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Characterization of non-volatile and volatile flavor profiles of *Coregonus peled* meat cooked by different methods

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ABSTRACT

This study investigated the effects of different cooking methods on non-volatile flavor (free amino acids, 5′-nucleotides, and organic acids, etc.) of *Coregonus peled* meat. The volatile flavor characteristics were also analyzed by electric nose and gas chromatography-ion migration spectrometry (GC-IMS). The results indicated that the content of flavor substances in *C. peled* meat varied significantly. The electronic tongue results indicated that the richness and umami aftertaste of roasting were significantly greater. The content of sweet free amino acids, 5′-nucleotides, and organic acids was also higher in roasting group. Electronic nose principal component analysis can distinguish *C. peled* meat cooked (the first two components accounted for 98.50% and 0.97%, respectively). A total of 36 volatile flavor compounds were identified among different groups, including 16 aldehydes, 7 olefine aldehydes, 6 alcohols, 4 ketones, and 3 furans. In general, roasting was recommended and gave more flavor substances in *C. peled* meat.

Introduction

Coregonus peled, a salmonid, is a typical cold-water fish that is heavily farmed in China. It has recently become popular as a new type of ready-to-eat raw fish with a pleasant taste (Fan et al., 2021; Guo et al., 2019). Modern life often leaves little time for cooking fish at home, and cooking without good culinary skills can result in fish dishes with less desirable flavor (Deng et al., 2019). To improve storage stability and convenience for consumers, precooked products with nutritional value and pleasant sensory characteristics have emerged in the modern food processing industry (Wang et al., 2020).

Flavor is a critical sensory property that varies with different thermal treatments for aquatic products. Generally, two types of flavor substances have been identified in cooked fish products: non-volatile flavor compounds (free amino acids, 5′-nucleotides, organic acids, inorganic ions) and volatile flavor compounds (aldehydes, alcohols, ketones, esters) (Yang et al., 2022; Zhang et al., 2019). Both are produced and accumulated through lipid oxidation, enzymatic reaction, protein hydrolysis, microbial degradation, and Maillard reactions during thermal processing (Luo et al., 2022). Changes in physicochemical indicators can promote formation and metabolism of flavor components and textural properties (Liang et al., 2022).

Boiling, steaming, roasting, and frying are commonly used cooking methods for fish products. However, different heating times, temperatures, and cooking methods have different impacts on flavor-binding ability. Previous studies have shown that boiling, steaming, and sous-vide cooking produced little lipid hydrolysis or oxidation in European sea bass meat (Nieva-Echevarría et al., 2017). Similar results were found in cooked turbot meat using different cooking methods; turbot meat underwent a series of chemical reactions including the Maillard reaction and lipid oxidation, accumulating volatile compounds such as ketones, alcohols, acids, hydrocarbons, and aldehydes. Compared to steaming,

Abbreviations: GC-MS, gas chromatograph-mass spectrometry; GC-IMS, gas chromatography-ion migration spectrometry; GC-O-MS, gas chromatograph-olfactometry-mass spectrometry; GMP, guanosine 5′-monophosphate; IMP, inosine 5′-monophosphate; AMP, adenosine 5′-monophosphate; FAAs, free amino acids; UPLC, ultra-performance liquid chromatography; ESI, electrospray ionization; SIM, selected-ion monitoring; HPLC, high-performance liquid chromatography; ICP-MS, Inductive Coupled Plasma Mass Spectrometer; RI, retention index; DT, drift time; LAV, laboratory analytical viewer; PCA, principal component analysis; TAV, taste active value; ND, not detected.

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frying and microwave heating significantly increased the number and proportion of characteristic compounds in cooked turbot, with more severe damage to fatty acids (Dong et al., 2018).

In recent years, the detection of food volatile flavor components has gained widespread attention in food industry. Gas chromatograph-mass spectrometry (GC–MS), gas chromatograph-olfactometry-mass spectrometry (GC-O-MS), two-dimensional gas chromatography, electronic nose, as well as gas chromatography -ion migration spectrometry (GC-IMS), etc. have been employed to analyze the flavor components in various types of foods (Wang, Chen, & Sun, 2020).

Compared with GC–MS, GC-IMS showed the great traits such as rapidness, high resolution and visualization through simple sample preparation, which has been employed in characterizing volatile flavor compounds of aquatic products prepared by different processing and storage conditions (Jin et al., 2021; Li et al., 2022).

Previous works have investigated the effect of super-chilling storage on shelf-life and quality indicators of *C. peled* muscle (Fan et al., 2021), flavor profile and microbial diversity of *C. peled*. caviar at different storage temperatures (Jiang et al., 2022). Wang et al (2020) studied the effects of different steaming conditions on quality characteristics of cooked *C. peled*, and found textural properties, cooking loss, color change, water holding capacity significantly correlated with the cooking condition. However, little information is available on the effects of different cooking methods on the flavor profiles of *C. peled*.

Herein, the objective of this study was to uncover the non-volatile flavor profiles (tastes, free amino acids, 5′-nucleotides, and organic acids, etc.) of *C. peled* cooked by different methods. Meantime, their volatile flavor profiles were also characterized by electric nose and GC-IMS methods. A whole information on flavor characteristics of *C. peled* cooked by different methods would be helpful for product development and quality control for precooked *C. peled* products in future.

Materials and methods

Materials and reagents

Fresh *C. peled* with a body weight of approximately 1–1.2 kg and a length of 38–42 cm (n = 30) was provided by Saihu Fishery Science and Technology Development Co., ltd. (Xinjiang Uygur Autonomous Region, China), who fished *C. peled* from Sailimu Lake, Xinjiang in September. *C. peled* were slaughtered and eviscerated, the scales and gills removed by the Saihu Fishery Science and Technology Development Co., ltd (Xinjiang Uygur Autonomous Region, China). After being washed with cold water, fish flesh was packed by vacuum and transported to the laboratory on ice by air transport.

Standards of guanosine 5′-monophosphate (GMP, purity ≥ 98 %), inosine 5′-monophosphate (IMP, purity ≥ 98 %), and adenosine 5′-monophosphate (AMP, purity ≥ 98 %) were purchased from Beijing Solarbio Science and Technology Co., ltd. (Beijing, China). 2, 4, 6-trimethylpridine (purity ≥ 98 %) was purchased from Shanghai Yuanye Biological Co., ltd. (Shanghai, China). Standard *n*-ketones (2-butanone, 2-pentanone, 2-hexanone, 2-heptanone, 2-octanone, and 2-nonanone, purity: 99 %) were bought from Sinopharm Chemical Reagent Co., ltd. (Beijing, China). All other reagents were analytical grade from premium suppliers.

Cooking treatments

Frozen *C. peled* was thawed at 4 °C for 12 h before the head, tail, and skin of the fish were removed. The dorsal muscle was removed and cut into 20 mm × 15 mm × 10 mm cuboids, and placed on ice in plastic wrap for further processing. The cuboids were randomly divided into six groups and subjected to different cooking methods, as described in previous studies (Wang et al., 2020; Zhao et al., 2021): (1) frying (A) at 190 ± 10 °C for 70 s; (2) roasting (B) at 190 ± 10 °C for 70 s; (3) steaming (C) at 100 °C for 4 min; (4) microwave heating (D) at 1700 W for 40 s; (5) sous-vide cooking (E) at 80 °C for 10 min; (6) air frying (F) at 180 °C for 10 min.

Preparation of taste extract

After cooling to room temperature, the treated samples were minced in a grinder (JYL-C010, Joyoung Co., Ltd., China). Approximately 100 g were mixed with 400 mL of ultrapure water and homogenized at 5000 rpm for 2 min with a homogenizer (T25, IKA Co., Germany). The supernatant (natural extract) was collected after centrifugation at 11,000 g for 20 min at 4 °C, and filtered to remove the lipid. This operation was repeated twice with the remaining precipitate. The supernatant was collected for later measurement. (Zhang et al., 2019).

