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Research Article

Effect of cumin on flavor and protein oxidation of roast lamb with different roasting time

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Abstract: The study aimed to explore the effect of cumin on flavor and protein oxidation of roasted lamb patties at different roasting time (10, 15 and 20 min). The results showed that the addition of cumin and then the reduction of aldehydes and the increase in the content of esters and heterocyclic flavor compounds in roasted lamb patties effectively improved the ester and roasted flavors of roasted lamb patties, suppressed the fishy and bloody flavors, and improved the overall acceptability to consumers. The carbonyl content of the cumin group was significantly lower than that of the blank group, and the total sulfhydryl and active sulfhydryl contents were significantly increased. A total of 16 amino acids were detected in the roasted lamb patties, and the amino acid content of the cumin group was higher than that of the blank group, with the highest content of glutamic acid reaching 7.21% of meat in the cumin group at 20 min of roasting. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis results showed that the cumin group had a lower loss of myosin heavy chain and light chain. Therefore, the addition of cumin to roasted lamb not only increased its ester flavor, umami, and characteristic cumin flavor, but also reduced the degree of protein oxidation in the roasted lamb. The results of this study may provide valuable reference data for the flavoring and antioxidant effects of cumin in meat processing.

Keywords: roast lamb; cumin; roasting time; protein oxidation

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1 Introduction

Lamb meat is delicate, rich in protein and trace elements, and has high nutritional value, and occupies an important position in China's meat consumption[1]. Common lamb processing methods include shabu, braising, roasting and so on[2]. Compared with the other 2 cooking methods, roast lamb is favored by consumers at home and abroad because of its rich meat aroma and delicious taste[3]. Most of the aroma of roast lamb is mainly produced during heat treatment[4]. Studies have shown that the volatile flavor compounds in roast lamb mainly include aldehydes, alcohols, ketones and hydrocarbons[5–6]. During the heating and roasting process, the high temperature promoted the release and interaction of aroma compounds, resulting in the unique taste of the barbecue product[7]. Flavor is the primary sensory indicator that consumers consider when purchasing roast meat products, and it determines the overall acceptability of roast lamb to a certain extent[8]. Volatile flavor compounds determine the flavor characteristics of roast lamb, so it is of great significance to clarify the key flavor compounds of roast lamb for the precise flavor control and process upgrading of traditional meat products.

As the material basis of meat products, protein is an important nutrient for keeping the human body healthy[9]. During heating, high temperatures cause changes in composition, mainly denaturation, degradation, polymerization, and oxidation of proteins[10]. Meat is susceptible to oxidation due to the presence of pro-oxidants, such as lipids and myoglobin. Meat quality traits such as a decrease in texture and juiciness and muscle discoloration after cooking are associated with protein oxidation, which greatly affects the sensory properties of meat and thus its economic value. Domínguez et al.[11] found that the loss of essential nutrients, damage to texture, water retention, color and flavor were the result of protein oxidation, and the control of oxidation process was crucial to retain consumers and reduce economic losses in the food industry. The oxidation of proteins is mainly manifested as the reduction of sulfhydryl group, the increase of carbonyl group, the formation of disulfide bond and the loss of solubility[12]. Changes in protein conformation affect flavor binding and sensory properties. Moderate oxidation of protein can improve the texture, aroma and taste of meat, etc., but excessive oxidation will lead to loss of flavor, texture and nutrition, and even damage to meat quality[13–14].

In meat cooking, spices are often used to improve or enhance the flavor of the product by removing odors and enhancing taste. For example, the addition of black pepper and cumin extract can improve the quality of Bulgarian-type dry-cured sausages[15]. Jung et al.[16] found that the addition of spices to beef patties significantly altered the volatile compounds released and interacted with meat aroma. Cumin (*Cuminum cyminum*) is one of the most commonly used spices in traditional roast lamb. To the best of our knowledge, cumin has a robust, warm and spicy aroma with a mild and astringent taste, which has the effect of removing the taint, its unique and strong aroma is very important for the formation of the flavor of roast lamb. Cumin owes its unique flavor and aroma to its characteristic volatile compounds. Studies have shown that cumin essential oil is mainly composed of terpenoids, including

terpene, terpene aldehyde and terpene alcohol, etc. Aromatic aldehydes, ketones, and ethers contribute to the fragrance of cumin, with the highest content being cuminaldehyde (*p*-isopropylbenzaldehyde)[17–18]. Oxidation is one of the main factors of food deterioration, which can lead to a decline in food quality and consumer acceptability. Previous studies have demonstrated that cumin has good antioxidant activity, which can effectively prevent meat oxidation, enhance the flavor of meat products, and prolong storage time[19–20]. Allahghadri et al.[21] found that cumin essential oil contained a high content of total phenols, which gives cumin strong antioxidant activity. The terpenoids and flavonoids in cumin have the ability to significantly scavenge hydroxyl radicals, 1,1-diphenyl-2-picrylhydrazyl free radicals and inhibit lipid peroxides[22]. Therefore, the introduction of cumin can effectively inhibit the excessive oxidation of meat products without the need for additional antioxidants.

Cumin will be added to foods with both flavoring and antioxidant benefits. In this paper, simple raw materials and condiments were used to thermally process the samples in the condition of uncured meat. Roast lamb patties were used to detect and analyze flavor compounds by headspace solid phase microextraction combined with gas chromatography-mass spectrometry (SPME-GC-MS) and electronic tongue (E-tongue). Exploring changed in the flavor of roasted lamb with the addition of cumin by sensory evaluation. In addition, the effects of cumin on protein oxidation and flavor sense of roast lamb at different roasting degrees were also analyzed, which provided a theoretical basis for revealing the interaction between volatile compounds and flavoring of roast lamb, and contributed to promoting the industrial utilization of cumin and roast lamb.

2 Materials and methods

2.1 Materials and reagents

Cumin powder was purchased from the network Shang Baijia good seasoning. Cyclohexanone and methanol were from Tianjin Fuchen Chemical Reagent Co., Ltd. Sodium hydroxide, copper sulfate and potassium sulfate were from Shanghai Aladdin Reagent Co., Potassium hydroxide, urea, guanidine hydrochloride, 2,4-dinitrophenylhydrazine (DNPH), ethylenediamine tetraacetic acid (EDTA) and sodium chloride were from Sinopharm Chemical Reagent Co.,. Anhydrous ethanol was from Shandong West Asia Chemical Industry Co., Ltd. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) kit was from Guangzhou Shuopu Biotechnology Co., Ltd. All reagents were of analytical grade.

2.2 Preparation of roast lamb patties

The 6-month-old Sunit sheep (average body weight was (30.0 ± 2.5) kg) used in this study were purchased from a commercial company of Xilingol League of Inner Mongolia in China. Lamb forelegs that had been matured at 4 °C for 72 h and then rapidly frozen to −35 °C were transported to the laboratory via air-freight cold chain logistics (−18 °C). After the samples arrived at the laboratory, the surface fat and connective tissue of sheep forelegs thawed to a core temperature of 3–5 °C were removed and ground and chopped into minced meat using a MM12 meat grinder (Zhucheng City Shengdi Food Packaging Machinery Factory, China).

Six portions of minced meat, 3 with cumin (1%, *m*/*m*) and 3 without cumin, were taken to make patties 6.5 cm in diameter and 1 cm thick. Samples were roasted in a Rational AG oven (Rational, Germany) at 220 °C for 10, 15 and 20 min (3 replicates).

2.3 SPME-GC-MS analysis

SPME-GC-MS (GC-MS, Agilent 7890N-5975, USA) was used to analyze the volatile compounds of roast lamb[23]. First, 4.5 g sample was taken into 20 mL headspace vial and 7.0 μL 0.747 μg/μL cyclohexanone standard (dissolved in ethanol) was added and quickly sealed. The headspace vials containing the samples were preheated in a constant temperature water bath at 55 °C for 15 min. A 75 μm carboxen/polydimethylsiloxane (CAR/PDMS) head of solid phase microextraction (Supelco, Bellefonte, PA, USA) was extracted at 55 °C for 45 min, then inserted into the fiber head GC injection port and desorbed at 250 °C for 5 min.

GC conditions: the capillary column was TP-5 (30 m × 320 μm, 0.25 μm), the temperature of the inlet was 250 °C, the flow rate of the carrier gas was 1.0 mL/min, and the sample was injected without shunt. Set the starting temperature at 35 °C for 5 min, 4 °C/min to 130 °C for 3 min, 8 °C/min to 200 °C for 3 min, and then 12 °C/min to 250 °C for 5 min. MS conditions: ionization mode; electron energy 70 eV; quadrupole temperature 150 °C, ion source temperature 230 °C; interface temperature 280 °C; mass scan range 30–550 *m*/*z*.

