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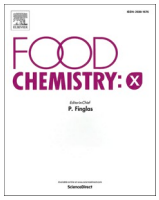

Evaluation of umami taste in Hanwoo with different feed sources by chemical analysis, electronic tongue analysis, and sensory evaluation

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ABSTRACT

This study aimed to evaluate umami taste in Hanwoo with different feed by chemical analysis, sensory evaluation and an electronic tongue system. Hanwoo cattle were divided into three groups: control group (fed only total mixed ration [TMR]), T1 (fed soybean meal + TMR), and T2 (fed soybean meal + corn-dried distiller's grain with solubles [Corn DDGS] + TMR). The three most abundant fatty acids (C18:1n-9, C16:0, and C18:0) in the T1, T2, and control groups accounted for 83.63%, 86.07%, and 85.52% of the total fatty acid content, respectively. Umami taste-related glutamic acid levels were significantly high in T1 (109.89 mg/kg), followed by T2 (66.66 mg/kg) and control (47.27 mg/kg). Fatty acid levels showed a high correlation with umami taste. The results of this study showed that the amino acid and fatty acid levels had been affected by feed types and soybean- or Corn DDGS-based feed potentially enhanced Hanwoo's umami flavor.

Introduction

Hanwoo is Korea's representative beef breed and a crossbreed between *Bos taurus* and *Bos zebu* (Hwang, Kim, Jeong, Hur, & Joo, 2010). In Korea, Hanwoo is recognized as premium beef because it is highly preferred; possesses a desirable, chewy texture; and is widely used in traditional Korean cuisine (Jeong & Lee, 2013). Compared with other cattle types, Hanwoo has relatively thin muscle fibers and low connective-tissue content; therefore, it possesses favorable genetic characteristics for the production of large quantities of beef intramuscular fat (IMF) and marbling (Joo, Hwang, & Frank, 2017). Therefore, owing to consumer perception that the higher the IMF content, the more tender and tastier the meat, Korean beef production has focused on increasing muscle fat content (Cho, Shin, Seol, Kim, Kang, & Seo, 2020). However, with the recent changes in health-conscious consumption trends, awareness regarding the potentially greater harm caused by higher IMF content in beef is growing (Shin, 2020; Kim, Cho & Choi, 2013).

The organoleptic properties of meat are influenced by several factors, such as breed, weight, sex, specification, and biochemical changes during further processing, slaughter, maturity, heat treatment, and cooking (Cho, Seo, Kim, & Kim, 2009). In addition, the most important factor influencing beef palatability, consumer preferences, and the purchasing habits of beef products is flavor (Zhao et al., 2020). Meat flavor is influenced by the complex effects of sweet, bitter, salty, and umami tastes as well as volatile ingredients (Kang et al., 2011). Various components, such as free amino acids, nucleic acid-related substances, minerals, protein hydrolysates, and free sugar, are generally known to affect meat taste in a complex manner. Moreover, glutamic acid and inosine monophosphate contents exert the greatest influence on flavor (Ishiwatari, Fukuoka, Hamada-Sato, & Sakai, 2013). Previous studies have demonstrated that unsaturated fatty acids (UFAs) also play an important role in meat taste (Lee et al., 2019; Elmore, Mottram, Enser, & Wood, 1999).

To date, studies have predominantly focused on means of increasing IMF to improve meat quality (Kim, Kim, Shin, Kim, Kim, & Choi, 2020; Ha et al., 2019). To increase IMF content in meat, high-energy feed has been used for a long period, even though the price of high-energy feed is exorbitant (Chung, Lunt, Kawachi, Yano, & Smith, 2007). However, due to recent changes in food culture, consumers increasingly prefer beef that is reasonably priced with low in IMF content (Park, Kang, & Chung, 2018). Therefore, altering feed composition to produce Hanwoo meat with enhanced flavor as well as a reasonable price is necessary.

In this study, we aimed to evaluate umami taste in Hanwoo with

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different feed by chemical analysis, sensory evaluation and an electronic tongue system. For this purpose, we used three different feed types and investigated their effects on Hanwoo quality by analyzing the color, texture, fatty acid content, and amino acid content of meat as well as conducting sensory evaluation and electronic-tongue analysis.

Materials and methods

Sample preparation

The sirloin used in this study was acquired from Daesan agricultural company corporations that raised Hanwoo steers. Hanwoo cattle (29 months old, n = 12) were randomly divided into three groups and fed three different feeds. The control group was fed a total mixed ration (TMR), which consisted of rain (corn), gourd (coconut meal, DDGS, corn germ meal), brans (Corn gluten feed, Wheat bran, Almond hulls), food processing by-products (Molasses), vitamins, and minerals. In addition to TMR, T1 was fed soybean meal (400 g/head), and T2 was fed soybean meal and corn-dried distiller's grain with solubles (Corn DDGS) for 100 and 400 g per head, respectively. The Hanwoo steers in this experiment were managed according to the scientific guidelines of the Animal Experiment Ethics Committee of Chung-Ang University (No: 2016-00105).

The steers were slaughtered at the Nonghyup Eumseong Livestock Market (Eumseong-gun, Chungbuk, Korea), and the sirloin parts collected from the cattle were analyzed. The samples were vacuum-packed and stored at –20 ℃ until analysis.

Quality characteristics

Instrumental color measurement

Instrumental color measurements were recorded on each beef sample through the packaging film at three, randomly selected different locations and averaged for statistical analysis (Kim et al., 2013). The objective color was measured for L* (psychometric lightness; black = 0, white = 100), a* (red = positive values; green = negative values), and b* (yellow = positive values; blue = negative values) using a HunterLab Spectrophotometer (Model LAS-3000; UltraScan® PRO, Hunter Associates Laboratory, Inc., Reston, VA, USA). The chroma value ($C^* = [a^{*2} + b^{*2}]^{1/2}$) and hue angle ($h^0 = \tan^{-1}$ [b*/a*]) were measured. The standard color plate was L (99.49), a (–0.05), and b (–0.12).

Texture profile analysis

Sample texture profiles were analyzed using a Texture Analyzer following the method proposed by Goni, Beriain, Indurain, and Insausti, (2007), with slight modifications. Each sample was vacuum-packed and heated in a constant-temperature water bath set to 80 °C for 30 min. For analysis, the central portion of each sample (2.5 × 2 × 2 cm^3) was measured five times. Texture profiles were analyzed under the following conditions: pre-test speed of 1.0 mm/s, post-test speed of 10.0 mm/s, test speed of 1.0 mm/s, target mode of strain, a strain of 40%, time of 1.0 s, and trigger force of 5.0 g. The parameters evaluated were hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience.