Non-volatile taste compounds

Quantitation of electronic tongue measurement

The taste extracts were filtered through a 0.45-μm membrane and measured using an electronic tongue sensor system (TS-5000Z, Insent Inc., Japan). All sensors, including five lipid membrane sensors (bitterness, umami, saltiness, sourness, astringency) and three standard electrodes, were preconditioned in 0.01 M potassium chloride for 24 h. The test program referenced the method used by Pan et al. (2018), modifying it slightly. Each sample was measured six times.

Quantitation of free amino acids

Free amino acids(FAAs) was quantified using the method developed by Adeyeye (2009), with some modification. The natural extract (500 μL) was acid-hydrolyzed by adding 500 μL of 12 M HCl for 12 h. The hydrolysate (200 μL) was collected and mixed with 535 μL of 2 M NaOH to neutralize. The sample (10 μL) was mixed with 70 μL AccQ·Tag Ultra Borate Buffer and 20 μL AccQ·Tag Reagent. The reaction mixture was heated at 55 °C for 10 min, cooled, and loaded into the machine. The sample extracts were analyzed using a UPLC-Orbitrap-MS system (UPLC, Vanquish; MS, QE). The analytical conditions were: ultra-performance liquid chromatography(UPLC): column, Waters BEH C18 (50 mm × 2.1 mm, 1.7 μm); column temperature: 55 °C; flow rate: 0.5 mL/min; injection volume: 1 μL; solvent system: water (0.1 % formic acid), acetonitrile (0.1 % formic acid); gradient program: 95:5(v/v) at 0 min, 90:10 (v/v) at 5.5 min, 75:25 (v/v) at 7.5 min, 40:60 (v/v) at 8 min, 95:5 (v/v) at 8.5 min, 95:5 (v/v) at 13 min. HRMS data were recorded on a Q Exactive hybrid Q-Orbitrap mass spectrometer equipped with a heated electrospray ionization (ESI) source (Thermo Fisher Scientific) using selected-ion monitoring (SIM) acquisition methods. The ESI source parameters were: spray voltage: 3 kV; sheath gas pressure: 40 arb; aux gas pressure: 10 arb; sweep gas pressure: 0 arb; capillary temperature: 320 °C; aux gas heater temperature: 350 °C (Bao et al., 2018; Feng et al., 2016; Glauser et al., 2016; Marhabaie et al., 2014).

Quantitation of 5′-nucleotides analysis

The 5′-nucleotides(GMP, IMP, and AMP) were extracted and analyzed on a HPLC system (UltiMate 3000, Thermo Fisher Scientific Co., Ltd., Massachusetts, USA), according to the method modified from Wen et al. (2020). A chromatographic column (Acclaim PolarAdvantage II C18, 50 mm × 4.6 mm, 3 μm) with mobile phase A of methanol and mobile phase B of 20 mM KH_2PO_4-K_2HPO_4 buffer solution (v/v = 1:1, pH = 5.8). The sample was eluted at a flow rate of 1 mL/min with 0 % A and 100 % B for 0–6 min, 8 % A and 92 % B for 7–14 min, 35 % A and 65 % B for 15–20 min, and 0 % A and 100 % B for 21–23 min.

Quantitation of organic acids

The Succinic acid and lactic acid contents of the taste extracts were analyzed by high-performance liquid chromatography (HPLC, UltiMate 3000, Thermo Fisher Scientific Co., ltd., Massachusetts, USA) using a chromatographic column (Acclaim Polar Advantage II C18, 50 mm × 4.6 mm, 3 μm) with a mobile phase of Na_2SO_4 buffer solution (pH 2.5

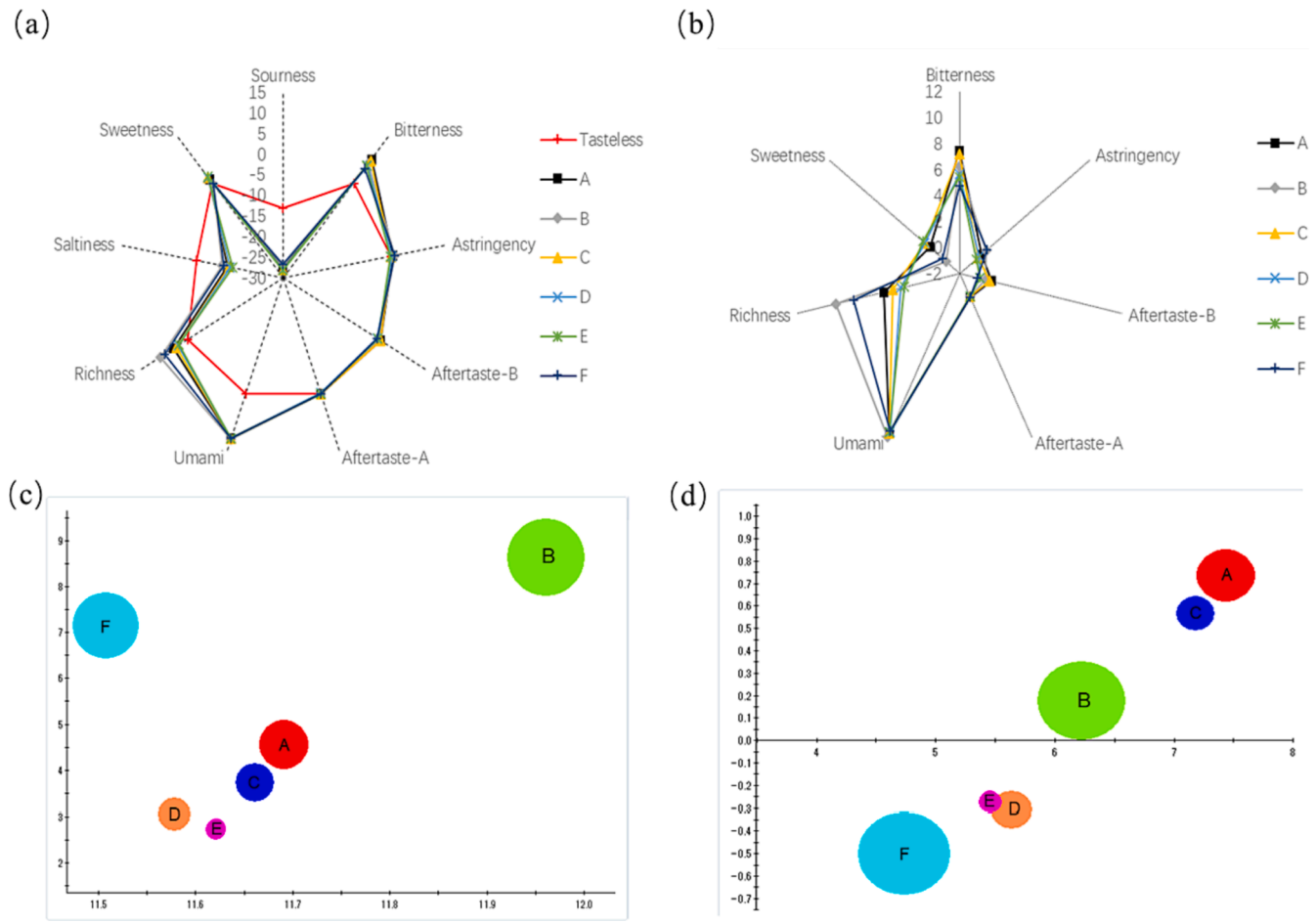

Fig. 1. Radar plots (a, b) and bubble plots (c, d) of electronic tongue measurement for *C. peled* meat cooked by different methods. The cooking methods A, B, C, D, E, and F stand for frying, roasting, steaming, microwave heating, sous-vide cooking, and air frying, respectively (a, b, c, d). Aftertaste A and B represent bitterness and umami, respectively (a, b).

modulated by mesylate) without gradient elution (Jing et al., 2022). The flow rate was 1 mL/min with 10-μL injection. The absorption was detected at 214 nm.