The volatile components in the samples were separated by GC and identified by MS. The results were searched through the NIST/Wiley Spectral Library, and compounds with a match greater than 80% were selected and qualitatively analyzed in conjunction with the references. Using cyclohexanone as the internal standard, the volatile flavor substances were quantified and the absolute concentration of each substance was calculated according to Eq. (1):

$$\text{Absolute concentration (ng/g)} = \frac{\text{Peak area of each material} \times 5\,228.06}{\text{Peak area of internal standard} \times \text{Sample mass}} \quad (1)$$

Where 5 228.06 indicates the internal standard mass (ng) added to the samples.

2.4 E-tongue analysis

Briefly, 5 g lamb samples were weighed and placed in a 500 mL centrifuge tube, then homogenized with 100 mL distilled water (6 000 r/min, 60 s) and centrifuged at 4 °C (5 000 r/min, 20 min). Filtered the supernatant with filter paper, drained and took 80 mL of clarification solution for later use. Each sample was cycled 4 times, and the last 3 results were obtained after removing the first cycle. The sensor response was stable throughout the assay, with good reproducibility and valid data. The analysis parameters of SA402B E-tongue (INSENT Co., Japan) were set: 1 CAO, COO, AE1, CTO and AAE test sensor, 2 reference electrodes, data acquisition time 120 s, acquisition cycle 1 s, acquisition delay 0 s, stirring rate 1 r/s.

2.5 Sensory evaluation

Forty sensory panelists were screened according to the GB/T 16291.1–2012 standard. All panelists were trained in ISO 4121:2003 and GB/T 29604–2013 guidelines. After a high level of agreement among panelists, 10 assessors were selected to make a sensory evaluation of the color, texture, odor, taste, and overall acceptability of the roasted lamb on a 0–10 points scale (in increments of 1 point)[24]. Color (0–3: dull, 7–10: glossy), texture (0–3: loose and inelastic structure, 7–10: tight and elastic structure), odor (0–3:

meatless odor, heavy stinky of blood, 7–10: strong roasted and fatty odor), and taste (0–3: no umami, 7–10: good umami). Finally, the overall acceptability of the samples (0–3: dislike, 7–10: favorite) was evaluated comprehensively. To avoid odor interaction between samples, panelists were required to take a 30 s break during the experiment. A total of 3 sessions were performed.

2.6 Protein oxidation measurement

2.6.1 Determination of carbonyl content

Carbonyl content was determined by the method of reference[25]. Samples (2 g) were added to 18 mL 0.9 g/100 mL NaCl, homogenized for 30 s, and centrifuged (8 000 r/min, 4 °C, 10 min). 0.4 mL protein solution and 0.2 mL 0.02 mol/L DNPH solution (solvent 2 mol/L HCl) were mixed in a water bath at 37 °C for 1 h. Blank samples were prepared without DNPH. Added 1 mL of 20% trichloroacetic acid and shook well, centrifuged (8 000 r/min, 4 °C, 15 min) and discarded the supernatant. The precipitate was washed 3 times with 1 mL ethanol-ethyl acetate solution (1:1, *V*/*V*). After the third washing of the precipitate, 1 mL of 6 mol/L guanidine hydrochloride solution was added. The absorbance at 370 nm was determined by UV-1800 ultraviolet spectrophotometer (Shimadzu Co., Japan). Three replicates were performed for each degree of roasting and carbonyl content was calculated by Eq. (2):

$$\text{Carbonyl content (nmol/mg)} = \frac{A_{370\text{ nm}} \times 10^6}{22\,000 \times \rho} \quad (2)$$

Where $A_{370\text{ nm}}$ represents absorbance at 370 nm; 10^6 represents the mole base unit; ρ stands for protein concentration (g/mL); 22 000 stands for molar absorption coefficient (L/(mol·cm)).

2.6.2 Determination of sulfhydryl content

The sulfhydryl content was determined according to the method of Chen et al.[26]. Totally, 2 g of samples were added to 15 mL of phosphate buffered saline (50 mmol/L) for high-speed homogenization, and the homogenized solution was centrifuged at 5 000 × *g* for 15 min. Reactive sulfhydryl content assay: 1 mL of protein solution was taken and 5 mL of buffer (containing 0.086 mol/L Tris, 0.09 mol/L glycine, 4 mmol/L EDTA, pH 8.0) was added. Total sulfhydryl content assay: 1 mL of protein solution was taken and 5 mL of buffer (containing 0.086 mol/L Tris, 0.09 mol/L glycine, 4 mmol/L EDTA, 8 mol/L urea, pH 8.0) was added. 4.5 mL homogenate was taken and 0.5 mL Ellman's reagent (10 mmol/L DTNB) was added. The absorbance of the supernatant at 412 nm was measured after standing at room temperature for 30 min away from light. The blank control was buffer solution. Three replicates were carried out for each degree of grilling sample. Sulfhydryl content was calculated by Eq. (3):

$$\text{Sulfhydryl content (μmol/mg)} = \frac{A_{412\text{ nm}} \times 10^6}{13\,600 \times \rho} \quad (3)$$

Where $A_{412\text{ nm}}$ represents absorbance at 412 nm; 10^6 represents molar base unit; ρ stands for protein concentration (mg/mL); 13 600 stands for molar absorption coefficient (L/(mol·cm)).

2.6.3 Determination of free amino acid content

Referring to the standard of GB 5009.124–2016 *Determination of Amino Acids in Foods*, L-8900 automatic amino acid analyzer (Hitachi, Japan) was used to determine the amino acid content in roasted lamb patties.

2.6.4 SDS-PAGE analysis

A meat sample of 2 g was taken, and 0.9 g/100 mL NaCl 18 mL was added, homogenized for 30 s, centrifuged at 8 000 r/min at 4 °C for 10 min, and the protein concentration was diluted to 4 mg/mL. Proteins can be separated by molecular weight using the SDS-PAGE technique[27]. Protein samples with a mass concentration of 2 mg/mL were obtained using a concentration gel of 4% and a separation gel of 12%. it was then mixed with 4 × buffer sample solution in 4:1 volume ratio.

2.7 Statistical analysis

SPSS version 19.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. For each roasting time, the experiment was repeated at least 3 times. The final result was expressed as a mean ± standard deviations (SD). The random effect of sensory evaluation was composed of group members, and the roasting time (10, 15, 20 min) and roasting temperature (220 °C) were fixed effects, and the addition of cumin was a random effect. The Duncan multiple comparative analysis method was used to analyze the significant differences in experimental data ($P < 0.05$), and Origin Pro 2021 and Microsoft Office 2019 software were used to plot and merge the plots.

3 Results and discussion

3.1 Analysis of volatile components of roast lamb

SPME-GC-MS was used to analyze and identify the volatile compounds and relative contents of roasted lamb patty, and the effect of cumin addition on the volatile compounds characteristics of roasted lamb patty was studied. Table 1 shows the volatile components of cumin group lamb patties roasted in 10–20 min, in which the total content of volatile flavor compounds detected in 10 min was 669 258.90 ng/g, 15 min was 1 307 769.76 ng/g, and 889 851.48 ng/g was detected in 20 min of roasting. In summary, the total content of volatile flavor compounds in the roasting process of lamb showed a trend of first increasing and then decreasing, and reached the maximum at 15 min of roasting. This might be due to the heating treatment changed the organizational structure of the meat products and decreased the specific heat capacity and water activity of the meat products, which led to an increase in the formation of volatile compounds[28]. But the roasting time was too long, and the lamb meat would be charred and hardened, which led to a decrease in the flavor compounds. Table 1 shows that a total of 82 common volatile components were detected, including 16 aldehydes, 8 alcohols, 8 ketones, 9 esters, 24 olefins, 7 aromatic hydrocarbons, 5 acids and 5 heterocycles. There was a significant difference between cumin on the type and content of volatile compounds in roasted lamb patties. A total of 48 volatile compounds were identified in roasted lamb patties without cumin, whereas the number of volatile flavor compounds in roasted lamb patties with added cumin increased to 60. As shown in Figure 1, the relative content of aldehydes, alcohols and alkanes decreased and the relative content of esters and olefins increased in the cumin group compared to the control group. And the addition of cumin and then (*E*)-2-hexenal, (*E*)-2-heptenal, (*E*)-2-octenal, (*E*)-nonenal, *cis*-4-decenal, 2-heptanone, benzene, normal butanol, 1-heptanol, isooctanol and other flavor compounds disappeared and were not detected, which may be due to the addition of cumin to inhibit protein oxidation and lipid degradation in lamb.

Table 1 The volatile components of roast lamb patty identify by SPME-GC-MS (ng/g).