Free amino acids

Free-amino-acid extraction was performed according to the method proposed by Kwon and Choi (2018). After adding 200 mL of an 80% ethanol solution to 5 g of homogenized sirloin, the mixture was allowed to stand for 24 h. After filtering through filter paper, it was concentrated using a rotary evaporator (EYELA Rotary evaporator CCA-1110; Tokyo Rikakikai Co., Tokyo, Japan). Thereafter, 40 mL of distilled water and 20 mL of ethyl ether were added and shaken several times; subsequently, the pellet was collected using a separatory funnel. After that, it was concentrated using a rotary evaporator, and 20 mL of 0.2 M citrate buffer was added, filtered through a 0.2-μm syringe filter, and analyzed using high-performance liquid chromatography (Dionex UltiMate™ 3000, Thermo Fisher Scientific, Waltham, MA, USA).

Fatty acid profile

The total lipid was quantitatively extracted from each beef sample, according to the method proposed by Folch, Lees, & Sloane-Stanley (1957). Each meat sample (50 g) was ground and added to a 2:1 mixed solution of chloroform and methanol, and the resulting mixture was shaken vigorously to ensure effective extraction from the ground meat. The resulting mixed solution was made up to four times the amount of ground meat. After extracting for approximately 10 h, the mixture was filtered through a separatory funnel using a filtration device. Distilled water (up to four times the amount of filtered solution) was added, and the diluted mixture was subsequently shaken vigorously and allowed to stand. The lower layer of the resulting layered solution was evaporated using a rotary evaporator to extract fat and subsequently evaporated again using nitrogen gas. Thereafter, fatty acids were methylated by modifying the method described by Morrison and Smith (1964). After adding 1 mL of 0.5 N NaOH, it was heated for 7 min at 90 °C in a sand bath and cooled for 5 min at 25 °C. After adding 1 mL of 14% boron trifluoride–methanol solution, methylation was performed at 90 °C for 10 min.

After cooling for 30 min at room temperature, 2 mL of hexane and 2 mL of distilled water were added. Finally, 1 mL of the supernatant was collected and placed in a vial for gas chromatography analysis. Fatty acid composition was analyzed using a gas chromatography–flame ionization detector (GC-FID 7890; Agilent Tech, Santa Clara, CA, USA). An SPTM 2560 column (100 m × 0.25 mm; Supelco Co., Bellefonte, PA, USA) was used.

Electronic tongue analysis and sensory evaluation

Electronic tongue analysis

Pretreatment was conducted according to the method proposed by Sasaki et al. (2005). Briefly, 100-g samples were each placed in 150 mL of cold, deionized water. Thereafter, the samples were extracted by boiling them in medium heat for 1 h and cooling them down to room temperature. A Whatman No. 42 filter paper was used to remove impurities, such as tissues and fats, from the sample. Standard solutions were prepared by dissolving each mixture in 1 L of distilled water to check the cross-selectivity of the sensors. The following standard solutions were prepared: sour solution (0.45 g tartaric acid and 2.24 g potassium chloride dissolved in 1 L of distilled water), salty solution (0.045 g tartaric acid and 22.37 g potassium chloride), umami solution (0.045 g tartaric acid, 2.24 g potassium chloride, and 1.87 g monosodium glutamate), astringent solution (0.045 g tartaric acid, 2.24 g potassium chloride, and 0.05 g tannic acid), bitter (+) solution (0.045 g tartaric acid, 2.24 g potassium chloride, and 0.04 g quinine hydrochloride), and bitter (−) solution (0.045 g tartaric acid, 2.24 g potassium chloride, and 100 μL *iso*-α-acid). Electronic tongue analysis was performed using an electronic tongue system (Taste Sensing System TS-5000Z; Intelligent Sensor Technology, Inc., Kanagawa, Japan).

Sensory evaluation

Sensory evaluation training and methods were conducted with reference to previous studies (Sun, Rasmussen, Cavender, & Sullivan, 2019; Phat et al., 2016; Maughan, Tansawat, Cornforth, Ward, & Martini, 2012). The sensory evaluation was conducted after receiving approval from the Chung-Ang University Ethics Committee (IRB No. 2020-00079). Nine trained panelists (eight women and one man aged 21–29 years, with an average of 24.9) participated in the sensory evaluation of samples. All panelists were trained to become familiar with the umami taste. During five 1-h training sessions, the panelists were trained using various monosodium glutamate (MSG) standard solution

concentrations (0.03, 0.09, 0.15, 0.21, and 0.27/100 mL). The panelists evaluated the intensity of the umami taste using a 9-point scale, where 1 meant "extremely weak," 5 "normal," and 9 "very strong." Sensory evaluation of the samples was performed thrice on different days. Beef samples were cooked in an oven at 180 ℃ for 20 min until the internal temperature reached 72 ℃. After cooking, the samples were cooled to room temperature and cut into cube shapes ($2 \times 2 \times 2$ cm^3). Before availing the samples to the panelists, the samples were reheated in a microwave for 10 s to release the meat's smell and flavor. The samples were assigned randomized, three-digit numbers, and water and a palate cleanser were provided to clean the mouth between tests.

In addition, the following four factors were evaluated to determine Hanwoo acceptance using a 9-point scale (1, "extremely dislike," to 9, "extremely like"): tenderness, juiciness, flavor, and overall acceptability.

Statistical analysis

Data are presented as the mean ± standard deviation based on triplicate experiments. Experimental results by group were analyzed for variance using SPSS software (SPSS Inc., Chicago, IL, USA), and significant differences between samples was verified using Duncan's multi-range test. Statistical significance was set at $p < 0.05$. Finally, principal component analysis (PCA) was performed to summarize the various characteristic differences in the samples.

Results & discussion

Quality characteristics

Meat color can be affected by the animal's feeding regimen (O'Sullivan, O'Sullivan, Galvin, Moloney, Troy, & Kerry, 2004). Table 1 shows the color parameters of sirloin fed with different feeds. According to Shin (2020), meat color and marbling are important criteria for determining meat quality. In this study, the redness (a*) and yellowness (b*) of the treated samples were higher than those of the control samples. A higher chroma (C *) causes a stronger red color to appear, and T1 exhibited the highest C * value, followed by T2 and the control group. The hue angle (h^0), which indicates the appearance of a brown color (Chu, Cho, & Ahn, 2004), was the lowest in T1, and no significant difference was noted between the control and T2 groups. Therefore, consumers potentially preferred the meat color of the T1 and T2 samples than that of the control because they had significantly more intense redness and less intense brownness than the control ($p < 0.05$).