Quantitation of inorganic ion analysis

The contents of sodium (Na^+), potassium (K^+), phosphate (PO_4^{3-}), and chlorine (Cl^-) were determined using an inductive coupled plasma mass spectrometer (ICP-MS, Thermo Fisher Scientific Co., ltd., Massachusetts, USA) and the method used by Wen et al. (2020). The ICP-MS was equipped with a detector (DS5 defection stabilizer), a suppressor (AERS500), and an anion exchange column (AS14). The mobile phase was an Na_2CO_3/$NaHCO_3$ mixed buffer (0.25 mol/L) with a 0.5 mL/min flow rate at room temperature to detect the 25-μL injection.

Volatile flavor analysis

Quantitation of electronic nose analysis

The volatile compounds of the six types of *C. peled* were determined using an electronic nose system (PEN3.0, AIRSENSE, Germany) equipped with ten types of sensors. Each cooked *C. peled* sample (1 g) was placed in a 10-ml glass injection bottle and equilibrated at room temperature for 15 min. The sensor cleaning time was 60 s; the auto-zero-time was 10 s; the sample preparation time was 5 s; the detection time was 60 s; the period between 54 s and 56 s, which exhibited a stable response curve, was used for data analysis (Ma et al., 2021).

Quantitation of gas chromatography-ion mobility spectrometry analysis

The volatile compounds in *C. peled* were determined by GC-IMS (FlavourSpec®, Gesellschaft für Analytische Sensorsysteme mbH [G.A. S.], Dortmund, Germany) and the method used by Jin et al. (2021), with slight modification. Thermal *C. peled* sample (2 g) was placed in 20-mL headspace bottles and implanted (500 μL) using a high-temperature injector (85 °C) maintained at 60 °C for 20 min with an incubation speed of 500 rpm. An unbranched procedure was used. The samples were driven by high-purity nitrogen into a chromatographic column (MXT-5, 15 m,0.53 mm ID,1.0 μm df, Restek Corporation, USA) maintained at 60 ℃. The 99.99 % nitrogen gas was used as a vehicle at a programmed speed as follows: 2 mL/min for 2 min, 10 mL/min for 8 min, 100 mL/min for 10 min, and 150 mL/min for 5 min. The mixture gas was ionized in the IMS ionization cell. To prevent cross-pollution, the injector was compulsorily planed 30 s before each assay and 5 min after each assay. The *n*-ketones C4–C9 were used as foreign standards to estimate the retention index (RI) of each volatile chemical. Via collations of RI and the drift time (DT) through the instrumental database (FlavourSpec®, Germany), the volatile flavor substances were compared with standard chemicals in terms of DT and RI. The signal intensity denoted the height or the peak area.

Statistical analysis

The data were expressed as mean ± standard deviation ($n \geq 3$), and a *t*-test was used for significance analysis ($P < 0.05$). Radar and bubble plots were plotted from a plug-in program using electric tongue device.

Table 1
Composition and contents of non-volatile taste compounds in *C. peled* meat cooked by different methods (mg/100 g).

Component	A	B	C	D	E	F
Lactic acid	127.83 ± 3.02b	167.70 ± 2.64a	98.82 ± 1.40e	114.71 ± 1.75c	108.42 ± 1.01d	126.91 ± 1.27b
Succinic acid	1.46 ± 0.01b	2.04 ± 0.07a	0.81 ± 0.02d	1.04 ± 0.03c	0.85 ± 0.01d	1.05 ± 0.01c
IMP	78.72 ± 0.58b	104.10 ± 1.46a	76.41 ± 0.25c	52.60 ± 0.05d	48.42 ± 1.19e	102.70 ± 0.08a
GMP	ND	ND	ND	27.03 ± 0.07a	27.07 ± 0.53a	ND
AMP	0.96 ± 0.01b	0.69 ± 0.02d	0.88c	0.27e	0.93 ± 0.02b	1.37a
Aspartic acid	1.12 ± 0.01b	1.34 ± 0.00a	0.33 ± 0.03e	0.54 ± 0.03d	0.23 ± 0.03f	1.04 ± 0.02c
Glutamic acid	1.09 ± 0.02a	0.93 ± 0.30a	0.38 ± 0.06b	1.01 ± 0.06a	0.26 ± 0.03b	1.24 ± 0.02a
Serine	54.95 ± 0.54b	82.69 ± 0.30a	24.50 ± 1.99e	26.76 ± 0.58d	19.78 ± 0.28f	48.81 ± 0.14c
Glycine	284.20 ± 0.36b	376.05 ± 2.59a	127.11 ± 4.39e	159.68 ± 1.31d	96.18 ± 0.57f	275.98 ± 0.57c
Threonine	32.86 ± 0.27b	46.76 ± 0.20a	14.07 ± 1.26e	16.37 ± 0.38d	12.31 ± 0.15f	28.87 ± 0.53c
Alanine	154.26 ± 0.38b	164.88 ± 0.02a	60.96 ± 7.29e	82.44 ± 0.41d	47.57 ± 0.07f	144.82 ± 0.38c
Histidine	125.12 ± 0.10b	167.04 ± 1.59a	51.70 ± 2.03e	63.54 ± 0.53d	53.28 ± 0.56e	105.18 ± 1.28c
Tyrosine	9.44 ± 0.54b	11.68 ± 0.06a	4.06 ± 0.20e	5.24 ± 0.07d	3.70 ± 0.01e	8.31 ± 0.03c
Leucine	12.90 ± 0.03b	13.80 ± 0.15a	5.27 ± 0.54e	6.88 ± 0.14d	4.22 ± 0.02f	12.01 ± 0.09c
Phenylalanine	6.96 ± 0.06b	9.18 ± 0.01a	3.17 ± 0.23e	4.15 ± 0.01d	2.87 ± 0.02f	6.33 ± 0.06c
Tryptophan	2.60 ± 0.21b	2.90 ± 0.09a	1.08 ± 0.12e	1.44 ± 0.00d	0.97 ± 0.02e	1.94 ± 0.01c
Isoleucine	7.31 ± 0.02a	7.55 ± 0.06a	3.04 ± 0.28d	3.84 ± 0.04c	2.31 ± 0.02e	6.73 ± 0.02b
Arginine	8.17 ± 0.28b	9.90 ± 0.07a	2.71 ± 0.23e	3.53 ± 0.03d	0.88 ± 0.22f	6.31 ± 0.50c
Proline	24.05 ± 0.17b	36.10 ± 0.20a	9.63 ± 1.05e	10.81 ± 0.29d	7.10 ± 0.09f	20.64 ± 0.03c
Lysine	9.97 ± 0.18a	8.00 ± 0.10b	3.25 ± 0.23e	4.12 ± 0.02d	1.78 ± 0.16f	7.01 ± 0.02c
Methionine	7.70 ± 0.06b	10.43 ± 0.19a	3.13 ± 0.28e	4.14 ± 0.11d	2.25 ± 0.04f	6.98 ± 0.07c
Valine	11.89 ± 0.14b	13.69 ± 0.17a	4.63 ± 0.62e	5.95 ± 0.21d	3.68 ± 0.03f	10.92 ± 0.02c
4-Hydroxy-L-Proline	1.83 ± 0.02a	1.85 ± 0.06a	0.68 ± 0.08d	0.95 ± 0.03c	0.47 ± 0.01e	1.51 ± 0.01b
Gamma-Aminobutyric acid	1.48 ± 0.00b	1.78 ± 0.01a	0.53 ± 0.04e	0.65 ± 0.02d	0.34 ± 0.00f	1.22 ± 0.00c
Cystine	ND	ND	ND	ND	ND	ND
Asparagine	4.00 ± 0.00a	3.45 ± 0.06b	1.65 ± 0.12e	0.92 ± 0.04f	1.93 ± 0.02d	2.86 ± 0.02c
Glutamine	37.75 ± 0.30a	25.87 ± 0.20c	14.15 ± 1.23f	22.56 ± 0.67d	16.78 ± 0.32e	35.92 ± 0.61b
Na^+	35.72 ± 3.20b	62.81 ± 2.94a	25.68 ± 2.37de	30.41 ± 0.34 cd	22.84 ± 0.37e	34.81 ± 0.50bc
Cl^-	610.81 ± 13.60c	903.68 ± 5.28a	487.52 ± 35.40e	584.68 ± 13.92 cd	540.96 ± 12.51d	681.72 ± 22.22b
K^+	37.29 ± 0.95b	61.27 ± 1.85a	30.33 ± 4.30c	37.97 ± 4.38b	23.86 ± 0.82c	41.80 ± 1.23b
PO_4^{3-}	598.83 ± 3.48c	1029.27 ± 18.01a	633.17 ± 29.10c	732.81 ± 20.50b	799.50 ± 16.04b	1038.38 ± 49.70a

A plug-in principal component analysis (PCA) and radar plots were acquired from electric nose system. The GC-IMS data and plot were obtained through GC × IMS Library Search, Laboratory Analytical Viewer (LAV), and gallery fingerprint plot for all volatile compounds identified between samples (Li et al., 2019).

