptability between a control group and chicken sausages containing 2% (w/v) red and brown algae (*Sargassum polycystum*) powders. Although restructured black goat jerky with added USP showed lower ratings in the color category, there was no significant difference in overall acceptability, showing that the USP did not adversely affect the final consumer preference. To summarize the sensory evaluation results, the groups did not show significant differences in any category other than color; however, as the SM group showed the highest numerical score for overall acceptability, ultra-ground SM powder addition could impact the sensory characteristics of restructured black goat jerky.

Electronic nose

The results of the electronic nose analysis of restructured black goat jerky with different added USPs are shown in Fig. 2. An electronic nose is a device that can rapidly and efficiently evaluate food quality by mimicking the process whereby olfactory receptor proteins in the human olfactory nerve bind to and identify odorant molecules (Lim and Park, 2012). The PCA results for PC (principal component)1 and PC2 for restructured black goat jerky analyzed using the electronic nose are shown in Fig. 2A, whereas Fig. 2B shows the molecular peaks when the jerky was analyzed using the electronic nose. Looking at PC1 in Fig. 2A, the control, ST, and SM groups are located in the 0 to 5,000 range, whereas the SS group is located at roughly –20,000, demonstrating flavor differences in the SS group compared with that in the other groups. In Fig. 2B, peaks 2, 5, 6, and 7 for the SS group show higher values than those for the control or other USP-treated groups. The compounds corresponding to peaks 2, 5, 6, and 7 are ethanol, acetonitrile, [E]-but-2-enal, and thiophene, respectively. [E]-but-2-enal and thiophene are compounds found in plants and seaweed that produce a grassy flavor (Cohen et al., 2017; HMDB, 2021). In sensory evaluation, the SS group showed lower scores than those exhibited by the other groups in the seaweed-like odor and overall acceptability categories, likely due to this molecule producing a seaweed-like odor. Nevertheless, the differences in these categories were not statistically significant; therefore, we believe that adding ultra-ground SS powder during the preparation of black goat jerky would not have a major effect on consumer acceptability.

Electronic tongue

The results of the electronic tongue analysis of restructured black goat jerky with different USPs added are shown in Fig. 3. An electronic tongue is a device that uses a sensory array corresponding to the human tongue and a sensor membrane corresponding to the taste buds to produce objective, numerical values for the extent of taste components based on non-selective responses to each component in the sample (Bae et al., 2003). The PCA results for PC1 and PC2, when the restructured black goat jerky was analyzed using the electronic tongue, are shown in Fig. 3A, and Fig. 3B shows the rankings based on the intensities measured by the taste component sensors CTS (salt), AHS (sour), and NMS (umami). As shown in Fig. 3A, for PC2, the control, SM, and SS groups are located in the range of −2 to 120, whereas the ST group is located at roughly −160, showing that the ST group differs from the control and other USP-treated groups. The salty taste was stronger in the USP-treated groups than in the control group, as shown in Fig. 3B. The Na concentrations in the USPs used in this experiment were 446.259 ppm for SM, 161.021 ppm for ST, and 26.308 ppm for SS, suggesting that the residual Na in the seaweed powders affected the final Na content of the black goat jerky. Acidic taste was strongest in the SM group, followed