Hanwoo's texture profile in the three groups demonstrated that T1 and T2 samples significantly decreased in hardness and significantly increased in springiness compared with the control (Table 1). No significant difference in adhesiveness and resilience was observed between the control and treated groups (T1 and T2). T1 and T2 exhibited significantly lower chewiness values than the control ($p < 0.05$). Hardness, which indicates the force required to influence meat deformation on the first bite, is directly related to the objective tenderness of the meat. Therefore, it is considered the most important textural attribute for meat tenderness (Salami et al., 2020; Caine, Aalhus, Besr, Dugan, & Jeremiah, 2003). Also furthermore, meat with low hardness and high springiness can be considered to possess favorable springiness and tender meat quality. Therefore, the treated samples (T1 and T2) were potentially tender in texture because their hardness and chewiness were significantly lower than those of the control ($p < 0.05$).

Free amino acids

Table 2 shows the effect of feed type on the free amino acid (FAA) content in Hanwoo. In general, FAAs possess a unique taste and exert considerable influence on the flavor of beef depending on their concentration (Kwon & Choi, 2018). Based on their tastes, FAAs can be classified into sweet, salty, sour, bitter, and umami taste groups (Cho

Table 1
Quality characteristics of the Hanwoo feed-type groups.

Physical characteristics	Parameters	Control	T1[1)]	T2[2)]
Color parameters	L*	46.09 ± 0.57^{b}	75.40 ± 0.58^{a}	42.72 ± 0.67^{c}
	a*	13.61 ± 0.66^{c}	52.85 ± 1.53^{a}	16.30 ± 0.22^{b}
	b*	11.52 ± 0.91^{b}	17.60 ± 1.12^{a}	12.89 ± 0.21^{b}
	Chroma value (C*)[3)]	17.85 ± 0.35^{c}	55.71 ± 1.79^{a}	20.78 ± 0.20^{b}
	Hue angle (h^0)[4)]	48.68 ± 6.03^{a}	19.07 ± 0.70^{b}	45.29 ± 1.04^{a}
Texture profile analyses (TPA)	Hardness, N	2760.12 ± 13.83^{a}	2488.66 ± 81.79^{b}	2051.89 ± 20.77^{c}
	Adhesiveness (–), g·s	37.26 ± 17.30 [ns5)]	27.66 ± 10.25	29.99 ± 20.77
	Springiness, mm	0.62 ± 0.05^{b}	0.73 ± 0.03^{a}	0.75 ± 0.00^{a}
	Cohesiveness	0.60 ± 0.02^{b}	0.64 ± 0.02^{a}	0.66 ± 0.02^{a}
	Gumminess, N	1707.00 ± 14.55^{a}	1582.02 ± 98.47^{a}	1358.09 ± 34.04^{b}
	Chewiness, N·mm	1347.31 ± 63.12^{a}	1078.38 ± 148.04^{b}	931.78 ± 52.75^{b}
	Resilience	0.29 ± 0.03 [ns]	0.31 ± 0.02	0.34 ± 0.03

[a, b, c] Within a row, different letters indicate significant differences at $p < 0.05$.
[1)] T1: Hanwoo fed with soybean meal.
[2)] T2: Hanwoo fed with soybean meal and corn distiller's grain with solubles.
[3)] Chroma value (C*): $\{(a^*)^2 + (b^*)^2\}^{1/2}$.
[4)] Hue angle (h^0): $\tan^{-1}$ (b*/a*).
[5)] ns: not significantly different within a row.

Table 2
Free-amino-acid contents (mg/kg) of the Hanwoo feed-type groups.

	Control	T1[1)]	T2[2)]
Aspartic acid	4.37 ± 0.15^{a}	4.12 ± 0.12^{ab}	4.05 ± 0.04^{b}
Glutamic acid	47.27 ± 1.99^{c}	109.89 ± 7.59^{a}	66.66 ± 0.66^{b}
Asparagine	22.96 ± 1.04^{c}	46.89 ± 3.21^{a}	31.62 ± 0.66^{b}
Serine	56.15 ± 1.23^{b}	103.86 ± 6.51^{a}	57.50 ± 1.09^{b}
Glutamine	1723.62 ± 42.32^{a}	1101.58 ± 51.68^{b}	1015.65 ± 26.84^{b}
Histidine	41.60 ± 0.31^{b}	59.93 ± 5.66^{a}	35.85 ± 0.82^{b}
Glycine	77.45 ± 1.71^{b}	97.16 ± 10.46^{a}	90.38 ± 1.44^{b}
Threonine	40.58 ± 1.25^{c}	82.21 ± 4.43^{a}	50.65 ± 1.15^{b}
Citrulline	16.15 ± 0.71^{a}	14.22 ± 0.33^{b}	11.90 ± 0.27^{c}
Arginine	70.01 ± 2.68^{b}	134.45 ± 5.60^{a}	76.25 ± 0.22^{b}
Alanine	480.12 ± 19.38^{b}	587.80 ± 38.43^{a}	434.02 ± 7.64^{b}
Tyrosine	62.53 ± 1.30^{c}	128.55 ± 6.52^{a}	78.40 ± 2.34^{b}
Valine	53.81 ± 1.36^{b}	111.76 ± 1.57^{a}	80.13 ± 1.69^{b}
Methionine	24.98 ± 0.55^{c}	76.49 ± 2.51^{a}	31.47 ± 0.92^{b}
Phenylalanine	47.51 ± 1.09^{c}	105.75 ± 3.10^{a}	63.15 ± 1.50^{b}
Isoleucine	36.42 ± 0.62^{a}	84.39 ± 2.02^{a}	53.53 ± 1.34^{b}
Ornithine	45.20 ± 3.70^{a}	47.35 ± 7.87^{a}	29.69 ± 4.36^{b}
Leucine	71.94 ± 2.21^{c}	167.61 ± 3.93^{a}	100.63 ± 1.59^{b}
Lysine	44.35 ± 1.60^{c}	103.90 ± 11.03^{a}	71.29 ± 1.22^{b}
Proline	29.16 ± 1.01^{b}	62.92 ± 14.83^{a}	37.92 ± 1.51^{b}
Essential amino acids (EAAs)[3)]	431.21 ± 10.41^{c}	926.56 ± 37.99^{a}	562.96 ± 9.63^{b}
Total amino acids	2996.19 ± 80.47^{a}	3230.83 ± 140.98^{a}	2420.72 ± 47.46^{b}