Table 2
Taste thresholds and taste active values of non-volatile taste compounds in *C. peled* meat *cooked by different methods.*

Component	Taste threshold mg/100 mL	A	B	C	D	E	F
Lactic acid	67.55	1.89 ± 0.04b	2.48 ± 0.04a	1.46 ± 0.02e	1.70 ± 0.03c	1.60 ± 0.01d	1.88 ± 0.02b
Succinic acid	10.63	0.14b	0.19 ± 0.01a	<0.10	0.1c	<0.10	0.1c
IMP	23.53	3.35 ± 0.02b	4.42 ± 0.06a	3.25 ± 0.01c	2.24d	2.06 ± 0.05e	4.36a
GMP	8.14	ND	ND	ND	3.32 ± 0.01a	3.33 ± 0.07a	ND
AMP	86.80	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Aspartic acid	53.24	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Glutamic acid	16.18	2.34 ± 0.02a	1.60 ± 0.01c	0.88 ± 0.08f	1.39 ± 0.04d	1.04 ± 0.02e	2.22 ± 0.04b
Serine	262.75	0.21 ± 0.00b	0.32 ± 0.01a	0.10 ± 0.01d	0.10d	0.08 ± 0.01e	0.19c
Glycine	187.75	1.52 ± 0.01b	2.00 ± 0.01a	0.68 ± 0.02e	0.86 ± 0.01d	0.51 ± 0.00f	1.47 ± 0.00c
Threonine	416.85	<0.10	0.11a	<0.10	<0.10	<0.10	<0.10
Alanine	106.92	1.45 ± 0.01b	1.54 ± 0.00a	0.57 ± 0.07e	0.77 ± 0.00d	0.45 ± 0.01f	1.36 ± 0.01c
Histidine	20.00	6.25 ± 0.01b	8.36 ± 0.08a	2.59 ± 0.11e	3.18 ± 0.03d	2.66 ± 0.03e	5.26 ± 0.06c
Tyrosine	72.44	0.14 ± 0.01b	0.16 ± 0.00a	<0.10	<0.10	<0.10	0.12 ± 0.01c
Leucine	144.32	<0.10	0.10 ± 0.01a	<0.10	<0.10	<0.10	<0.10
Phenylalanine	743.40	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Tryptophan	102.12	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Isoleucine	131.20	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Arginine	1306.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Proline	287.75	<0.10	0.13 ± 0.01a	<0.10	<0.10	<0.10	<0.10
Lysine	1169.60	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Methionine	74.60	0.10b	0.14a	<0.10	<0.10	<0.10	<0.10
Valine	351.45	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
4-Hydroxy-L-Proline	327.825	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Gamma-Aminobutyric acid	0.2062	7.19 ± 0.02b	8.63 ± 0.06a	2.55 ± 0.20e	3.16 ± 0.12d	1.66 ± 0.01f	5.91 ± 0.02c
Cystine	24.22	ND	ND	ND	ND	ND	ND
Asparagine	660.60	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Glutamine	730.75	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Na^+	8.97	3.98 ± 0.36b	7.00 ± 0.33a	2.86 ± 0.26de	3.39 ± 0.04 cd	2.55 ± 0.04e	3.88 ± 0.06bc
Cl^-	50.83	12.02 ± 0.27c	17.78 ± 0.10a	9.59 ± 0.70e	11.50 ± 0.27 cd	10.64 ± 0.25d	13.41 ± 0.44b
K^+	13.85	2.69 ± 0.07b	4.42 ± 0.13a	2.19 ± 0.31c	2.74 ± 0.32b	1.72 ± 0.06c	3.02 ± 0.09b
PO_4^{3-}	142.46	4.20 ± 0.02c	7.23 ± 0.13a	4.44 ± 0.20c	5.14 ± 0.14b	5.61 ± 0.11b	7.29 ± 0.35a

Results and discussion

Non-volatile compounds of taste extracts

Electronic tongue measurement of taste extracts

The effect of different cooking methods on the six basic tastes and three aftertastes of *C. peled* meat was investigated. As shown in Fig. 1a, the sourness and saltiness were lower than tasteless (reference solution) and the other taste indicators. Based on previous information, richness, bitterness, and sweetness were three significantly different taste indicators in the effective radar plot (Fig. 1b) with slight modification (without sourness and saltiness). The umami taste was another major taste indicator; the samples did not exhibit considerable differences. To determine the difference between major and minor taste indicators, a bubble plot (Fig. 1c) of umami, saltiness, and richness and a bubble plot (Fig. 1d) of bitterness, bitterness aftertaste, and astringent are presented. The umami value is large, but the difference is small. Between 11.5 and 12, the difference for richness (and umami aftertaste) is large: roasting (group B) is slightly larger than group F (air frying) and significantly larger than the other four cooking groups. The difference for bitter taste is also obvious; frying (A) and steaming (C) are significantly larger than other cooking groups. These results showed that taste profiles of *C. peled* meat cooked by different methods varied to some extent, and the specific taste compounds that induced taste changes in *C. peled* meat samples after cooking deserve further exploration.

Analysis of free amino acid content in taste extracts

The free amino acids (FAAs) produced by the protein in fish meat after heat treatment were important precursors for the characteristic flavor of *C. peled* meat. There were 21 FAAs detected in *C. peled* meat of the six cooking methods investigated. They showed some differences between them; 19 amino acids were common and two were uncommon (Table 1). Cystine was not detected in *C. peled* meat. The two uncommon amino acids were 4-hydroxy-l-proline and gamma-aminobutyric acid. The contents of histidine, alanine, and glycine were higher in each cooking group, indicating that these three amino acids were the main flavor substances in *C. peled* meat. Their contents were highest in roasting group(B) and lowest in steaming (C) ($P < 0.05$), indicating that roasting treatment is more conducive to release of flavor substances in *C. peled* meat.

Most FAAs can be categorized as umami, sweet, or bitter amino acids (Chen et al., 2022). Of the six cooked *C. peled* meat samples, the total sweet amino acids were the most prevalent, followed by bitter amino acids, and the umami amino acid contents were the lowest (Table 1). The bitter amino acid histidine, which has a low threshold, has a meaty and sweet flavor, and contributes more to the flavor of *C. peled* meat, which was strongly related to the type of heat treatment. The other bitter amino acids contributed little to the flavor due to their high thresholds. The sweet amino acids glycine and alanine had higher taste active value (TAV) with roasting treatment (group B), demonstrating that roasting treatment facilitates expression of sweet substances. The TAV of the umami glutamic acid was > 1, which contributed to the umani aroma and had a positive effect on heat-treated *C. peled* meat. The contents and contributions of flavor substances were significantly different in *C. peled* meat with different cooking methods. The *C. peled* meat in the roasting treatment (group B) exhibited a more pleasant flavor, while fewer positive taste substances were exhibited in steaming group of *C. peled* meat.

Different amino acids have different taste thresholds. Thus, the content of FAAs cannot be used to evaluate their contribution to the flavor of *C. peled* meat. Generally, TAV values are used to evaluate the contribution of amino acids to taste. TAV > 1 indicates that the substance contributes to the taste (Chen et al., 2014). As shown in Table 2, the TAV values of histidine and gamma-aminobutyric acid were > 1. Meantime, the TAV values of histidine and gamma-aminobutyric acid reached 2.59–8.36 and 1.66–8.63, respectively. After treatment with frying (group A), roasting (group B), and air frying (group F), the TAV values of glycine and alanine were > 1. The TAV values of glutamic acid were > 1 in all cooked *C. peled* meat samples except steaming. The TAV values of all amino acids except glutamic acid were significantly higher with roasting (group B) treatment than with other cooking treatments.