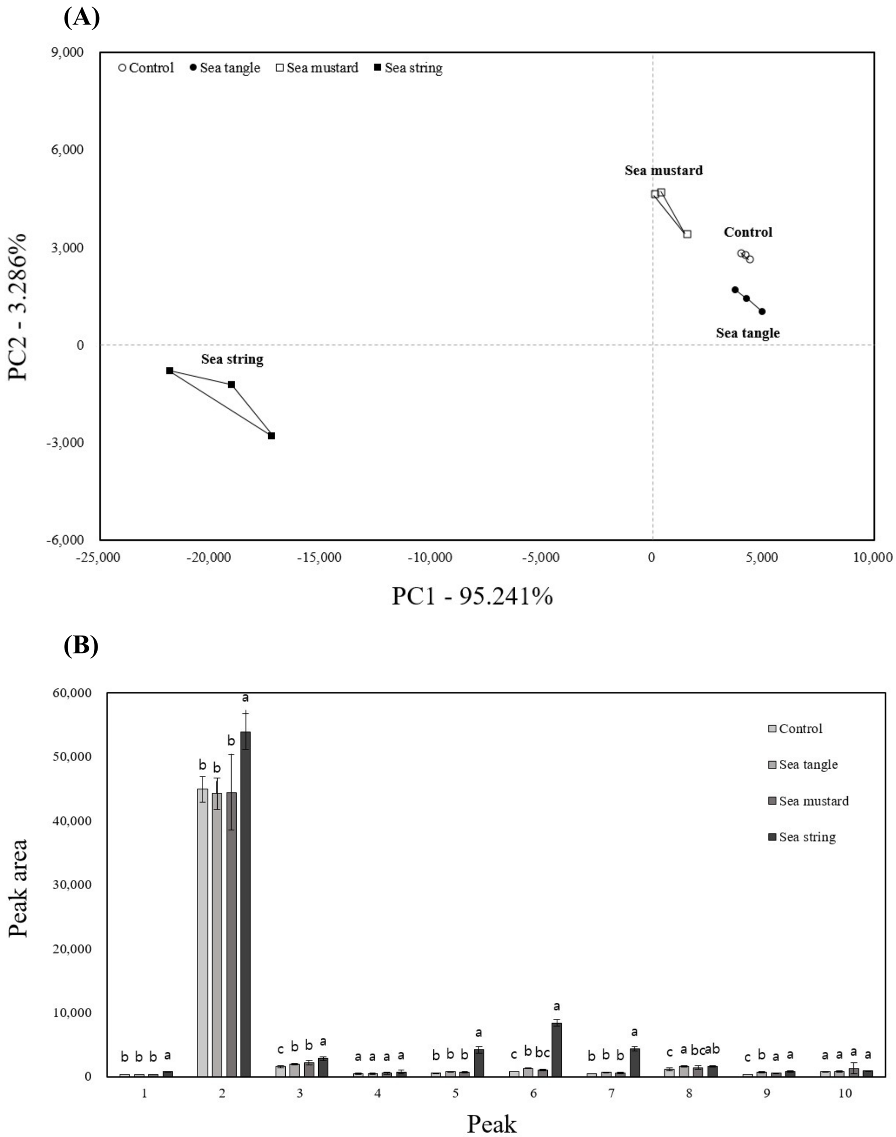

Fig. 2. Electronic nose of restructured black goat jerky with various types of ultra-ground seaweed powder. (A) Principal component analysis (PCA) sample distribution diagram of organoleptic characteristics of restructured black goat jerky added with various types of ultra-ground powders by electronic nose. (B) Peak of organoleptic characteristics of restructured black goat jerky added with various types of ultra-ground powders by electronic nose. peak 1, methanol; peak 2, ethanol; peak 3, propan-2-one; peak 4, pentane; peak 5, acetonitrile; peak 6, but-[E]-2enal; peak 7, thiophene; peak 8, limonene; peak 9, decane, peak 10, methyl eugenol. [a–c] Means with different letters are significantly different ($p<0.05$).

by that in the SS, control, and ST groups in that order. Thus, the ST group showed the weakest acidic taste. According to Kim et al. (2020), the electronic tongue measures acidic taste based on the potential difference of hydrogen ions, including citrate, acetate, and chloride. Lee (2016) reported that bivalent metal ions, like Fe, promote lipid oxidation and that metal ion chelates, like citrate, inhibit the oxidation-reduction cycle of metals by binding to metal ions. Thus, ST, which is rich in Fe, is thought to have shown a lower acidic taste due to inhibition of the oxidation-reduction cycle by citrate. Umami was higher in the USP-treated groups than in the control group, with the strongest umami taste measured in the SM group. Seaweeds contain compounds that produce an umami taste, such as the amino acids glutamine, asparagine, lysine, and leucine, which explains the strong umami taste in the USP-treated groups (Moerdijk-Poortvliet et al., 2022). Dawczynski et al. (2007)