[a,b,c] Within a row, different letters indicate significant differences at $p < 0.05$.
[1)] T1: Hanwoo fed with soybean meal.
[2)] T2: Hanwoo fed with soybean meal and corn distiller's grain with solubles.
[3)] Essential amino acids (EEAs): valine, leucine, isoleucine, methionine, threonine, lysine, phenylalanine, histidine, and arginine.

et al., 2019). In brief, glycine, alanine, threonine, proline, and serine are related to sweet taste; leucine, isoleucine, methionine, phenylalanine, lysine, valine, histidine, and arginine are associated with a bitter taste; aspartic acid, glutamic acid, and histidine confer a salty taste; and alanine, serine, lysine, and methionine are related to umami taste. Essential amino acids, which constitute the basis for evaluating the nutritional value of protein (Kwon & Choi, 2018), were significantly more abundant in the treated groups than in the control group ($p < 0.05$). The total and essential FAA levels in the T2 group were lower and higher than those in the control group, respectively. These results imply that the treated groups possessed greater protein nutritional value than the control group. The most prominent FFAs in T1 and T2 were alanine and glutamine, which are related to sweet taste. According to the Korea Food Research Institute, glutamic acid and methionine have a positive effect on meat taste. The methionine levels in T1 and T2 were 76.49 and 31.47 mg/kg, respectively, and they were significantly higher than those in the control group (24.98 mg/kg). Moreover, the glutamic acid content was also significantly higher in the treated groups (109.89 mg/kg and 66.66 mg/kg) than in the control group (47.27 mg/kg). These results confirm that soybean meal and Corn DDGS influence the content of meat taste-related amino acids. Therefore, preference toward the treated group was expected to be superior to that toward the control group because of a higher FFA content, which affects umami and sweet tastes.

Fatty acid profiles

Regarding the nutritional value and sensory properties of beef, fat content plays a considerably important role (Legako, Dinh, Miller, & Brooks, 2015; Lee et al., 2010). The fatty acid contents of beef are shown in Table 3. The three most abundant fatty acids (C18:1n-9, C16:0, and C18:0) in the T1, T2, and control groups accounted for 83.63%, 86.07%, and 85.52% of the total fatty acid content, respectively. These results are consistent with those of previous studies that have investigated the fatty acid composition of Hanwoo (Joo et al., 2017; Gajaweera, Chung, Kwon, Hwang, Cho, & Lee, 2018).

Oleic acid was the most abundant free fatty acid in all samples. Joo et al. (2017) reported that Hanwoo contained higher oleic acid levels than other breeds. In addition, the taste of beef is affected by the oleic acid content, and a higher the content improves consumer preference (Lee et al., 2010). T1 had significantly higher lauric, myristic, tetradecanoic, palmitic and hexadecenoic acid levels than the other groups ($p < 0.05$). T2 had significantly higher oleic, linoleic, eicosenoic, and α-linolenic acid levels than the other groups ($p < 0.05$). T2 displayed significantly higher unsaturated fatty acid (UFA) and lower saturated fatty acid (SFA) levels than other samples ($p < 0.05$); accordingly, the UFA/SFA ratios were higher in T2 than in other samples ($p < 0.05$). However, no significant differences in UFA (monounsaturated fatty acids [MUFAs] and polyunsaturated fatty acids [PUFAs]) and SFA levels were noted between the T1 and control groups. This was in accordance with the results obtained by Lee, Choi, and Kim (2014) wherein UFA levels were significantly increased in Corn DDGS-fed Hanwoo cattle than in those fed with corn and soybean meal.

Electronic tongue analysis and sensory evaluation

The results of the electronic tongue analysis of sirloin for the three groups are shown in Table 4. No significant differences in sourness and bitterness were observed among all three groups. Umami taste, saltiness, richness, and astringency were more pronounced in the treated groups than in the control group ($p < 0.05$). As shown in Table 2, the overall aspartic acid, glutamic acid, and histidine content associated with saltiness was also significantly higher in T1 and T2 than in the control group. On comparing the treatment groups, T2 had significantly greater saltiness than T1 ($p < 0.05$).

Umami taste is primarily contributed by glutamic and aspartic acids. In particular, glutamic acid is the most important ingredient contributing to the umami taste in meat (Lee et al., 2019; Zhao, Schieber, & Gänzle, 2016). The FAA-measurement results (Table 3) revealed that the overall aspartic acid and glutamic acid levels in T1 and T2 were significantly higher than that in the control group ($p < 0.05$); moreover, T1 and T2 exhibited a stronger umami taste than the control group in the electronic tongue analysis. According to Phat et al. (2016), mushrooms with high umami taste also possess characteristically high levels of saltiness. In addition, although no clear mechanisms for saltiness exist, the electronic tongue system has proven that if umami substances are present, a salty taste is also detected due to the complementary effect of both tastes (Ismaila, Hwang, & Joo, 2020). Our results confirmed that saltiness and umami taste were associated with the taste characteristics evaluated by the electronic tongue.

Table 4 shows Hanwoo's sensory evaluation results. Umami intensity as well as preference for tenderness, juiciness, flavor, and overall acceptability were evaluated using a 9-point scale. Umami intensity yielded scores of 7.00, 6.19, and 4.74 for the T1, T2, and control groups, respectively. These findings exhibited consistency with the electronic tongue results. Umami taste potentially enhances meat flavor (Kim, Kim, Ji, Lee, Yoon, & Lee, 2017).

Tenderness is an important factor for consumer satisfaction with beef, and the treated groups received significantly higher tenderness, flavor, and juiciness scores than the control group ($p < 0.05$). No significant differences were observed between the two treatment groups. In general, juiciness affects the tenderness of beef (Kim, Jung, Kim, Kim, & Choi, 2011), and it is known that the more tenderness, the more flavorful (May et al., 1992). In addition, the treatment groups yielded

Table 3
Fatty acid profiles (g/100 g) of the Hanwoo feed-type groups.