Data are expressed as mean ± standard error. Different letters in the same row indicate significant differences between groups ($P < 0.05$). The cooking methods A, B, C, D, E, and F stand for frying, roasting, steaming, microwave heating, sous-vide cooking, and air frying, respectively. ND: not detected, Na^+: sodium, K^+: potassium, PO_4^{3-}: phosphate, Cl^-: chlorine, AMP: adenosine 5′-monophosphate, GMP: guanosine 5′ -monophosphate, IMP: inosine 5′-monophosphate.

Data are expressed as mean ± standard error. Different letters in the same row indicate significant differences between groups ($P < 0.05$). The cooking methods A, B, C, D, E, and F stand for frying, roasting, steaming, microwave heating, sous-vide cooking, and air frying, respectively.

Threshold data were from ChemTastes database (https://zenodo.org/record/5747393#.%20YwR3gu5BxPY).

Analysis of 5′-nucleotides in taste extracts

Table 1 and Table 2 also showed the taste profile of 5′-nucleotides (GMP, IMP, and AM) in taste extracts from cooked *C. peled* meat. The highest IMP content is found in 5′-nucleotide after different cooking treatments, compared to GMP and AMP. TAV of IMP are > 2. The contents of IMP in *C. peled* meat after roasting and air frying are the highest, reaching 4.42 and 4.36, respectively, indicating that umami taste was enhanced, consistent with the electronic tongue results (Fig. 1a,b). GMP was only detected in *C. peled* meat after microwave heating and sous-vide cooking, but not detected in the other four cooking groups. Umami plays an important role in food texture and can be obtained with the presence of glutamate and enhanced by addition of IMP and GMP (Chew et al., 2017). As an umami enhancer, IMP plays an important role in food taste (Rocha et al., 2020). AMP and GMP may interact with FAAs to enhance taste (Yamaguchi et al., 2013). The present results found that the effect of cooking method on 5′-nucleotides was significant. GMP is only present within *C. peled* meat after microwave heating and low temperature slow cooking. IMP and GMP were the taste-active compound in *C. peled* meat. A similar study about the effect of IMP and AMP on taste of Chinese mitten crab meat and shrimp meat was also reported by Chen & Zhang (2007).

Analysis of organic acids in taste extracts

In Table 1 and Table 2, both succinic acid and lactic acid were detected in *C. peled* meat after various cooking methods, and the content of lactic acid in *C. peled* meat after all cooking treatmenst exceeds its threshold value. The lactic acid content in *C. peled* meat after roasting is the highest, and has a TAV of 2.48, exhibiting an important contribution to taste. The present results showed that the effect of cooking methods on lactic acid was obvious, and it seemed that higher temperatures produce a higher lactic acid content. The content of succinic acid was well below the threshold, and did not contribute to taste. Zhang, Ma, & Dai (2019) found some organic acids like tartaric acid, malic acid, lactic acid, and succinic acid could be detected in cooked tuna samples, and tartaric acid and lactic acid were dominant organic acids. The present study investigated lactic acid, and succinic acid in *C. peled* meat after various cooking methods, and lactate is a potential taste factor of organic acids in cooked *C. peled* meat.

Analysis of inorganic ions in taste extracts

Some inorganic ions may enhance the flavor and taste of food products (Jiang, McPhedran, Hou, Chen, & Huang, 2023). In Table 1 and Table 2, inorganic ions (Na^+, K^+, PO_4^{3-}, Cl^-) were detected in *C. peled* meat after various cooking methods, are significantly higher in roasting group than in the other five cooking treatments; the values of these inorganic ions in *C. peled* meat after steaming and sous-vide cooking are significantly lower, probably because the two cooking treatments

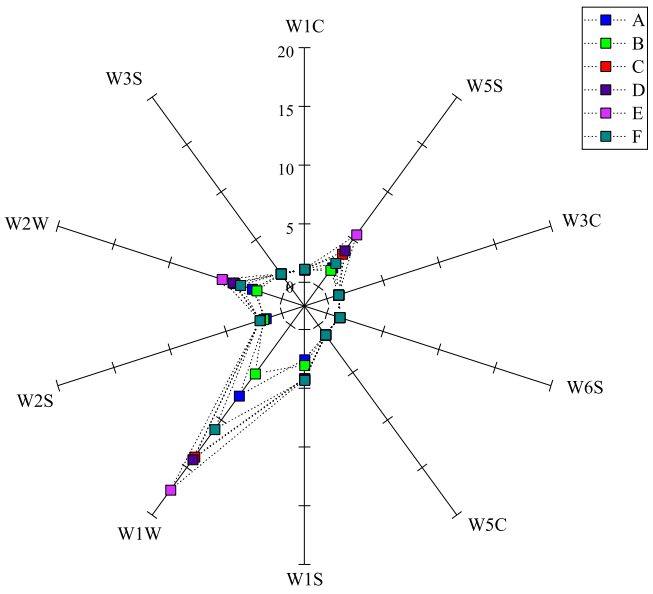

Fig. 2. Radar plot of electronic nose analysis of *C. peled* meat cooked by different methods. A, B, C, D, E, and F stand for frying, roasting, steaming, microwave heating, sous-vide cooking, and air frying, respectively. **Note**: W1C: aromatics; W5S: nitrogen oxides; W3C: ammonia and aromatic components; W6S: hydride; W5C: olefins and aromatic molecules; W1S: methane; W1W: sulfides; W2S: ethanol and some aromatics; W2W: organic sulfides: W3S: alkanes and aliphatics.

contained more water, resulting in a relatively low inorganic ion content in *C. peled*.

Volatile flavor compounds

Electronic nose analysis of cooked C. peled meat

An electronic nose was used to analyze volatile flavor compounds in *C. peled* meat with different cooking treatments. The sensor signal intensities of volatile flavor compounds with different treatments are plotted in Fig. 2. *C. peled* meat samples produced almost no response in sensors W1C, W3C, W6S, W5C, and W3S, demonstrating that benzenes, ammonia, hydrides, short-chain alkanes, and long-chain alkanes were poorly represented and did not differ significantly among different cooking condition. For the W1S and W2S sensors, the response value for fish samples was not high, but there were differences between different cooked samples, indicating that different processing methods had an impact on the content of flavor substances in *C. peled* meat after cooking. *C. peled* meat samples had higher response values at W5S, W1W, and W2W; these three sensors can distinguish *C. peled* meat samples with different cooking treatments. Sous-vide cooking (group E) had the highest response value, followed by microwave heat (group D); roasting (group B) had the lowest value, indicating that the content of nitrogen oxides, inorganic sulfides, and organic sulfides was higher with sous-vide cooking treatment, and that roasting treatment was not conducive to formation of these substances. The PCA score plot result was displayed in Fig. 3, and PC1 and PC2 accounted for 98.50 % and 0.97 %, respectively. The cumulative contribution rate reached 99.47 %, indicating that the information contained in the first two principal components can better represent the overall data. Flavor substances produced in *C. peled* meat samples with different cooking treatments clustered together in one area with no obvious overlap, except for steaming (groups C) and microwave heating (group D), showing that the two cooked methods possessed certain similarity. These flavor characteristics of *C. peled* meat samples differ from each other, mainly caused by cooking state and conditions (Fedorov et al., 2021). Overall, electronic nose coupled with PCA can better distinguish flavor substances in *C. peled* meat after different cooking treatments.

Gas chromatography-ion mobility spectrometry analysis of cooked C. peled meat

GC-IMS technology was used to identify the volatile organic compounds in the *C. peled* meat. Fig. 4(a) presents a three-dimensional graph. It is observed that the volatile organic compounds in *C. peled* meat cooked by different methods were generally similar, with subtle differences. In the three-dimensional graph, the difference is difficult to distinguish with the naked eye. Thus, the three-dimensional graph was converted to a two-dimensional graph (Fig. 4(b)) to see the difference between the types and contents of volatile flavor substances with different treatments more clearly (Cui et al., 2020). Fig. 4(c) uses frying sample (A) as the reference; the other five cooked samples are the deducted reference spectra. After deduction, the background is white.