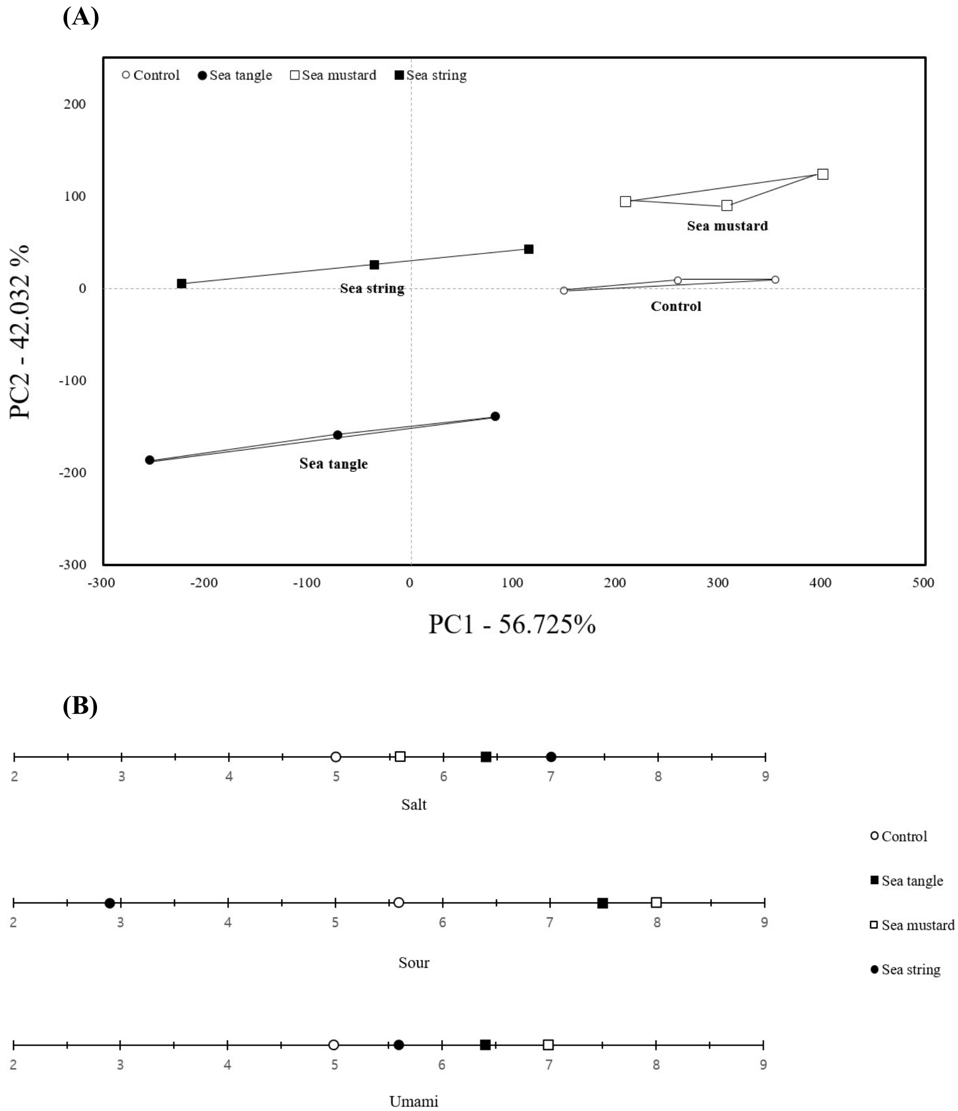

Fig. 3. Electronic tongue of restructured black goat jerky with various types of ultra-ground seaweed powder. (A) Principal component analysis (PCA) sample distribution diagram of organoleptic characteristics of restructured black goat jerky added with various types of ultra-ground powders by electronic tongue. (B) Changes of ranking of organoleptic characteristics of black goat restructured jerky added with various types of ultra-ground powders by electronic tongue.

compared the amounts of umami-tasting amino acids in different types of seaweed powders and reported that glutamine and asparagine were most abundant in ST (*Laminaria japonica*), which is consistent with our results. Therefore, when producing black goat jerky with added USP, it seems suitable to use SM, which has the strongest umami taste and the least salty taste.

Conclusion

This study analyzed the physicochemical properties of restructured black goat jerky when different types of USP were added. Adding USP to the restructured black goat jerky improved moisture content, calcium content, overall acceptability in sensory evaluation, umami taste in electronic tongue, and shear force. Among the USP-treated groups, the SM group showed the highest K, Ca, and Zn contents. Also, the results of sensory evaluation, electronic nose, and electronic tongue show the

SM group expressed similar consumer preference to control. Therefore, the addition of SM in meat products can bring positive effects on physicochemical properties without consumer repulsion.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Kim HY. Data curation: Baek UB. Formal analysis: Baek UB, Kim HY. Methodology: Kim HY. Software: Baek UB, Kim HY. Validation: Baek UB. Investigation: Baek UB, Kim HY. Writing - original draft: Baek UB. Writing - review & editing: Baek UB, Kim HY.

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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