	Control	T1[1)]	T2[2)]
Capric acid (C10:0)	0.04 ± 0.00^{b}	0.07 ± 0.01^{a}	0.05 ± 0.00^{ab}
Undecanoic acid (C11:0)	0.11 ± 0.02 ns[3)]	0.10 ± 0.03	0.10 ± 0.02
Lauric acid (C12:0)	0.05 ± 0.00^{b}	0.09 ± 0.01^{a}	0.05 ± 0.00^{b}
Myristic acid (C14:0)	2.95 ± 0.10^{b}	3.50 ± 0.04^{a}	2.29 ± 0.09^{c}
Tetradecenoic acid (C14:1)	0.45 ± 0.03^{b}	1.20 ± 0.11^{a}	0.56 ± 0.03^{b}
Pentadecanoic acid (C15:0)	0.25 ± 0.01 ^{ns}	0.23 ± 0.04	0.20 ± 0.00
Palmitic acid (C16:0)	25.30 ± 0.35^{b}	27.36 ± 0.60^{a}	24.01 ± 0.31^{c}
Hexadecenoic acid (C16:1)	3.50 ± 0.13^{b}	4.06 ± 0.30^{a}	2.79 ± 0.03^{c}
Margaric acid (C17:0)	0.18 ± 0.00^{a}	0.15 ± 0.02^{b}	0.18 ± 0.00^{a}
Stearic acid (C18:0)	15.24 ± 0.42^{a}	11.58 ± 0.37^{c}	13.31 ± 0.28^{b}
oleic acid (C18:1n-9, Cis)	44.98 ± 0.17^{b}	44.69 ± 0.69^{b}	48.75 ± 0.47^{a}
Linoleic acid (C18:2n-6, cis)	1.58 ± 0.03^{b}	1.59 ± 0.04^{b}	2.16 ± 0.03^{a}
Arachidic acid (C20:0)	0.09 ± 0.00 ^{ns}	0.08 ± 0.01	0.08 ± 0.01
Eicosenic acid (C20:1)	0.15 ± 0.01^{c}	0.20 ± 0.02^{b}	0.32 ± 0.02^{a}
α-linolenic acid (C18:3n-3)	0.09 ± 0.00^{b}	0.10 ± 0.01^{b}	0.13 ± 0.01^{a}
Dihomo-γ-linoleic acid (C20:3n-6)	0.05 ± 0.00 ^{ns}	0.05 ± 0.00	0.06 ± 0.01
Erucic acid (C22:1n-9)	0.02 ± 0.01 ^{ns}	0.03 ± 0.01	0.03 ± 0.00
Tricosanoic acid (C23:0)	0.05 ± 0.00 ^{ns}	0.04 ± 0.01	0.05 ± 0.00
Σ MUFA[4)]	49.11 ±.021^{b}	50.19 ± 1.07^{b}	52.45 ± 0.49^{a}
Σ PUFA[5)]	1.71 ± 0.03^{b}	1.74 ± 0.05^{b}	2.35 ± 0.04^{a}
Σ UFA[6)]	50.82 ± 0.21^{b}	51.93 ± 1.12^{b}	54.80 ± 0.52^{a}
Σ SFA[7)]	44.27 ± 0.30^{a}	43.19 ± 0.85^{a}	40.34 ± 0.50^{b}
UFA:SFA	1.15 ± 0.01^{b}	1.20 ± 0.05^{b}	1.36 ± 0.03^{a}

^{a,b,c} Within a row, different letters indicate significant differences at $p < 0.05$.
1) T1: Hanwoo fed with soybean meal
2) T2: Hanwoo fed with soybean meal and corn distiller's grain with solubles.
3) ns: not significantly different within a row.
4) MUFA: mono unsaturated fatty acid
5) PUFA: poly unsaturated fatty acid.
6) UFA: total unsaturated fatty acid
7) SFA: total saturated fatty acid.

Table 4
Electronic tongue analysis and sensory evaluation of the Hanwoo feed-type groups.

	Attributes	Control	T1[1)]	T2[2)]
Electronic tongue analysis	Umami	11.07 ± 0.02[c]	11.18 ± 0.04[b]	11.32 ± 0.03[a]
	Saltiness (–)	7.27 ± 0.02[c]	7.63 ± 0.11[b]	7.99 ± 0.03[a]
	Richness	6.37 ± 0.03[b]	6.44 ± 0.10[ab]	6.56 ± 0.03[a]
	Sourness (–)	29.88 ± 0.18 [ns3)]	30.09 ± 0.29	30.00 ± 0.07
	Bitterness	7.02 ± 0.12 [ns]	7.02 ± 0.09	7.15 ± 0.07
	Astringency (–)	0.15 ± 0.02[b]	0.20 ± 0.01[a]	0.22 ± 0.01[a]
Sensory evaluation	Umami intensity	4.74 ± 1.89[b]	6.19 ± 1.55[a]	7.00 ± 1.59[a]
	Tenderness	5.00 ± 1.78[b]	6.33 ± 1.69[a]	6.48 ± 1.85[a]
	Juiciness	4.74 ± 1.72[b]	6.30 ± 1.64[a]	6.74 ± 1.40[a]
	Flavor	4.96 ± 1.48[b]	6.44 ± 2.01[a]	6.74 ± 1.46[a]
	Overall acceptability	4.70 ± 1.38[b]	6.48 ± 1.70[a]	6.74 ± 1.61[a]

[a, b, c] within a row, different letters indicate significant differences at $p < 0.05$.
[1)] T1: Hanwoo fed with soybean meal.
[2)] T2: Hanwoo fed with soybean meal and corn distiller's grain with solubles.
[3)] ns: not significantly different within a row.

higher scores for overall acceptability than the control group; however, no significant differences in all sensory scores were noted between T1 and T2.

The high oleic acid content of the treatment group contributed to the treated groups having superior flavor to the control group. Westerling and Hedrick (1979) reported that oleic acid has many effects on flavor in terms of sensory properties. The high oleic acid and UFA levels in the T2 group potentially justify its high sensory evaluation scores. Therefore, the fatty acid compositions and amino acid levels of the samples might have contributed to the more intense umami taste and greater preference among all sensory attributes in T1 and T2 than in the control group.