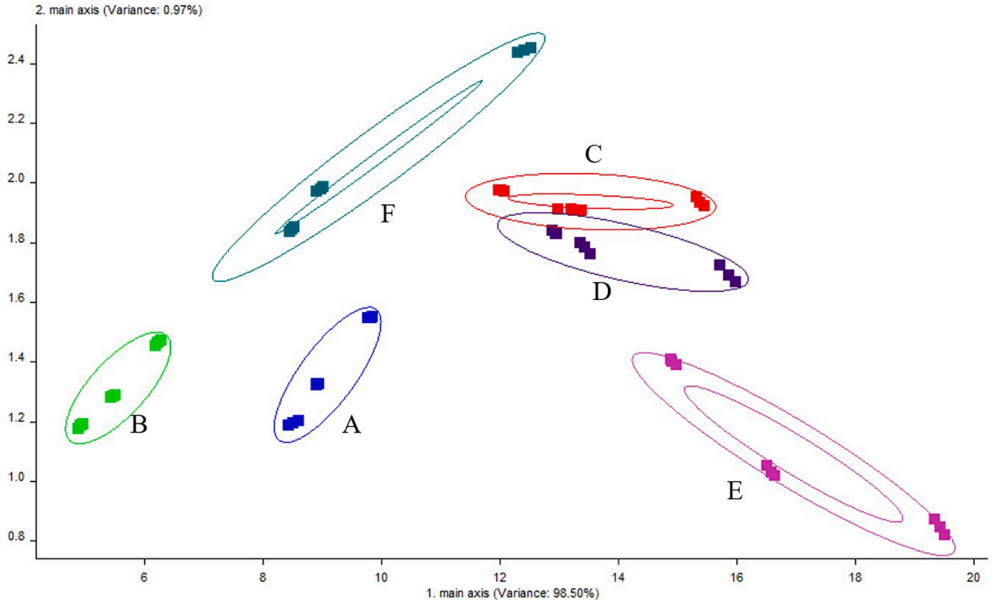

Fig. 3. PCA score plot of electronic nose analysis of *C. peled* meat cooked by different methods. The groups A, B, C, D, E, and F stand for frying, roasting, steaming, microwave heating, sous-vide cooking, and air frying, respectively.

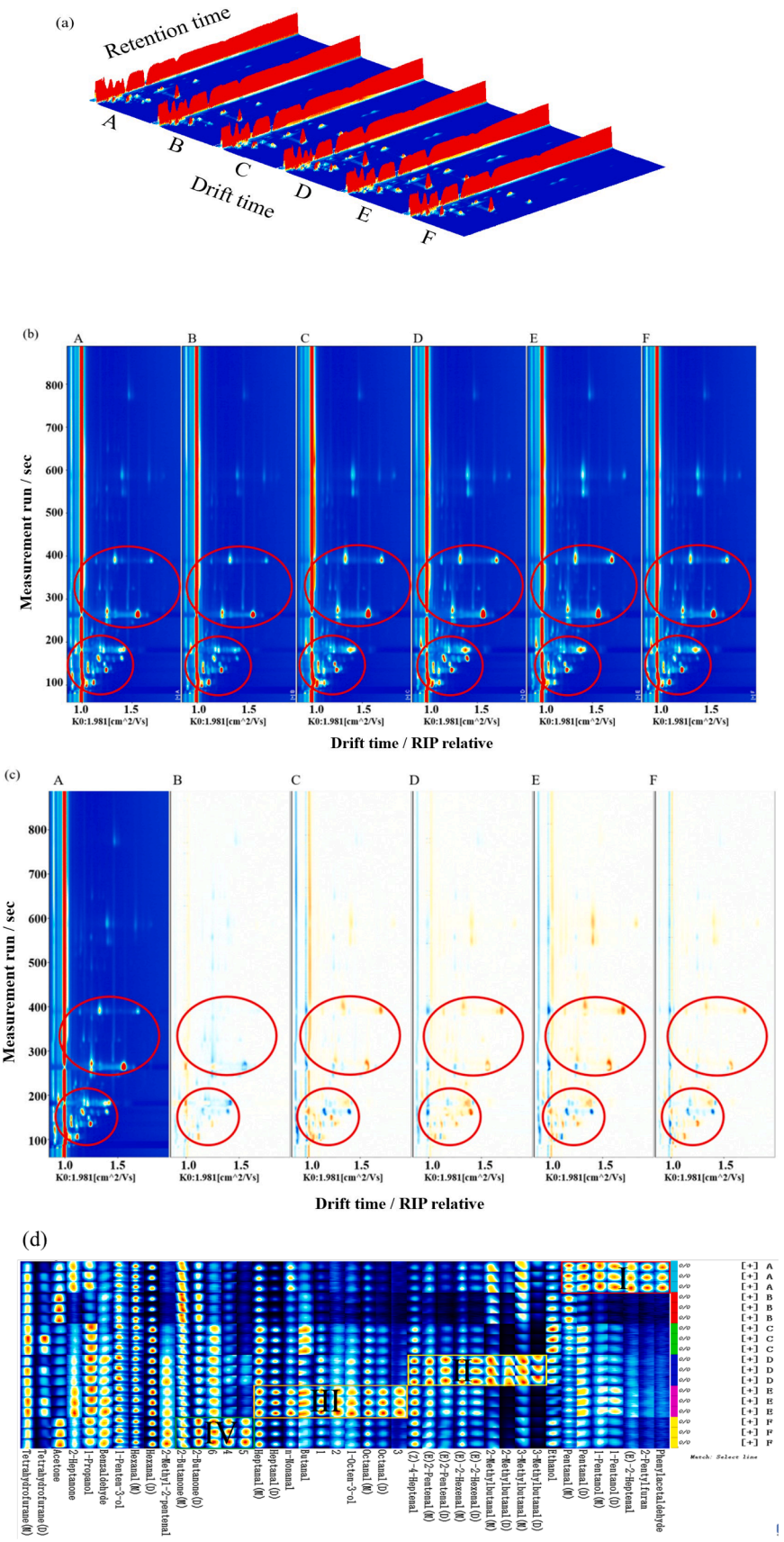

Fig. 4. 3D-topographic plots (a), 2D-topographic plots (b: vertical view; c: difference view), and gallery plot (fingerprint, d) of characteristic volatile organic compounds in *C. peled* meat cooked by different methods.

Table 3
Key volatile compounds in *C. peled* meat with different cooking methods detected by GC-IMS.