Volatile compounds		Control group			Cumin group		
		10-0	15-0	20-0	10-1	15-1	20-1
Aldehydes	Pentanal	612.59 ± 64.60^{Aa}	438.02 ± 21.57^{Ba}	692.49 ± 22.28^{A}	61.12 ± 22.21^{Ab}	40.85 ± 2.99^{Bb}	ND
	Hexanal	14 986.51 ± 1 059.53^{Ba}	13 481.79 ± 442.31^{Ca}	18 528.14 ± 410.58^{Aa}	1 124.49 ± 82.51^{Ab}	858.29 ± 9.14^{Bb}	1 115.25 ± 99.31^{Ab}
	Heptanal	1 464.38 ± 61.67^{Ba}	1 554.29 ± 15.49^{Ba}	1 962.67 ± 59.64^{Aa}	180.92 ± 7.31^{ABb}	127.53 ± 14.44^{Bb}	196.82 ± 60.52^{Ab}
	Octanal	2 695.69 ± 95.39^{Ba}	2 993.70 ± 276.23^{Ba}	3 453.60 ± 129.60^{Aa}	1 430.25 ± 117.60^{Ab}	1 460.25 ± 232.60^{Ab}	1 325.21 ± 138.21^{Ab}
	Nonanal	7 505.30 ± 186.30^{Ca}	9 463.69 ± 97.77^{Ba}	10 102.75 ± 251.22^{Aa}	1 968.98 ± 42.25^{Bb}	1 725.56 ± 14.38^{Cb}	2 922.90 ± 509.87^{Ab}
	Decanal	137.37 ± 21.38^{Cb}	189.65 ± 4.36^{Ba}	215.33 ± 8.72^{Ab}	164.18 ± 9.31^{Ba}	171.93 ± 13.77^{Ba}	259.20 ± 49.70^{Aa}
	(*E*)-2-Hexenal	ND	12.35 ± 1.12	23.44 ± 1.30	ND	ND	ND
	(*E*)-2-Heptenal	155.32 ± 11.23	162.36 ± 15.48	186.92 ± 5.92	ND	ND	ND
	Benzaldehyde	162.36 ± 15.48^{Ba}	189.15 ± 5.11^{Bb}	306.49 ± 23.01^{Aa}	197.67 ± 21.82^{Cb}	271.87 ± 31.05^{Ba}	315.61 ± 12.09^{Aa}
	(*E*)-2-Octenal	153.40 ± 8.52^{B}	156.42 ± 6.87^{B}	241.91 ± 8.11^{A}	ND	ND	ND
	Pentadecanal	43.11 ± 5.80^{Cb}	56.07 ± 18.36^{Bb}	71.07 ± 26.90^{Ab}	134.76 ± 13.25^{Ba}	136.99 ± 12.33^{Ba}	147.30 ± 0.84^{Aa}
	Cumin aldehyde	185.11 ± 17.12^{Cb}	236.78 ± 21.24^{Bb}	285.37 ± 17.07^{Ab}	571 236.25 ± 348.27^{Ca}	1 205 599.53 ± 303.89^{Aa}	712 928.16 ± 275.49^{Ba}
	Tetradecanal	88.54 ± 7.94^{B}	79.41 ± 3.97^{B}	134.47 ± 2.24^{A}	ND	ND	62.63 ± 15.32
	(*E*)-Nonenal	194.00 ± 46.62^{A}	189.00 ± 33.34^{A}	205.51 ± 17.35^{A}	ND	ND	ND
	cis-4-Decenal	ND	154.22 ± 5.35	173.89 ± 6.81	ND	ND	ND
	1-Cyclohexene-1-carboxaldehyde	ND	ND	ND	1 889.53 ± 20.20^{C}	3 718.02 ± 89.62^{A}	2 330.78 ± 298.66^{B}
Acids	Ethanoic acid	62.95 ± 3.26^{b}	ND	51.81 ± 6.41^{b}	316.50 ± 29.321^{Ba}	238.31 ± 16.14^{C}	405.20 ± 48.32^{Aa}
	2-Amino-4-methylbenzoic acid	6.64 ± 0.52	ND	103.41 ± 8.93	ND	ND	ND
	2-Amino-5-methylbenzoic acid	ND	48.22 ± 1.43	725.64 ± 56.60	ND	467.69 ± 23.96	ND
	2-Amino-6-methylbenzoic acid	ND	46.87 ± 2.20	236.41 ± 13.76	ND	266.11 ± 16.73	ND
	2-Phenyl-2-ethylbutyric acid	ND	ND	ND	279.94 ± 20.19^{B}	224.41 ± 13.51^{C}	690.30 ± 9.15^{A}
Esters	Allyl heptanoate	121.95 ± 11.85	ND	ND	ND	ND	ND
	Vinyl stearate	23.59 ± 1.53	ND	ND	ND	ND	62.64 ± 1.00
	Dimethyl sulfite	ND	ND	ND	18.80 ± 1.22	ND	ND
	Phenylbutyrate	ND	ND	ND	77.29 ± 7.90	ND	ND
	Ethyl acetate	ND	ND	ND	ND	ND	351.37 ± 11.57
	Propyl acetate	ND	ND	ND	ND	ND	66.55 ± 5.85
	Methyl palmitate	ND	ND	ND	ND	ND	111.71 ± 11.68
	Ethyl 2-picolinate	ND	ND	ND	ND	ND	96.98 ± 8.59
	Ethyl acetoacetate	ND	ND	ND	ND	ND	69.27 ± 2.04
Ketones	2-Heptanone	126.74 ± 4.21	93.89 ± 4.75	ND	ND	ND	ND
	2,5-Octanedione	97.90 ± 7.00	ND	ND	ND	ND	ND
	Stearone	24.46 ± 2.15	ND	ND	ND	ND	ND
	2,3-Octanedione	ND	26.14 ± 3.23	ND	ND	ND	ND
	Cycloamyl ethyl ketone	ND	154.28 ± 7.86	ND	ND	ND	ND
	1-Phenyl-1-butanone	ND	ND	ND	6 086.69 ± 443.57^{A}	5 137.69 ± 346.79^{B}	3 861.21 ± 214.81^{C}
	5-Hepten-2-one, 6-methyl-	ND	ND	ND	ND	ND	60.68 ± 3.29
	2-Allyl cyclohexanone	ND	ND	ND	ND	ND	105.70 ± 7.31
Alkenes	1-Butene	13.95 ± 2.57	ND	ND	ND	ND	ND
	trans-1,4-Hexadiene	121.09 ± 9.75	ND	ND	ND	ND	ND
	Pentane, 3-methylene	49.02 ± 5.83	ND	217.19 ± 7.41	ND	52.62 ± 3.14	ND
	D-Terpenediene	20.76 ± 1.02^{Cb}	34.10 ± 2.57^{Bb}	45.33 ± 2.93^{Ab}	1 105.15 ± 23.44^{Ca}	1 362.37 ± 88.52^{Ba}	3 098.72 ± 162.81^{Aa}
	1-Methylcyclopentene	ND	91.04 ± 8.55	ND	ND	ND	ND
	5-Undecene	ND	63.99 ± 5.84	ND	ND	ND	ND
	cis-2-Pentene	ND	ND	262.32 ± 5.82	ND	ND	ND
	Hexyl acrylate	ND	ND	96.29 ± 8.43	ND	ND	ND
	Styrene	ND	ND	ND	64.76 ± 3.80^{C}	89.36 ± 8.54^{B}	99.70 ± 7.97^{A}
	Cumene	ND	ND	ND	34.47 ± 2.72	ND	53.10 ± 4.83
	L-*β*-Pinene	ND	ND	ND	3 533.77 ± 162.34	ND	4 278.28 ± 263.34
	1,3-Cyclohexadiene, 1-methyl-4-(1-methylethyl)-	ND	ND	ND	232.93 ± 8.53	ND	1 048.67 ± 64.61
	β-Ocimene	ND	ND	ND	98.18 ± 7.33^{C}	111.21 ± 8.18^{B}	258.25 ± 9.29^{A}
	γ-Terpinene	ND	ND	ND	16 730.83 ± 657.57^{C}	20 867.55 ± 973.79^{B}	43 385.64 ± 1 401.58^{A}
	3-Carene	ND	ND	ND	100.27 ± 8.47	ND	446.66 ± 23.82
	Cyclohexene	ND	ND	ND	101.32 ± 3.41^{B}	107.24 ± 7.64^{B}	486.52 ± 29.04^{A}
	Benzene, 1-methyl-4-(1-methylethenyl)-	ND	ND	ND	344.70 ± 7.29^{B}	230.37 ± 11.54^{C}	504.11 ± 36.29^{A}
	1,2-Pentadiene	ND	ND	ND	130.57 ± 9.91	ND	ND
	Tricyclo[5.4.0.0(2,8)]undec-9-ene, 2,6,6,9-tetramethyl-, (1*R*,2*S*,7*R*,8*R*)-	ND	ND	ND	154.59 ± 5.98	ND	269.96 ± 7.48
	Copaene	ND	ND	ND	244.42 ± 18.92^{B}	226.40 ± 3.91^{C}	335.98 ± 7.23^{A}
	Caryophyllene	ND	ND	ND	837.74 ± 30.89^{B}	801.33 ± 79.75^{C}	2 121.21 ± 82.45^{A}
	(*E*)- *β*-Famesene	ND	ND	ND	677.92 ± 4.26^{B}	643.45 ± 35.35^{C}	1 968.15 ± 155.78^{A}
	(+)-*α*-Cypress terpene	ND	ND	ND	76.25 ± 3.42^{C}	84.77 ± 5.88^{B}	91.71 ± 5.72^{A}
	α-Pinene	ND	ND	ND	ND	505.42 ± 26.83	142.22 ± 9.68
Aromatic hydrocarbons	Benzene	50.59 ± 3.80	19.37 ± 0.96	ND	ND	ND	ND
	Toluene	303.22 ± 27.58^{Aa}	213.47 ± 11.16^{Bb}	226.69 ± 17.95^{Ba}	68.94 ± 6.55^{Cb}	283.00 ± 19.89^{Aa}	126.66 ± 11.75^{Bb}
	Ethylbenzene	39.72 ± 2.54	ND	47.71 ± 4.25	39.69 ± 3.56	ND	654.81 ± 49.27
	1,3-Xylene	204.49 ± 5.61^{Aa}	195.68 ± 11.11^{Aa}	175.99 ± 12.74^{Bb}	149.37 ± 8.49^{Bb}	136.74 ± 9.27^{Cb}	392.84 ± 19.37^{Aa}
	p-Isopropyl toluene	ND	ND	ND	19 240.93 ± 973.28^{B}	23 448.32 ± 1 077.17^{A}	644.19 ± 13.27^{C}
	Benzene, 1-methyl	ND	ND	ND	ND	155.89 ± 8.42	51 040.61 ± 2 819.39
	1,3-Dimethyl-4-ethylbenzene	ND	ND	ND	317.54 ± 18.49	ND	54.71 ± 4.48
Alcohols	1,8-Cineole	ND	ND	ND	395.89 ± 10.59^{C}	445.84 ± 29.02^{B}	460.57 ± 16.47^{A}
	Terpinen-4-ol	ND	ND	ND	423.05 ± 20.82^{B}	385.28 ± 16.53^{C}	830.75 ± 42.17^{A}
	p-Cymen-7-ol	ND	ND	ND	2 660.51 ± 173.54^{B}	1 062.49 ± 121.75^{C}	3 440.06 ± 201.77^{A}
	Normal butanol	142.50 ± 7.93^{A}	82.62 ± 7.36^{C}	97.04 ± 7.72^{B}	ND	ND	ND
	1-Heptanol	340.50 ± 13.17^{A}	194.70 ± 10.55^{C}	231.44 ± 6.62^{B}	ND	ND	ND
	1-Octene-3-ol	2 918.96 ± 189.26^{A}	2 081.45 ± 189.45^{C}	2 525.61 ± 182.48^{B}	ND	124.12 ± 10.29	125.29 ± 7.57
	Isooctanol	1 170.29 ± 53.92^{C}	1 350.58 ± 116.57^{B}	1 762.83 ± 144.93^{A}	ND	ND	ND
	1-Octanol	501.01 ± 44.28^{Aa}	238.11 ± 11.00^{Ca}	309.60 ± 30.57^{Ba}	41.78 ± 2.73^{Bb}	54.61 ± 4.16^{Ab}	26.42 ± 1.15^{Cb}
Heterocyclic sedative-hypnotics	Pyridine	610.02 ± 35.97^{Ca}	981.06 ± 37.22^{Ba}	1 213.66 ± 46.46^{Aa}	67.28 ± 4.56^{Cb}	81.16 ± 6.58^{Bb}	141.39 ± 7.88^{Ab}
	2-Pentylfuran	120.77 ± 5.68^{Bb}	142.76 ± 12.36^{ABb}	195.40 ± 16.27^{Ab}	200.65 ± 28.17^{Ca}	294.00 ± 25.48^{Ba}	466.18 ± 30.28^{Aa}
	2-Hydroxy-propanamide	ND	ND	10.69 ± 0.98	ND	3.79 ± 0.11	11.44 ± 1.33
	2(1*H*)-Pyridinone	ND	ND	44.25 ± 5.63	ND	16.32 ± 4.67	54.25 ± 7.62
	Furfural	97.05 ± 7.71^{Ab}	41.85 ± 3.85^{Bb}	22.83 ± 0.86^{Cb}	466.18 ± 6.25^{Aa}	294.00 ± 3.25^{Ba}	120.77 ± 7.80^{Ca}