The correlation coefficients between umami taste and flavor components yielded by electronic tongue analysis and sensory evaluation were analyzed (Table 5). The electronic tongue analysis results were strongly correlated with the human sensory evaluation findings of umami taste, exhibiting a significantly positive correlation ($p < 0.05$). Phat et al. (2016) reported a similar finding wherein human sensory evaluation and electronic tongue measurement results correlated well in taste analysis. Electronic tongue analysis for umami showed a significant correlation with MUFA and PUFA ($p < 0.05$). Park, Choe, & Shim (2019) reported that oleic acid, the main MUFA, increases the richness and sweetness of beef. In the fatty acid analysis results of this study, T2 exhibited a significantly higher oleic acid content than the T1 and control groups ($p < 0.05$). Consequently, T2 received the highest umami taste score in the electronic tongue analysis and human sensory evaluation.

Table 5
Correlation coefficients between components related to umami flavor of Hanwoo.

Variables	Correlation coefficients	*p* value
Human sensory evaluation (Umami) and electronic tongue (Umami)*	0.76	0.017
Human sensory evaluation (Umami) and MSG-like	0.63	0.07
Human sensory evaluation (Umami) and aspartic acid**	–0.81	0.008
Human sensory evaluation (Umami) glutamic acid	0.63	0.07
Human sensory evaluation (Umami) and MUFA	0.65	0.06
Human sensory evaluation (Umami) and PUFA*	0.69	0.041
Human sensory evaluation (Umami) and SFA**	–0.83	0.006
Electronic tongue (Umami) and MSG-like	0.50	0.17
Electronic tongue (Umami) and aspartic acid	–0.64	0.07
Electronic tongue (Umami) and glutamic acid	0.50	0.17
Electronic tongue (Umami) and MUFA**	0.81	0.008
Electronic tongue (Umami) and PUFA*	0.78	0.014
Electronic tongue (Umami) and SFA***	–0.90	0.001

Correlation is significant at a p value < 0.05*, p value < 0.01**, p value < 0.001***,
MSG: monosodium glutamate; MUFA: Mono unsaturated fatty acid; PUFA: poly unsaturated fatty acid; SFA: saturated fatty acid.

PCA

PCA analysis was performed to evaluate the overall associations among texture, electronic tongue measurement, umami taste-related amino acids, fatty acid profile, and sensory evaluation in the three groups. The results shown in Fig. 1 indicate that the first (PC1) and second (PC2) principal components accounted for 76.47% and 23.53% of the total variation, respectively. Moreover, PC1 explains most of the association. In the positive direction of PC1, SFAs, gumminess, hardness, saltiness, chewiness, astringency, aspartic acid, and glutamine were strong (| factor loading | > 0.7). In the negative direction, bitterness, PUFAs, UFAs, MUFAs, richness, resilience, electronic umami, cohesiveness, sensory umami, juiciness, springiness, flavor, overall acceptability, and tenderness were strong (| factor loading | > 0.5). Asparagine, glutamic acid, and essential amino acid appeared strongly in the positive direction of PC2 (| factor loading | > 0.7). As a result of the samples represented by the main component, the control group appeared strong in the positive direction of PC1. T1 appeared strongly in the positive direction of PC2, whereas T2 was strong in the negative direction (| factor loading | > 0.7).

Conclusions

This study aimed to evaluate umami taste in Hanwoo with different feed by chemical analysis, sensory evaluation and an electronic tongue system. Samples were divided into a control group (fed only TMR), T1 (fed only soybean meal in addition to TMR), and T2 (fed soybean meal and Corn DDGS in addition to TMR). The hardness and chewiness of T1 and T2 were significantly lower than those of the control, and the redness of the meat color was also significantly intense. The levels of glutamic acid and methionine, which have a positive effect on meat taste, were significantly higher in T1 and T2 than in the control group ($p < 0.05$). The fatty acid composition of T2 showed significantly higher UFA levels than control. Regarding umami taste, as analyzed using the electronic tongue and sensory evaluation, T1 and T2 exhibited significantly higher values than the control group ($p < 0.05$). Although no significant differences were observed between T1 and T2, T2 had relatively higher sensory evaluation scores than T1. The electronic tongue analysis results were strongly correlated with the human sensory evaluation findings of umami taste. Especially, fatty acid levels showed a high correlation with umami taste analyzed by electronic tongue system. The results of this study showed that the amino acid and fatty acid levels had been affected by feed types and soybean- or Corn DDGS-based feed potentially enhanced Hanwoo's umami flavor.

CRediT authorship contribution statement

Juhyun Min: Methodology, Formal analysis, Writing – original draft. **Jo-Won Lee:** Methodology, Formal analysis, Data curation, Writing – original draft. **Gui-Seck Bae:** Validation, Project administration. **BoKyung Moon:** Conceptualization, Validation, Supervision, Writing – review & editing, Funding acquisition.

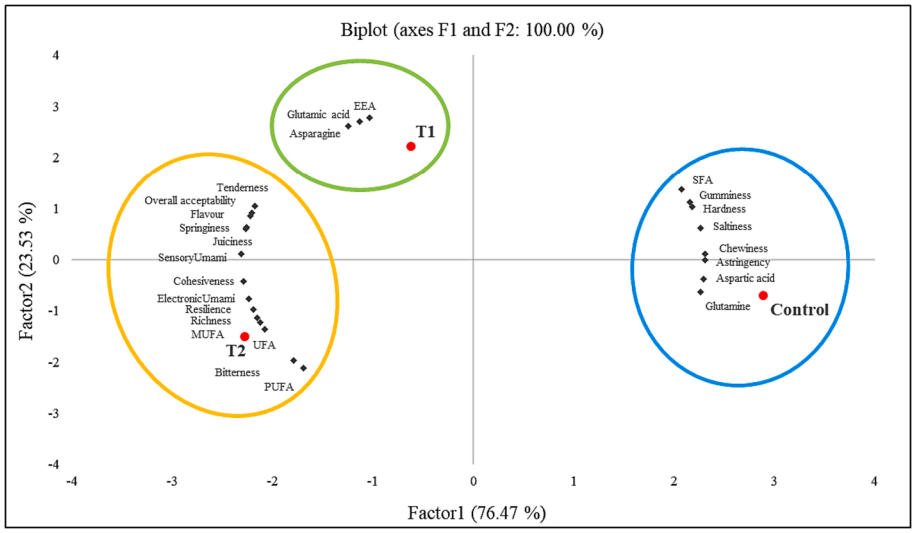

Fig. 1. Principal component analysis of 25 variables according to Hanwoo feed-type group (T1: Hanwoo fed with soybean meal; Hanwoo fed with soybean meal and corn distiller's grain with solubles).

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.