Classification	Compound	Rt [*sec*]	Dt [a. u.]	RI	Odor description	Relative amount/%					
						A	B	C	D	E	F
aldehydes	*n*-Nonanal	772.44	1.47252	1104.1	fat, citrus, green	1.57 ± 0.03a	1.07 ± 0.03b	1.06 ± 0.01b	0.88 ± 0.06c	1.50 ± 0.10a	1.12 ± 0.03b
	Octanal(M)	590.886	1.40877	1013.7	fat, soap, lemon, green	3.61 ± 0.03d	3.14 ± 0.16e	5.03 ± 0.06b	4.94 ± 0.08b	6.46 ± 0.10a	4.70 ± 0.11c
	Octanal(D)	585.521	1.82116	1010.6	fat, soap, lemon, green	0.37 ± 0.02c	0.28 ± 0.06d	0.61 ± 0.02b	0.62 ± 0.02b	1.09 ± 0.06a	0.59 ± 0.02b
	Benzaldehyde	528.041	1.15726	980.7	almond, burnt sugar	0.42 ± 0.04b	0.63 ± 0.08a	0.42 ± 0.08b	0.56 ± 0.05a	0.59 ± 0.06a	0.67 ± 0.04a
	Heptanal(M)	391.701	1.33588	903.7	fat, citrus, rancid	6.26 ± 0.10e	6.81 ± 0.12d	8.19 ± 0.08a	7.11 ± 0.06c	7.88 ± 0.16b	7.25 ± 0.04c
	Heptanal(D)	394.965	1.69303	905.8	fat, citrus, rancid	2.48 ± 0.10e	2.38 ± 0.06e	5.57 ± 0.02b	5.36 ± 0.04c	7.72 ± 0.05a	4.82 ± 0.16d
	Hexanal(M)	263.769	1.26028	792.7	grass, tallow, fat	9.63 ± 0.17b	10.88 ± 0.09a	8.73 ± 0.17c	7.22 ± 0.09e	7.00 ± 0.25e	7.71 ± 0.15d
	Hexanal(D)	262.065	1.56495	790.8	grass, tallow, fat	21.22 ± 0.10c	17.91 ± 0.25d	24.85 ± 0.48a	21.90 ± 0.06b	24.85 ± 0.43a	21.80 ± 0.04b
	Pentanal(M)	184.23	1.18731	692.4	almond, malt, pungent	2.47 ± 0.06b	2.86 ± 0.02a	1.51 ± 0.01c	1.04 ± 0.03e	1.08 ± 0.00e	1.21 ± 0.04d
	Pentanal(D)	183.106	1.42591	690.7	almond, malt, pungent	3.53 ± 0.04a	1.69 ± 0.06e	2.58 ± 0.04b	2.15 ± 0.01c	2.63 ± 0.05b	2.05 ± 0.07d
	2-Methylbutanal(M)	169.04	1.16656	660.3	cocoa, almond	2.13 ± 0.05a	1.79 ± 0.03c	0.70 ± 0.02e	1.91 ± 0.02b	0.68 ± 0.01e	1.06 ± 0.03d
	2-Methylbutanal(D)	167.242	1.40448	656.1	cocoa, almond	1.14 ± 0.03b	0.51 ± 0.01c	0.10 ± 0.01e	2.14 ± 0.11a	0.11 ± 0.00e	0.23 ± 0.02d
	3-Methylbutanal(M)	158.853	1.18228	636.1	malt	2.68 ± 0.07a	2.52 ± 0.07b	0.95 ± 0.04d	2.44 ± 0.05b	1.03 ± 0.02d	1.42 ± 0.01c
	3-Methylbutanal(D)	159.452	1.40762	637.5	malt	1.32 ± 0.08b	0.75 ± 0.02c	0.15 ± 0.02e	2.75 ± 0.14a	0.16 ± 0.01e	0.30 ± 0.01d
	Butanal	138.744	1.29222	583.3	pungent, green	0.41 ± 0.01e	0.55 ± 0.01c	0.67 ± 0.02a	0.37 ± 0.02f	0.58 ± 0.01b	0.48 ± 0.01d
	Phenylacetaldehyde	652.164	1.26254	1047	hawthorne, honey, sweet	0.41 ± 0.04a	0.12 ± 0.02b	0.12 ± 0.02b	0.13 ± 0.02b	0.13 ± 0.01b	0.12 ± 0.01b
				subtotal		59.63 ± 0.56c	53.89 ± 0.19e	61.25 ± 0.67b	61.52 ± 0.28b	63.49 ± 0.58a	55.52 ± 0.03d
olefine aldehyde	(E)-2-Heptenal	493.974	1.25547	963.5	soap, fat, almond	0.40 ± 0.03a	0.13 ± 0.02d	0.14 ± 0.01 cd	0.17 ± 0.02bc	0.20 ± 0.01b	0.17 ± 0.02bc
	(E)-2-Hexenal(M)	327.215	1.17772	853.8	apple, green	1.18 ± 0.01b	0.67 ± 0.03e	0.89 ± 0.02d	1.39 ± 0.03a	1.05 ± 0.05c	1.15 ± 0.01b
	(E)-2-Hexenal(D)	326.363	1.51611	853.1	apple, green	0.21 ± 0.01c	0.08 ± 0.02e	0.18 ± 0.01d	0.38 ± 0.01a	0.25 ± 0.01b	0.22 ± 0.03bc
	(E)2-Pentenal(M)	228.052	1.10605	751.9	strawberry, fruit, tomato	0.85 ± 0.02b	0.48 ± 0.02d	0.74 ± 0.01c	1.15 ± 0.02a	0.87 ± 0.02b	0.86 ± 0.04b
	(E)2-Pentenal(D)	227.153	1.36108	750.8	strawberry, fruit, tomato	0.19 ± 0.01c	0.09 ± 0.01d	0.19 ± 0.02c	0.49 ± 0.02a	0.30 ± 0.03b	0.27 ± 0.03b
	(Z)-4-Heptenal	388.852	1.15067	901.8	biscuit, cream	0.94 ± 0.05e	1.10 ± 0.01d	1.46 ± 0.04c	1.67 ± 0.01ab	1.72 ± 0.04a	1.62 ± 0.02b
	2-Methyl-2-pentenal	300.369	1.16082	829.5		0.12 ± 0.01d	0.12 ± 0.02d	0.15 ± 0.01c	0.20 ± 0.01b	0.17 ± 0.00c	0.26 ± 0.01a
				subtotal		3.91 ± 0.05c	2.67 ± 0.03d	3.76 ± 0.05c	5.47 ± 0.09a	4.55 ± 0.11b	4.56 ± 0.09b
alcohol	1-Octen-3-ol	561.763	1.15598	996.7	mushroom	0.51 ± 0.01bc	0.41 ± 0.07d	0.49 ± 0.05c	0.58 ± 0.02b	0.73 ± 0.05a	0.56 ± 0.02bc
	1-Penten-3-ol	182.657	0.94698	690	butter, pungent	6.33 ± 0.14b	6.08 ± 0.03c	6.70 ± 0.07a	6.64 ± 0.16a	6.37 ± 0.08b	6.75 ± 0.03a
	Ethanol	99.226	1.05441	452.6	sweet	3.04 ± 0.06d	4.19 ± 0.03b	4.67 ± 0.10a	3.32 ± 0.02c	1.98 ± 0.03e	3.13 ± 0.02d
	1-Propanol	129.12	1.11925	555.3	alcohol, pungent	1.13 ± 0.08bc	0.80 ± 0.05d	1.32 ± 0.08a	1.20 ± 0.06abc	1.25 ± 0.05ab	1.10 ± 0.07c
	1-Pentanol(M)	245.925	1.25359	773	balsamic	1.32 ± 0.01a	0.48 ± 0.01e	0.59 ± 0.02d	0.73 ± 0.01c	0.76 ± 0.03b	0.79 ± 0.01b
	1-Pentanol(D)	246.327	1.50933	773.4	balsamic	0.32 ± 0.01a	0.06 ± 0.01e	0.14 ± 0.01d	0.16 ± 0.01c	0.21 ± 0.01b	0.15 ± 0.01 cd
				subtotal		12.66 ± 0.18b	12.01 ± 0.08c	13.92 ± 0.23a	12.64 ± 0.24b	11.31 ± 0.08d	12.48 ± 0.10b
furfuran	2-Pentylfuran	557.164	1.25301	994.5	green bean, butter	0.48 ± 0.02a	0.13 ± 0.01c	0.13 ± 0.01c	0.15 ± 0.01c	0.19 ± 0.02b	0.15 ± 0.02c
	Tetrahydrofurane (M)	151.961	1.06384	618.8		2.91 ± 0.35bc	3.44 ± 0.05a	3.10 ± 0.28ab	2.44 ± 0.24d	2.78 ± 0.17bcd	2.57 ± 0.09 cd
	Tetrahydrofurane (D)	150.763	1.23049	615.7		1.14 ± 0.41b	1.31 ± 0.08b	2.20 ± 0.75a	1.17 ± 0.42b	1.78 ± 0.40ab	0.92 ± 0.11b
				subtotal		4.53 ± 0.78ab	4.87 ± 0.12ab	5.42 ± 1.03a	3.75 ± 0.65b	4.75 ± 0.56ab	3.63 ± 1.20b
ketone	2-Heptanone	375.332	1.26028	892.7	cream						

(*continued on next page*)