Note: Different lowercase letters indicate the same roasting time with significant differences between groups ($P < 0.05$). Different capital letters indicate significant differences within different roasting time groups ($P < 0.05$). 10-0, 15-0 and 20-0 represented the roast lamb patties without cumin at different degrees of roasting; 10-1, 15-1 and 20-1 represented the roast lamb patties with cumin at different degrees of roasting. ND, not detected.

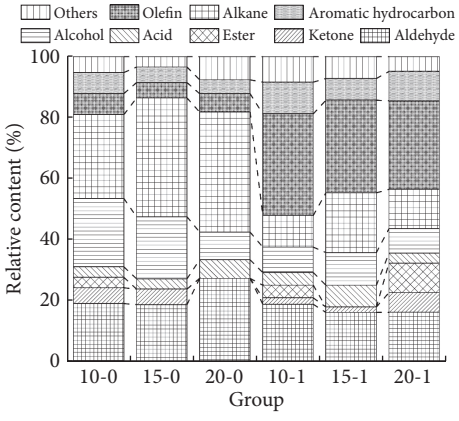

Figure 1 Distribution of relative content of volatile flavor compounds in roast lamb. 10-0, 15-0 and 20-0 represented the roast lamb patties without cumin at different degrees of roasting; 10-1, 15-1 and 20-1 represented the roast lamb patties with cumin at different degrees of roasting.

As a common volatile flavor substance in cooked meat, aldehydes have a great influence on the flavor of cooked meat because of their low odor threshold[29]. The results showed that the main volatile flavor compounds in the samples of roast lamb patty were aldehydes, including valeraldehyde, hexanal, heptanal, octanal, nonanal, caprical, benzaldehyde, *trans*-2-octenal and so on. Jinap et al.[30] proposed that nonanal, hexanal, and octanal are the key aroma substances in roast lamb. Hexanal is the most abundant volatile organic compound in all types of cooked meat, with meaty, grassy, and fatty flavors, which are mainly derived from the oxidation of phospholipids and polyunsaturated fatty acids[31]. The introduction of cumin resulted in a significant reduction in the hexanal content. The addition of (*E*)-2-hexenal, (*E*)-2-heptenal, *trans*-2-octenal, myristic aldehyde, (*E*)-nonenal, and (*Z*)-4-decenal were significantly eliminated, possibly due to the antioxidant effect of cumin reducing the oxidation of key aldehydes. In the control group, nonanal was the aldehyde with the highest concentration except hexanal, which may be related to the experimental raw meat. The content of benzaldehyde in the cumin group was higher than that in the control group, and the benzaldehyde was produced by the degradation of phenylalanine, and it had the smell of bitter almond and aromatic odor when burned, which was the main aromatic aldehyde in Sunit sheep. The contents of cumin-aldehyde and anisaldehyde increased significantly after roasting with spices. These are the most abundant component of cumin which may be due to the introduction of cumin powder during roasting, which imparted the lamb with aromas such as withered, citrus, and spicy[32–33].

In addition to aldehydes, alcohols and ketones, acids, esters, olefins and heterocycles were also important volatile flavor substances in roast meat. Acids may be derived from the degradation of fatty acids or the oxidation of aldehydes and ketones, which can effectively modify flavor. Due to its low content and relatively high sensory threshold, it contributes less to the overall flavor of roast lamb[29]. The acids detected in the samples were mainly 2-phenyl-2-ethylbutyric acid and acetic acid, which was degraded from lamb fat and mainly provided the oily taste of roast lamb[34]. The acids in meat were related to the formation of the unique smell of lamb, and 4-methylcaprylic acid and 4-methylnonanoic acid have been confirmed to be the main acids in the smell of lamb[35], which were not detected in this experiment, and the samples may have a mild odor. The esters in lamb were mainly formed by the interaction between acids and alcohols, and most of the esters have a high flavor threshold and have little contribution to the overall flavor of lamb. The *D*-limonene content in roast lamb was significantly increased after the addition of cumin. Xi et al.[36] found that the effect of spice addition on the volatile flavor of roast lamb can be attributed to the production of flavor volatiles after the heat action of spices, as well as the formation of small amounts of volatiles during boiling, which was consistent with our results. The synergy of alkanes and olefins also contributed to the overall flavor of roast lamb. The high temperature during roasting promoted the formation of heterocyclic compounds, such as 2-pentylfuran and furfural. 2-Amylfuran was the main flavor compound in hot-processed foods, derived from *n*-6 fatty acids such as linoleic acid, which can provide a low threshold for plant aroma[28]. As one of the characteristic flavor substances, 2-ethylfuran can make the kebab have a lighter smell. Crews et al.[37] also noted that a small amount of 2-ethylfuran was beneficial for improving the flavor of lamb. In summary, some volatile compounds such as aldehydes (cuminaldehyde, anisaldehyde), alcohols (*p*-isopropylbenzyl alcohol) and olefins (*D*-limonene) mainly came from the cumin added to lamb during roasting. Roasting with ingredients could enhance the fat aroma and barbecue aroma of the roast lamb patty, and together with the aroma of cumin itself, it gave the roast lamb patty a new and pleasant flavor, so as to achieve the role of raising and giving aroma.