Data availability

Data will be made available on request.

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References

Caine, W. R., Aalhus, J. L., Best, D. R., Dugan, M. E. R., & Jeremiah, L. E. (2003). Relationship of texture profile analysis and Warner-Bratzler shear force with sensory characteristics of beef rib steaks. *Meat Science, 6*(4), 333–339. https://doi.org/10.1016/S0309-1740(02)00110-9

Cho, S. H., Seo, G., Kim, D. H., & Kim, J. H. (2009). Palatability grading analysis of Hanwoo beef using sensory properties and discriminant analysis. *Food Science of Animal Resources, 29*(1), 132–139. https://doi.org/10.7318/KJFC/2017.32.2.150

Cho, S. H., Shin, J. S., Seol, K. H., Kim, Y. S., Kang, S. M., & Seo, H. W. (2020). A study on the characteristics of purchasing propensity by preferences quality grade of Hanwoo beef. *Journal of the Korea Academia-Industrial cooperation Society, 21*(3), 537–2020. https://doi.org/10.5762/KAIS.2020.21.3.537

Cho, W. K., Jeong, C. S., Kim, H. J., Kim, J. E., Kim, B. R., Lee, S. S., & Moon, Y. H. (2019). Effects of supplemental concentrate during the late fattening phase on performance, carcass characteristics, biochemical composition and sensory test of loin in TMR feeding of Korean steers. *Annals of Animal Resource Sciences, 30*(4), 156–164. https://doi.org/10.14397/jals.2014.48.4.175.

Chu, G. M., Cho, H. W., & Ahn, B. H. (2004). Effects of dietary vitamin C and E on lipid oxidation and stability of color in Hanwoo steer beef. *Journal of Animal Science and Technology, 45*(4), 635–644. https://doi.org/10.5187/JAST.2004.46.4.635

Chung, K. Y., Lunt, D. K., Kawachi, H., Yano, H., & Smith, S. B. (2007). Lipogenesis and stearoyl-CoA desaturase gene expression and enzyme activity in adipose tissue of short- and long-fed Angus and Wagyu steers fed corn- or hay-based diets. *Journal of Animal Science, 85*, 380–387. https://doi.org/10.2527/jas.2006-087

Elmore, J. S., Mottram, D. S., Enser, M., & Wood, J. D. (1999). Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. *Journal of Agricultural and Food Chemistry, 47*, 1619–1625. https://doi.org/10.1021/jf980718m

Folch, J., Lees, M., & Sloane-Stanley, G. H. (1957). A simple method for the isolation and purification of total from animal tissues. *Journal of Biological Chemistry, 226*(1), 497. https://doi.org/10.1016/S0021-9258(18)64849-5

Gajaweera, C., Chung, K. Y., Kwon, E. G., Hwang, I. H., Cho, S. H., & Lee, S. H. (2018). Evaluation of sensory attributes of Hanwoo longissimus dorsi muscle and its relationships with intramuscular fat, shear force and environmental factors. *Canadian Journal of Animal Science, 98*, 443–452. https://doi.org/10.1139/cjas-2017-0064

Goni, M. V., Beriain, M. J., Indurain, G., & Insausti, K. (2007). Predicting longissimus dorsi texture characteristics in beef based on early post-mortem colour measurements. *Meat Science, 76*(1), 38–45. https://doi.org/10.1016/j.meatsci.2006.10.012

Ha, Y., Hwang, I., Kang, S. M., Kim, Y., Seol, K. H., Seo, H. W., Kim, J., & Cho, S. (2019). Comparison of meat quality traits for *M. longissimus thoracis, M. glutaseusmedus*, *M. semimembranosus* low-grade Hanwoo cow beef by dry aging and wet aging conditions. *Annals Animal Resource Sciences*, *90(3)*, 121–132. https://doi.org/10.12718/AARS. 20 19.30 .3.121.

Hwang, Y. H., Kim, G. D., Jeong, J. Y., Hur, S. J., & Joo, S. T. (2010). The relationship between muscle fiber characteristics and meat quality traits of highly marbled Hanwoo (Korean native cattle) steers. *Meat Science, 86*(2), 456–461. https://doi.org/10.1016/j.meatsci.2010.05.034

Ishiwatari, N., Fukuoka, M., Hamada-Sato, N., & Sakai, N. (2013). Decomposition kinetics of umami component during meat cooking. *Journal of Food Engineering, 119* (2), 324–331. https://doi.org/10.1016/j.jfoodeng.2013.05.040

Ismail, I., Hwang, Y. H., & Joo, S. T. (2020). Low-temperature and long-time heating regimes on non-volatile compound and taste traits of beef assessed by the electronic tongue system. *Food Chemistry, 320*, Article 126656. https://doi.org/10.1016/j.foodchem.2020.12

Jeong, H. S. & Lee, T. N. (2013). Survey on Hanwoo usage and menu development using lean cut Hanwoo for school foodservice. *The Korean Journal of Food and Nutrition*, 2013, *26(4)*, 620–632. https://doi.org/10.9799/ksfan.2013.26.4.620.

Joo, S. H., Hwang, Y. H., & Frank, D. (2017). Characteristics of Hanwoo cattle and health implications of consuming highly marbled Hanwoo beef. *Meat Science, 132*, 45–51. https://doi.org/10.1016/j.meatsci.2017.04.262

Kang, S. M., Kang, G. H., Seong, P. N., Kim, H. S., Jung, S. G., Park, B. Y., … Cho, S. H. (2011). Free amino acids and aroma compounds of Hanwoo (Korean cattle) cow beef by muscle parts and aging. *Animal Resource Sciences, 22*(2), 109–119. https://www.earticle.net/Article/A168588.