Table 3 (*continued*)

Classification	Compound	Rt [*sec*]	Dt [a.u.]	RI	Odor description	Relative amount/%					
						A	B	C	D	E	F
						0.52 ± 0.03a	0.24 ± 0.01c	0.25 ± 0.01c	0.31 ± 0.01b	0.34 ± 0.02b	0.33 ± 0.02b
	2-Butanone(M)	133.983	1.06699	569.7	fruit	4.20 ± 0.13b	5.51 ± 0.05a	2.86 ± 0.03d	2.88 ± 0.02d	2.60 ± 0.02e	3.27 ± 0.01c
	2-Butanone(D)	134.882	1.24516	572.3	fruit	6.40 ± 0.11c	9.21 ± 0.22a	5.71 ± 0.16e	6.10 ± 0.07d	5.60 ± 0.04e	8.82 ± 0.07b
	Acetone	104.919	1.12254	474.4	Pungent,butter	5.54 ± 0.22c	9.15 ± 0.14a	3.60 ± 0.16d	3.36 ± 0.08d	2.50 ± 0.09e	6.80 ± 0.16b
				subtotal		16.66 ± 0.27c	24.11 ± 0.21a	12.42 ± 0.27d	12.65 ± 0.13d	11.04 ± 0.13e	19.22 ± 0.18b

Red indicates a higher content of volatile flavor substances than the reference; blue indicates a lower content. The contents of volatile flavor substances increase or decrease in different treatment conditions (Jin, et al., 2021; Zhao et al., 2022).

To distinguish the changes for all aroma substances, all peaks were used to draw fingerprints (Fig. 4(d)) to further analyze the volatile flavor substances in *C. peled* meat with different processing methods. Each row in the figure represents the volatile compounds in a *C. peled* meat sample; each column compares a volatile compound in different samples. The color intensity indicates the volatile compound content; brighter colors indicate higher content (Li et al., 2022). Each sample was measured in triplicate. A total of 42 signal peaks were detected in *C. peled* meat with different cooking methods. A total of 36 volatile organic compounds (monomers and dimers) were identified through comparison with the database in the instrumental software, including 16 aldehydes, 7 olefine aldehydes, 6 alcohols, 4 ketones, and 3 furans (Fig. 4(d) and Table 3).

The I region represents the unique volatile flavor substances of frying treatment, including pentanol(M), pentanol(D), 1-propanolm, (*E*)-2-heptenal, 2-pentylfuran, and phenylacetaldehyde. The II region represents the unique flavor substances of microwave heating treatment, including (*E*)-2-pentenal(M), (*E*)-2-pentenal(D), (*E*)-2-hexenal(M), (*E*)-2- hexenal(D), 2-methylbutanal(M), 2-methylbutanal(D), 3-methylbutanal(M), and 3-methylbutanal(D). The III region represents the unique flavor substances of sous-vide cooking treatment, including heptanal (M), heptanal(D), *n*-nonanal, butanal, 1-octen-3-ol, octanal(M), octanal (D), and (*Z*)-4 -heptenal. The IV region represents the unique flavor substances of air frying treatment, including 2-butanone (M) and 2-butanone (D). Therefore, the characteristic volatile fingerprint of *C. peled* meat cooked by different methods are different from each other.

The volatile organic compound content in *C. peled* meat was further summarized and compared using the peak volume normalization method. It is observed in Table 3 that the content of aldehydes was the greatest in each sample, ranging from 53.89 % to 63.49 %. Aldehydes are formed mainly by oxidation and decomposition of fatty acids, and have a low threshold, indicating a greater impact on the overall flavor of fish samples (Yang et al., 2017). The content of hexanal (grass, fat) (monomer, dimer) was the highest. The content in groups steaming and sous-vide cooking was significantly higher than in the other cooking groups. High concentrations of aldehydes can produce an unpleasant spoilage smell (Ana et al., 2020). The content of total aldehydes in group sous-vide cooking was the highest ($P < 0.05$). The content in group roasting was the lowest, indicating that roasting was more conducive to the final product exhibiting a pleasing smell. Olefine aldehydes are derived mainly from the degradation of linoleic acid and linolenic acid, including (*E*)-2-heptenal, (*E*)-2-hexenal (monomer, dimer), (*E*) −2-pentenal (monomer, dimer), (*Z*)-4-heptenal, and 2-methyl-2-pentenal (Luo et al., 2022). The content of ketones was second only to that of aldehydes (11.04–24.11 %), including 2-heptanone (cream), 2-butanone (fruit) (monomer, dimer), and acetone (butter). The content in group roasting was significantly higher than in other groups. Studies have shown that ketones can reduce fish smell (Dong et al., 2018; Cui et al., 2020). Although the threshold of ketones was lower, it still made a positive contribution to the flavor of fish samples.

The content of alcohol substances ranked third (11.31– 13.92 %), including 1-octen-3-ol, 1-penten-3-ol, ethanol, *n*-propanol, and 1-pentanol (monomer, dimer). The content of 1-penten-3-ol (butter) and ethanol (sweet) was relatively high; the flavor threshold of alcohols is higher than that of aldehydes, which can impart buttery, sweet, and other odors to fish meat (Fratini et al., 2012). The content of furans was low, including 2-pentylfuran and tetrahydrofurane (monomer, dimer). There was no significant difference between cooking groups, indicating that different cooking treatments had little effect on furans in *C. peled* meat. Overall, the cookeing methods had a great influence on formation of certain volatile flavor compounds in *C. peled* meat. Sous-vide cooking treatment produced a higher content of aldehydes and more unpleasant odors. Roasting treatment facilitated formation of more positive odors in *C. peled* meat, probably because of combined effects of high temperature, protein denaturation, lipid oxidation, and Maillard reaction, etc. (Jin et al., 2021; Jing, Fan, Zhu, Wang, & Hou, 2022).

Data are expressed as mean ± standard error. Different letters in the same row indicate significant differences between groups ($P < 0.05$). The cooking methods A, B, C, D, E, and F stand for frying, roasting, steaming, microwave heating, sous-vide cooking, and air frying, respectively. M and D suffixed after the chemicals indicated monomer and dimer, respectively. Odor descriptions were searched from https://www.thegoodscentscompany.com/search2.html.

Conclusions

In summary, non-volatile (electric tongue, free amino acids, 5′-nucleotides, and organic acids, etc) and volatile flavor compounds (electric nose and GC-IMS) in *C. peled* meat cooked by different methods were detected and analyzed. In terms of non-volatile taste, the content of sweet free amino acids, 5′-nucleotides, and organic acids was higher in roasting samples. Sweet amino acids, umami glutamic acid, lactic acid, IMP, and inorganic ions were main taste active components in cooked *C. peled* meat. In terms of volatile odor, a total of 36 volatile flavor compounds were identified among different groups by GC-IMS technology, including 16 aldehydes, 7 olefine aldehydes, 6 alcohols, 4 ketones, and 3 furans. PCA of electronic nose detection results indicated that the flavor substances differed greatly from various cooking methods and could be well distinguished (the first two components accounted for 98.50 % and 0.97 %, respectively.). In general, roasting was the best method that gives more flavor substances in *C. peled* meat after cooking. These results might provide a reference for selection of thermal processing methods, and development of pre-cooked *C. peled* products in future.

Author contributions

Wengang Jin conducted the investigation, wrote the original draft, and performed plot analysis. Xinru Fan, Caiyan Jiang, Yang Liu, Kaiyue Zhu, and Xiaoqing Miao performed partial analysis, visualization, and

the language check. Pengfei Jiang reviewed and edited the manuscript, supervised the work, and acquired funding.

CRediT authorship contribution statement

Wengang Jin: Investigation, Writing – original draft. **Xinru Fan:** Visualization, Data curation, Formal analysis. **Caiyan Jiang:** Visualization, Data curation, Formal analysis. **Yang Liu:** . **Kaiyue Zhu:** Visualization, Data curation, Formal analysis. **Xiaoqing Miao:** . **Pengfei Jiang:** Supervision, Funding acquisition, Writing – review & editing.

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

The authors do not have permission to share data.

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