3.2 Results of E-tongue analysis

The E-tongue converts electrical signals into taste signals to distinguish the taste of the foods, and it has a small threshold of sensation and excludes the subjectivity of sensory evaluation. Figure 2A shows the response values of bitterness, saltiness, astringency, sourness, aftertaste-B, aftertaste-A, richness and umami. Compared to roasted lamb patties without cumin, roasted lamb patties with cumin decreased in bitterness and sourness ($P < 0.05$), indicating that cumin may mask or blend unpleasant tastes by releasing characteristic volatile flavor compounds. The signal values of aftertaste-A and aftertaste-B were not significant ($P > 0.05$) with the addition of cumin. As the degree of roasting deepened, the 20-1 group showed a decrease in umami flavor, which may be due to the Maillard reaction between free amino acids released from the thermal decomposition of proteins and reducing sugars. Xu et al.[38] found that in addition to the salty taste caused by the addition of salt, the most prominent taste characteristic of roast lamb patties was umami.

Based on the data of roasted lamb patties on different electronic tongue sensors, principal component analysis (PCA) was used to separate lamb patties with different degrees of roasting before and after the addition of cumin. As can be seen in Figures 2B and C, the contributions of PC1 and PC2 were 59.0% and 30.7%, respectively, with a cumulative contribution of 89.7% (> 85%), indicating that PC1 and PC2 reflect a great deal of information about the overall characteristics of the sample. The roasted lamb patties (10-1, 15-1 and 20-1) from the cumin group were almost all in the positive semiaxis of PC2 with a positive PC2 score value, indicating that the samples from the cumin group had a higher umami, saltiness, astringency, richness, and aftertaste response values as compared to the other samples. Samples from the 20-0 group were differentiated from the other samples with a positive PC1 score value, which indicated that the 20-0 group had a higher sourness response value as compared to the other samples.

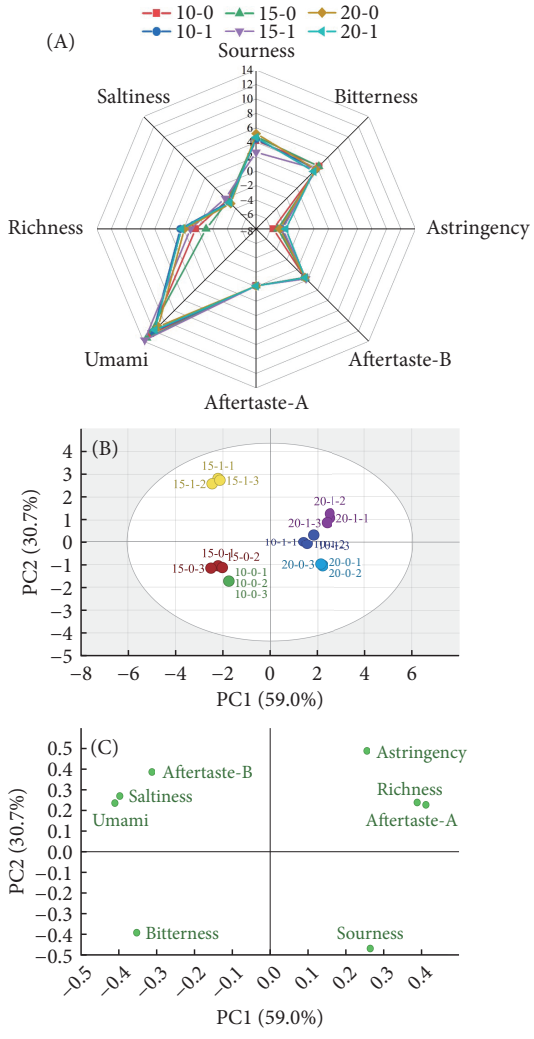

Figure 2 (A) Radar chart of electronic tongue (E-tongue) and (B) PCA of data and (C) PCA loading plot of E-tongue response values data for roasted lamb patties with different roasted times. E-tongue radar chart of roast lamb patties. 10-0, 15-0 and 20-0 represented the roast lamb patties without cumin at different time of roasting; 10-1, 15-1 and 20-1 represented the roast lamb patties with cumin at different time of roasting.

3.3 Results of sensory evaluation

The sensory evaluation of the sensory indexes such as color, texture, taste, smell and overall acceptability of different roasted lamb patties was carried out. The highest sensory evaluation of the samples was in 20-1 group, with a score of 31.5 ± 0.1, as shown in Figure 3. The grilled lamb patty had a rich barbecue flavor and a delicious taste. However, with the increase of roasting time, the texture and color scores of the samples generally decreased with the increase of roasting time, and the smell, taste and overall acceptability scores of the samples improved. Sensory evaluations showed that the color scores of both the 15-1 and 20-1 groups were lower than those of the control group, which may be due to the darkening of the samples with increasing heating time[39]. When roasted for the same time, the odor, taste, texture and overall acceptability of the lamb patties were higher than those of the control group, which may be due to the fact that the addition of cumin reduced the smell and bloody taste of the samples. This suggested that adding cumin to a roasted lamb patty can mask the smell of roasted lamb and enhance its flavor. This was consistent with the results of GC-MS and E-tongue, where the addition of cumin could improve umami, increase the characteristic aroma of cumin, mask the odor, and improve the ester aroma. In summary, the addition of cumin can improve the flavor of the roast lamb patty and the overall acceptability of consumers to it.

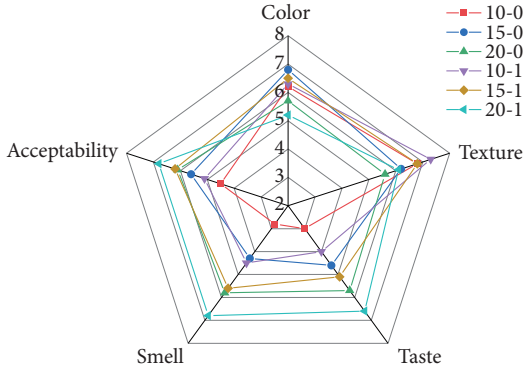

Figure 3 Sensory evaluation diagram of roast lamb patties. 10-0, 15-0 and 20-0 represented the roast lamb patties without cumin at different degrees of roasting; 10-1, 15-1 and 20-1 represented the roast lamb patties with cumin at different degrees of roasting.

3.4 Carbonyl content analysis

Changes in carbonyl content are one of the distinguishing features of changes in the degree of protein oxidation, and higher levels indicate a higher degree of protein oxidation, which is usually measured using DNPH technology[40]. The effect of cumin on the carbonyl content of roast lamb patty was shown in Figure 4. The protein carbonyl content of lamb increased significantly with the increase of roasting time. This was due to the gradual decrease in the moisture and fat content of the lamb, resulting in an increase in the relative content of dry matter in the meat and an increase in the percentage of protein per unit of meat, which in turn affected the taste, color and texture of the roast lamb. The carbonyl content of lamb was significantly lower than that of the control group after cumin was added, which may be due to the antioxidant activity of flavonoids, terpene aldehydes and terpenes in cumin, which inhibited the oxidation of lamb protein during roasting.

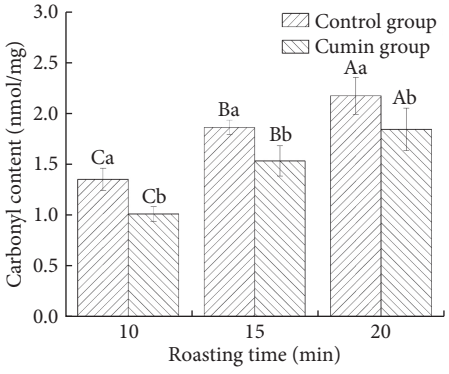

Figure 4 Effect of cumin on carbonyl content in roast lamb patties. Control group represented the roast lamb patties without cumin at different degrees of roasting; cumin group represented the roast lamb patties with cumin at different degrees of roasting. Different lowercase letters indicate the same roasting time with significant differences between groups ($P < 0.05$). Different capital letters indicate significant differences within different roasting time groups ($P < 0.05$).