Kim, J. H., Kim, D. H., Ji, D. S., Lee, H. J., Yoon, D. K., & Lee, C. H. (2017). Effect of the aging process and time on physicochemical and sensory evaluation of raw beef top round and shank muscles using an electronic tongue. *Korean Journal for Food Science Animal Resources, 2017*(37), 823–832. https://doi.org/10.5851/kosfa.2017.37.6.823

Kim, J. H., Kim, T. K., Shin, D. M., Kim, H. W., Kim, Y. B., & Choi, Y. S. (2020). Comparative effects of dry-aging and wet-aging on physicochemical properties and digestibility of Hanwoo beef. *Asian-Australas Journal of Animal Science, 33*(3), 501–505. https://doi.org/10.5713/ajas.19.0031

Kim, S. I., Cho, B. R., & Choi, C. B. (2013). Effects of sesame meal on growth performances and fatty acid composition, free amino acid contents, and panel tests of loin of Hanwoo steers. *Journal of Animal Science and Technology, 55*(5), 451–460. https://doi.org/10.5187/JAST.2013.55.5.451

Kim, S. I., Jung, K., Kim, D. Y., Kim, J. Y., & Choi, C. B. (2011). Effects of supplementation of rice bran and roasted soybean in the diet on physico-chemical and sensory characteristics of *M. longissimus dorsi* of Hanwoo steers. *Korean Journal of Food Science, 31*(3), 451–459. https://doi.org/10.5851/kosfa.2011.31.3.451

Kwon, H. N. & Choi, C. B. (2018). Comparison of free amino acids, anserine, and carnosine contents of beef according to the country of origin and marbling score. *Journal of the Korean Society of Food and Nutrition, 47(3)*, 357–362. https://doi.org/10.3746 /jkfn.20 18. 47.3.357.

Lee, S. H., Kim, C. N., Ko, K. B., Park, S. P., Kim, H. K., Kim, J. H., & Ryu, Y. H. (2019). Comparisons of beef fatty acid and amino acid characteristics between Jeju Black Cattle, Hanwoo, and Wagyu breeds. *Food Science of Animal Resources, 39*(3), 402–409. https://doi.org/10.5851/kosfa.2019.e33

Lee, S. O., Choi, C. B., & Kim, S. I. (2014). Effects of supplementary of distiller's dried grains with solubles in the diets on performances, carcass characteristics and composition of fatty acid in Hanwoo steers. *Journal of Agriculture & Life Science, 48*(1), 115–125. https://doi.org/10.14397/jals.2014.48.1.115.

Lee, Y. J., Kim, C. J., Kim, J. H., Park, B. Y., Seong, P. N., Kang, G. H., … Cho, S. H. (2010). Comparison of fatty acid composition of Hanwoo beef by different quality grades and cuts. *Food Science of Animal Resources, 30*(1), 110–119. https://doi.org/10.5851/kosfa.2010.30.1.110

Legako, J. F., Dinh, T. T. N., Miller, M. F., & Brooks, J. C. (2015). Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions. *Meat Science, 100*, 246–255. https://doi.org/10.1016/j.meatsci.2014.10.013

Maughan, C., Tansawat, R., Cornforth, D., Ward, R., & Martini, S. (2012). Development of a beef flavor lexicon and its application to compare the flavor profile and consumer acceptance of rib steaks from grass- or grain-fed cattle. *Meat Science, 90*, 116–121. https://doi.org/10.1016/j.meatsci.2011.06.006

May, S. G., Dolezal, H. G., Gill, D. R., Ray, F. K., & Buchanan, D. S. (1992). Effects of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. *Journal of Animal Science, 70*, 444–453. https://doi.org/10.2527/1992.702444x

Morrison, W. R., & Smith, L. M. (1964). Preparation of fatty acid methyl esters and dimethyl acetals from lipids with boron trifluoride-methanol. *Journal of Lipid Research., 5*, 600–608. https://doi.org/10.1016/S0022-2275(20)40190-7

O'Sullivan, A., O'Sullivan, K., Galvin, K., Moloney, A. P., Troy, D. J., & Kerry, J. P. (2004). Influence of concentrate composition and forage type on retail packaged beef quality. *Journal of Animal Science, 82*(8), 2384–2391. https://doi.org/10.2527/2004.8282384x

Park, B. H., Kang, D. H., & Chung, K. Y. (2018). Current situation of Hanwoo industry and future prospects for precision livestock farming. *Food Science and Industry, 51*(3), 238–244. https://doi.org/10.23093/FSI.2018.51.3.238.

Park, J. R., Choe, H. S., & Shim, K. S. (2019). Effect of fatty acid compositions on eating quality of pork loin. *Annals of Animal Resource Sciences, 30*(2), 49–55. https://doi.org/10.12718/AARS.2019.30.2.49.

Phat, K. C., Moon, B. K., & Lee, C. (2016). Evaluation of umami taste in mushroom extracts by chemical analysis, sensory evaluation, and an electronic tongue system. *Food Chemistry, 192*, 1068–1077. https://doi.org/10.1016/j.foodchem.2015.07.113

Salami, S. A., O'Grady, M. N., Luciano, G., Priolo, A., McGee, M., Moloney, A. P., & Kerry, J. P. (2020). Quality indices and sensory attributes of beef from steers offered grass silage and a concentrate supplemented with dried citrus pulp. *Meat Science, 168*, Article 108181. https://doi.org/10.1016/j.meatsci.2020.108181

Sasaki, K., Tani, F., Sato, K., Ikezaki, H., Taniguchi, A., Emori, T., … Mitsumoto, M. (2005). Analysis of pork extracts by taste sensing system and the relationship between umami substances and sensor output. *Sensors and Materials, 17*(7), 397–404.

Shin, J. S. (2020). A study on the change of beef consumption and recognition of aged meat. *Journal of the Korea Academia-Industrial Cooperation Society, 21*(9), 373–379. https://doi.org/10.5762/KAIS.2020.21.9.373

Sun, S., Rasmussen, F. D., Cavender, G. A., & Sullivan, G. A. (2019). Texture, color and sensory evaluation of sous-vide cooked beef steaks processed using high pressure processing as method of microbial control. *LWT – Food Science and Technology, 103*, 167–177. https://doi.org/10.1016/j.lwt.2018.12.072

Westerling, D. B., & Hedrick, H. B. (1979). Fatty acid composition of bovine lipids as influenced by diet, sex and anatomical location and relationship to sensory characteristics. *Journal of Animal Science, 48*, 1343–1348. https://doi.org/10.2527/jas1979.4861343x

Zhao, C. J., Schieber, A., & Gänzle, M. G. (2016). Formation of taste-active amino acids, amino acid derivatives and peptides in food fermentations – A review. *Food Research International, 89*, 39–47. https://doi.org/10.1016/j.foodres.2016.08.042

Zhao, D., Li, H., Huang, M. X., Wang, T. L., Hu, Y., Wang, L. P., … Zhou, G. H. (2020). Influence of proteolytic enzyme treatment on the changes in volatile compounds and odors of beef longissimus dorsi. *Food Chemistry, 333*, Article 127549. https://doi.org/10.1016/j.foodchem.2020.127549