3.5 Sulfhydryl content analysis

A large number of sulfhydryl groups are buried in myofibrillar proteins, and the active sulfhydryl groups on the surface of protein particles are easily oxidized, so that the oxidation reaction between the active sulfhydryl groups forms disulfide bonds, which maintains the stability of the protein spatial structure. The disulfide bond is regarded as the main oxidation-induced cross-linking type in fresh meat[41]. As can be seen from Figure 5, with the continuous extension of roasting time, the active sulfhydryl content and total sulfhydryl content in the control group decreased slightly. This may be due to the fact that high-temperature heating promoted the oxidation of the active sulfhydryl groups of myofibrillar proteins, which promoted the conversion of active sulfhydryl groups into disulfide bonds, resulting in a decrease in sulfhydryl content. Compared with the control group, the total and active sulfhydryl contents of the cumin group increased, which may be due to the ability of some antioxidant substances in cumin to reduce the loss of sulfhydryl content. After adding cumin, the roasting time changed most significantly from 10 to 15 min, and this result also corresponded to the determination of carbonyl content. This indicated that cumin had the ability to prevent protein carbonyl formation and reduce the loss of sulfhydryl content, but the antioxidant effect of cumin was not obvious after long-term heat treatment.

3.6 Free amino acid content analysis

Free amino acids are important taste substances and flavor precursors of meat, and they are excellent contributors to the taste of meat[42]. The changes in the content of free amino acids in roast lamb patties were shown in Table 2, and a total of 16 amino acids were detected. The most abundant amino acid was glutamic acid (Glu), followed by arginine (Arg), leucine (Leu) and aspartic acid (Asp). Madruga et al.[43] noted high levels of Glu in roast lamb, and the results of this trial were consistent with them. During the heating process, the endogenous protease in lamb enzymatically hydrolyzed the protein to produce amino acids, and the content of free amino acids in lamb increased. Since the increase or decrease of free amino acids depends on their formation and loss, this may also be the reason for the different changes in the amino acid content in the meat. With the extension of roasting time, the total amount of free amino acids in roast lamb increased with the extension of roasting time, while the 5 amino acids of Arg, serine (Ser), glycine (Gly), threonine (Thr) and methionine (Met) increased first and then decreased with the extension of roasting time. This may be due to the fact that during the roasting process, the protein was thermally broken down to release free amino acids, increasing its total content. The 5 amino acids, such as Ser and Arg, underwent thermal degradation and Maillard reaction with reducing sugars, thereby reducing their content. The contents of various free amino acids and the total amount of free amino acids in the lamb were higher than those in the control group. The addition of cumin can inhibit the oxidation of roast lamb protein to a certain extent, thereby changing the content of free amino acids in lamb, and the content of umami amino acids and sweet amino acids in the roasting process generally showed an upward trend, which was conducive to the formation of good flavor of roast lamb. The

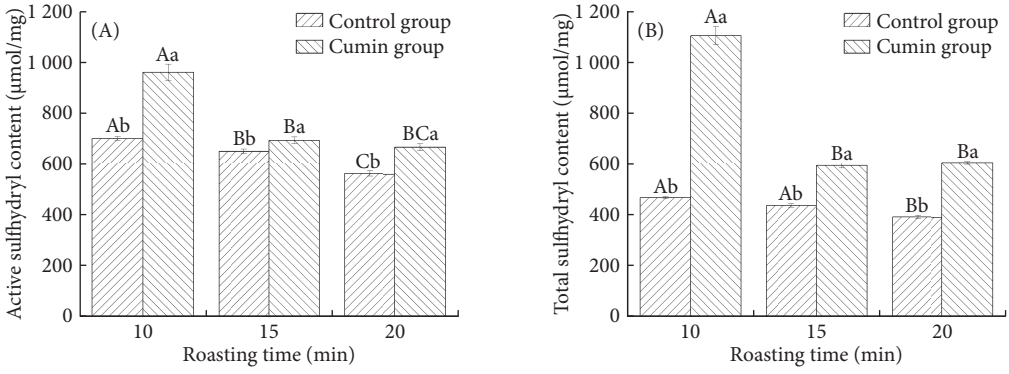

Figure 5 Effect of cumin on (A) active sulfhydryl content and (B) total sulfhydryl content. Control group represented the roast lamb patties without cumin at different degrees of roasting; cumin group represented the roast lamb patties with cumin at different degrees of roasting. Different lowercase letters indicate the same roasting time with significant differences between groups ($P < 0.05$). Different capital letters indicate significant differences within different roasting time groups ($P < 0.05$).

Table 2 Effect of cumin on the free amino acid content of roast lamb patties (%).

Free amino acid	Control group			Cumin group		
	10-0	15-0	20-0	10-1	15-1	20-1
Asp	3.42 ± 0.22^{Cb}	3.74 ± 0.56^{Bb}	4.02 ± 0.46^{Ab}	3.65 ± 0.78^{Ca}	3.89 ± 0.47^{Ba}	4.24 ± 0.39^{Aa}
Glu	6.02 ± 0.45^{Cb}	6.82 ± 0.67^{Bb}	7.07 ± 1.11^{Ab}	6.75 ± 0.78^{Ca}	6.94 ± 0.37^{Ba}	7.21 ± 0.48^{Aa}
His	1.56 ± 0.21^{Cb}	1.62 ± 0.23^{Bb}	1.65 ± 0.23^{Ab}	1.69 ± 0.47^{Ca}	1.77 ± 0.38^{Ba}	1.75 ± 0.87^{Aa}
Ser	2.31 ± 0.31^{Cb}	2.52 ± 0.89^{Ab}	2.44 ± 0.67^{Bb}	2.43 ± 0.58^{Ca}	2.67 ± 0.27^{Aa}	2.53 ± 0.57^{Ba}
Arg	3.45 ± 0.09^{Bb}	3.76 ± 0.11^{Aa}	3.71 ± 0.84^{Aa}	3.70 ± 0.57^{Aa}	3.85 ± 0.37^{Aa}	3.79 ± 0.59^{Aa}
Gly	1.82 ± 0.03^{Ab}	1.49 ± 0.78^{Bb}	1.32 ± 0.13^{Cb}	1.93 ± 0.60^{Aa}	1.66 ± 0.12^{Ba}	1.51 ± 0.47^{Ca}
Thr	1.55 ± 0.11^{Cb}	1.82 ± 0.57^{Ab}	1.77 ± 0.57^{Bb}	1.64 ± 0.48^{Ca}	1.92 ± 0.15^{Aa}	1.83 ± 0.23^{Ba}
Pro	1.67 ± 0.17^{Cb}	1.78 ± 0.35^{Bb}	2.11 ± 0.12^{Ab}	1.77 ± 0.09^{Ca}	1.95 ± 0.27^{Ba}	2.21 ± 0.46^{Aa}
Ala	2.21 ± 0.32^{Bb}	2.53 ± 0.23^{Ab}	2.59 ± 0.36^{Ab}	2.34 ± 0.70^{Ba}	2.69 ± 0.37^{Aa}	2.66 ± 0.25^{Aa}
Val	2.53 ± 0.33^{Cb}	2.78 ± 0.56^{Bb}	3.11 ± 0.95^{Ab}	2.65 ± 0.48^{Ca}	2.87 ± 0.46^{Ba}	3.31 ± 0.16^{Aa}
Met	1.32 ± 0.21^{Bb}	1.45 ± 0.89^{Ab}	1.38 ± 0.13^{Bb}	1.43 ± 0.58^{Ba}	1.65 ± 0.47^{Aa}	1.43 ± 0.25^{Ba}
Cys	0.69 ± 0.08^{Cb}	1.27 ± 0.67^{Bb}	1.89 ± 0.14^{Ab}	0.98 ± 0.80^{Ca}	1.65 ± 0.52^{Ba}	2.11 ± 0.37^{Aa}
Ile	2.56 ± 0.34^{Cb}	2.71 ± 0.78^{Bb}	2.98 ± 0.34^{Ab}	2.67 ± 0.89^{Ca}	2.89 ± 0.38^{Ba}	3.21 ± 0.75^{Aa}
Leu	4.36 ± 0.56^{Cb}	4.68 ± 0.36^{Bb}	5.17 ± 0.65^{Ab}	4.47 ± 0.69^{Ca}	4.93 ± 0.49^{Ba}	5.28 ± 0.84^{Aa}
Phe	1.97 ± 0.67^{Cb}	2.12 ± 0.23^{Bb}	2.29 ± 0.37^{Ab}	2.15 ± 0.69^{Ca}	2.39 ± 0.18^{Ba}	2.45 ± 0.74^{Aa}
Lys	3.17 ± 0.98^{Bb}	3.69 ± 0.68^{Ab}	3.78 ± 0.68^{Ab}	3.23 ± 0.48^{Ba}	3.97 ± 0.26^{Aa}	4.03 ± 0.36^{Aa}
Total content	40.61 ± 2.57^{Cb}	44.78 ± 1.23^{Bb}	47.28 ± 3.32^{Ab}	43.48 ± 2.13^{Ca}	47.69 ± 0.76^{Ba}	49.55 ± 3.26^{Aa}

Note: Different lowercase letters indicate the same roasting time with significant differences between groups ($P < 0.05$). Different capital letters indicate significant differences within different roasting time groups ($P < 0.05$). 10-0, 15-0 and 20-0 represented the roast lamb patties without cumin at different degrees of roasting; 10-1, 15-1 and 20-1 represented the roast lamb patties with cumin at different degrees of roasting.

umami content increased significantly with the introduction of cumin spices, which was consistent with the results of electronic tongue detection.

3.7 SDS-PAGE analysis

The effects of cumin and roasting time on myofibrillar protein were analyzed by SDS-PAGE. The electropherograms obtained at different roasting times were shown in Figure 6. The characteristic bands of myofibrillar protein mainly include myosin heavy chain (MHC, 200 kDa), troponin-T (35 kDa), actin (43 kDa), and myosin light chain (16–25 kDa). Martinaud et al.[44] considered myosin to be the most oxidizing of myofibrillar proteins. As can be seen in Figure 6, the MHC band gradually becomes lighter with the increase of roasting time, indicating that its content decreases with the extension of roasting time, which may be due to the denaturation of some proteins at increased temperature, which decomposes the myosin heavy chain into light chains, resulting in a decrease in optical density values[45–46]. Compared with the control group, the MHC and actin bands in the cumin group were slightly deeper, indicating that cumin had certain antioxidant properties. The color of the protein bands at 35–50 kDa gradually became lighter and blurry with the increase of roasting time, which may be due to the decomposition of actin into tropomyosin at high temperature, but the color of the bands deepened after the addition of cumin, especially when the roasting was 20 min, the contrast with the control group was the most obvious, which also indicated that the cumin added during roasting could prevent the oxidation of some proteins. At the same time, the myosin light chain band in the cumin group was darker, which corresponded to the breakdown of myosin heavy chains into light chains at high temperatures.

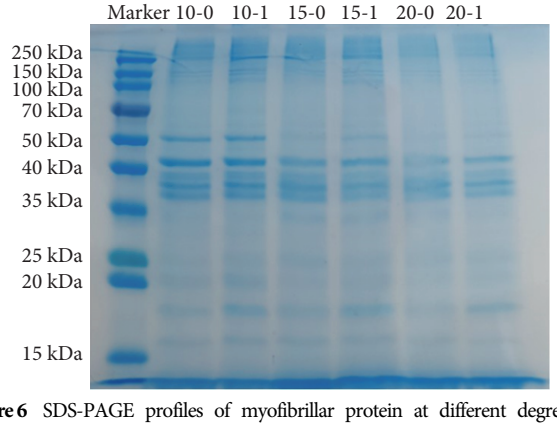

Figure 6 SDS-PAGE profiles of myofibrillar protein at different degrees of roasting. 10-0, 15-0 and 20-0 represented the roast lamb patties without cumin at different degrees of roasting; 10-1, 15-1 and 20-1 represented the roast lamb patties with cumin at different degrees of roasting.

4 Conclusion

The findings of this study suggested that different roasting time and cumin addition had significant effects on the flavor and protein oxidation of roast lamb patties. The addition of cumin as an ingredient not only reduced the original undesirable flavor substances in roast lamb, but also increased the excellent flavor substances such as fat aroma and roast meat aroma, and introduced cumin characteristic flavor substances to enhance the flavor of roast lamb patty, and the overall acceptability in sensory evaluation was significantly improved. Besides, to some extent, the antioxidants in cumin, such as terpenes, can effectively reduce the oxidation of lamb protein during roasting. The results of this study can provide a basis for the wider application of cumin in the roasting process of meat products to improve flavor and delay protein oxidation.

Conflict of 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.

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References

[1] K. Z. Zheng, Y. Y. Yin, Y. Cao, et al., Proteomic and parallel reaction monitoring approaches to evaluate biomarkers of mutton tenderness, Food Chem. 397 (2022) 133746. https://doi.org/10.1016/j.foodchem.2022.133746.

[2] O. R. Oltra, L. J. Farmer, A. W. Gordon, et al., Identification of sensory attributes, instrumental and chemical measurements important for consumer acceptability of grilled lamb *Longissimus lumborum*, Meat Sci. 100 (2015) 97–109. https://doi.org/10.1016/j.meatsci.2014.09.007.

[3] H. Liu, J. Y. Li, D. Q. Zhang, et al., The effect of thermal times of circulating non-fried roast technique on the formation of (non) volatile compounds in roasted mutton by multi-chromatography techniques and heat transfer analysis, Food Res. Int. 174 (2023) 113567. https://doi.org/10.1016/j.foodres.2023.113567.

[4] S. M. Bassam, C. Noleto-Dias, M. A. Farag, Dissecting grilled red and white meat flavor: its characteristics, production mechanisms, influencing factors and chemical hazards, Food Chem. 371 (2022) 131139. https://doi.org/10.1016/j.foodchem.2021.131139.

[5] H. Liu, T. Hui, F. Fang, et al., The formation of key aroma compounds in roasted mutton during the traditional charcoal process, Meat Sci. 184 (2022) 108689. https://doi.org/10.1016/j.meatsci.2021.108689.

[6] A. Sohail, S. Al-Dalali, J. N. Wang, et al., Compounds identified in cooked meat: a review, Food Res. Int. 157 (2022) 111385. https://doi.org/10.1016/j.foodres.2022.111385.

[7] Y. M. Yu, A. S. M. Saleh, X. X. Sun, et al., Exploring the interaction between myofibrillar proteins and pyrazine compounds: based on molecular docking, molecular dynamics simulation, and multi-spectroscopy techniques, Int. J. Bio. Macromol. 253 (2023) 126844. https://doi.org/10.1016/j.ijbiomac.2023.126844.

[8] M. I. Khan, C. Jo, M. R. Tariq, Meat flavor precursors and factors influencing flavor precursors: a systematic review, Meat Sci. 110 (2015) 278–284. https://doi.org/10.1016/j.meatsci.2015.08.002.

[9] H. Liu, Z. Y. Wang, R. Suleman, et al., Effect of protein thermal stability and protein secondary structure on the roasted mutton texture and colour from different cuts, Meat Sci. 156 (2019) 52–58. https://doi.org/10.1016/j.meatsci.2019.05.014.

[10] S. H. Hernández-López, J. G. Rodríguez-Carpena, C. Lemus-Flores, et al., Antioxidant protection of proteins and lipids in processed pork loin chops through feed supplementation with avocado, J. Food Sci. Technol. 53 (2016) 2788–2796. https://doi.org/10.1007/s13197-016-2252-6.

[11] R. Domínguez, M. Pateiro, P. E. S. Munekata, et al., Protein oxidation in muscle foods: a comprehensive review, Antioxidants 11(1) (2021) 60. https://doi.org/10.3390/antiox11010060.

[12] T. L. Han, Z. X. Wang, C. X. Li, et al., Raw to charred: changes of protein oxidation and *in vitro* digestion characteristics of grilled lamb, Meat Sci. 204 (2023) 109239. https://doi.org/10.1016/j.meatsci.2023.109239.

[13] C. Zhang, Y. X. Li, X. F. Xia, et al., Changes in protein oxidation, structure, and thermal stability of chicken breast subjected to ultrasound-assisted immersion freezing during frozen storage, Food Chem. 398 (2023) 133874. https://doi.org/10.1016/j.foodchem.2022.133874.

[14] S. R. Vaudagna, G. Sánchez, M. S. Neira, et al., Sous vide cooked beef muscles: effects of low temperature-long time (LT-LT) treatments on their quality characteristics and storage stability, Int. J. Food Sci. Technol. 37(4) (2002) 425–441. https://doi.org/10.1046/j.1365-2621.2002.00581.x.

[15] P. Borrajo, M. Karwowska, J. M. Lorenzo, The effect of *Salvia hispanica* and *Nigella sativa* seed on the volatile profile and sensory parameters related to volatile compounds of dry fermented sausage, Molecules 27(3) (2022) 652. https://doi.org/10.3390/molecules27030652.

[16] S. Jung, C. Jo, I. S. Kim, et al., The influence of spices on the volatile compounds of cooked beef patty, Korean J, Food Sci. An. 34(2) (2014) 166. https://doi.org/10.5851/kosfa.2014.34.2.166.

[17] N. S. Iacobellis, P. Lo Cantore, F. Capasso, et al., Antibacterial activity of *Cuminum cyminum* L. and *Carum carvi* L. essential oils, J. Agric. Food Chem. 53(1) (2005) 57–61. https://doi.org/10.1021/jf0487351.

[18] R. Ravi, M. Prakash, K. K. Bhat, Characterization of aroma active compounds of cumin (*Cuminum cyminum* L.) by GC-MS, E-nose, and sensory techniques, Int. J. Food Prop. 16 (2013) 1048–1058. https://doi.org/10.1080/10942912.2011.576356.

[19] H. B. Li, L. L. Zhao, Q. Y. Dai, et al., Blended cumin/zanthoxylum essential oil improve the antibacterial, fresh-keeping performance and flavor of chilled fresh mutton, Meat Sci. 200 (2023) 109173. https://doi.org/10.1016/j.meatsci.2023.109173.

[20] H. B. Sowbhagya, Chemistry, technology, and nutraceutical functions of cumin (*Cuminum cyminum* L.): an overview, Crit. Rev. Food Sci. 53 (2013) 1–10. https://doi.org/10.1080/10408398.2010.500223.

[21] T. Allahghadri, I. Rasooli, P. Owlia, et al., Antimicrobial property, antioxidant capacity, and cytotoxicity of essential oil from cumin produced in Iran, J. Food Sci. 75(2) (2010) H54–H61. https://doi.org/10.1111/j.1750-3841.2009.01467.x.

[22] T. P. Krishnakantha, B. R. Lokesh, Scanvenging of superoxide anions by spice principles, Indian J. Biochem. Bio. 30 (1993) 133–134.

[23] H. Liu, J. L. Huang, Q. K. Hu, et al., Dualfiber solid-phase microextraction coupled with gas chromatography-mass spectrometry for the analysis of volatile compounds in traditional Chinese dry-cured ham, J. Chromatogr. B 1140 (2020) 121994. https://doi.org/10.1016/j.jchromb.2020.121994.

[24] S. Al-Dalali, C. Li, B. C. Xu, Evaluation of the effect of marination in different seasoning recipes on the flavor profile of roasted beef meat via chemical and sensory analysis, J. Food Biochem. 46(6) (2022) e13962. https://doi.org/10.1111/jfbc.13962.

[25] J. M. Fagan, B. G. Sleczka, I. Sohar, Quantitation of oxidative damage to tissue proteins, Int. J. Biochem. Cell Biol. 31(7) (1999) 751–757. https://doi.org/10.1016/S1357-2725(99)00034-5.

[26] Q. Chen, B. H. Kong, Q. Han, et al., The role of bacterial fermentation in the hydrolysis and oxidation of sarcoplasmic and myofibrillar proteins in Harbin dry sausages, Meat Sci. 121 (2016) 196–206. https://doi.org/10.1016/j.meatsci.2016.06.012.

[27] N. Sharma, R. Sharma, Y. S. Rajput, et al., Separation methods for milk proteins on polyacrylamide gel electrophoresis: critical analysis and options for better resolution, Int. Dairy J. 114 (2021) 104920. https://doi.org/10.1016/j.idairyj.2020.104920.

[28] H. Liu, T. Hui, X. C. Zheng, et al., Characterization of key lipids for binding and generating aroma compounds in roasted mutton by UPLC-ESI-MS/MS and Orbitrap Exploris GC, Food Chem. 374 (2022) 131723. https://doi.org/10.1016/j.foodchem.2021.131723.

[29] L. Zhang, Y. Y. Hu, Y. Wang, et al., Evaluation of the flavor properties of cooked chicken drumsticks as affected by sugar smoking times using an electronic nose, electronic tongue, and HS-SPME/GC-MS, LWT-Food Sci. Technol. 140 (2021) 110764. https://doi.org/10.1016/j.lwt.2020.110764.

[30] S. Jinap, S. S. Iqbal, N. H. Talib, et al., Heterocyclic aromatic amines in deep fried lamb meat: the influence of spices marination and sensory quality, J. Food Sci. Technol. 53(3) (2015) 1411–1417. https://doi.org/10.1007/s13197-015-2137-0.

[31] C. Li, S. Al-Dalali, H. Zhou, et al., Influence of mixture of spices on phospholipid molecules during water-boiled salted duck processing based on shotgun lipidomics, Food Res. Int. 149 (2021) 110651. https://doi.org/10.1016/j.foodres.2021.110651.

[32] M. Kiralan, Volatile compounds of black cumin seeds (*Nigella sativa* L.) from microwave-heating and conventional roasting, J. Food Sci. 77(4) (2012) C481–C484. https://doi.org/10.1111/j.1750-3841.2012.02638.x.

[33] G. Benelli, R. Pavela, R. Petrelli, et al., Not just popular spices! Essential oils from *Cuminum cyminum* and *Pimpinella anisum* are toxic to insect pests and vectors without affecting non-target invertebrates, Ind. Crop. Prod. 124 (2018) 236–243. https://doi.org/10.1016/j.indcrop.2018.07.048.

[34] K. Tahri, C. Tiebe, N. El Bari, et al., Geographical provenience differentiation and adulteration detection of cumin by means of electronic sensing systems and SPME-GC-MS in combination with different chemometric approaches, Anal. Methods 8(42) (2016) 7638–7649. https://doi.org/10.1039/c6ay01906d.

[35] J. K. Ha, R. C. Lindsay, Mass spectra of butyl esters of volatile branched-chain and other fatty acids occurring in milkfat and meat lipids, J. Food Compos. Anal. 2(2) (1989) 118–131. https://doi.org/10.1016/0889-1575(89)90072-0.

[36] J. P. Xi, P. Zhan, H. L. Tian, et al. , Effect of spices on the formation of VOCs in roasted mutton based on GC-MS and principal component analysis, J. Food Quality (2019) 1–11. https://doi.org/10.1155/2019/8568920.

[37] C. Crews, L. Castle, A review of the occurrence, formation and analysis of furan in heat-processed foods, Trends Food Sci. Tech. 18(7) (2007) 365–372. https://doi.org/10.1016/j.tifs.2007.03.006.

[38] Y. J. Xu, D. Q. Zhang, H. Liu, et al., Comprehensive evaluation of volatile and nonvolatile compounds in oyster cuts of roasted lamb at different processing stages using traditional Nang roasting, Foods 10(7) (2021) 1508. https://doi.org/10.3390/foods10071508.

[39] B. Wang, H. J. Li, Z. B. Huang, et al., Dynamic changes in the qualities and heterocyclic aromatic amines of roasted pork induced by frying temperature and time, Meat Sci. 176 (2021) 108457. https://doi.org/10.1016/j.meatsci.2021.108457.

[40] A. Berardo, H. De Maere, D. A. Stavropoulou, et al., Effect of sodium ascorbate and sodium nitrite on protein and lipid oxidation in dry fermented sausages, Meat Sci. 121 (2016) 359–364. https://doi.org/10.1016/j.meatsci.2016.07.003.

[41] M. N. Lund, M. Heinonen, C. P. Baron, et al., Protein oxidation in muscle foods: a review, Mol. Nutr. Food Res. 55(1) (2011) 83–95. https://doi.org/10.1002/mnfr.201000453.

[42] Y. H. Zou, D. C. Kang, R. Liu, et al., Effects of ultrasonic assisted cooking on the chemical profiles of taste and flavor of spiced beef, Ultrason. Sonochem. 46 (2018) 36–45. https://doi.org/10.1016/j.ultsonch.2018.04.005.

[43] M. S. Madruga, J. S. Elmore, M. J. Oruna-Concha, et al., Determination of some water-soluble aroma precursors in goat meat and their enrolment on flavour profile of goat meat, Food Chem. 123(2) (2010) 513–520. https://doi.org/10.1016/j.foodchem.2010.04.004.

[44] A. Martinaud, Y. Mercier, P. Marinova, et al., Comparison of oxidative processes on myofibrillar proteins from beef during maturation and by different model oxidation systems, J. Agric. Food Chem. 45(7) (1997) 2481–2487. https://doi.org/10.1021/jf960977g.

[45] M. L. Bax, L. Aubry, C. Ferreira, et al., Cooking temperature is a key determinant of *in vitro* meat protein digestion rate: investigation of underlying mechanisms, J. Agric, Food Chem. 60(10) (2012) 2569–2576. https://doi.org/10.1021/jf205280y.

[46] V. Santé-Lhoutellier, T. Astruc, P. Marinova, et al., Effect of meat cooking on physicochemical state and *in vitro* digestibility of myofibrillar proteins, J. Agric. Food Chem. 56(4) (2008) 1488–1494. https://doi.org/10.1021/jf072999g.