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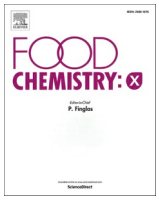

Characterization of prepared soft-shelled turtle dishes of different pretreatment combined with irradiation based on flavor profiles using *E*-nose, *E*-tongue and HS-SPME-GC–MS

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A R T I C L E I N F O

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A B S T R A C T

The effects of different pretreatment combined with irradiation on the flavor profiles of prepared soft-shelled turtle dishes were explored by using electronic nose, electronic tongue and headspace solid-phase micro-extraction gas chromatography–mass spectrometry (HS-SPME-GC–MS). The results showed that electronic nose analysis indicated distinct odor profiles before and after irradiation, with PCA effectively differentiating them. The low-temperature pretreatment group had the smallest difference from the control (CK). After 180 days of storage, odor profiles of all samples converged, with low-temperature, 0.1 % rosemary, and 0.1 % TBHQ groups showing minimal differences from CK. Electronic tongue profiles showed no significant differences among treatments, with PCA unable to effectively distinguish most groups, except for the 0.1 % rosemary and 0.1 % sesamol groups. The results of HS-SPME-GC–MS analysis showed that the volatile compounds of the samples of each treatment were significantly different. The 6 kGy (kilogray) irradiation group, the low temperature pre-treatment and the control group (CK) clustered into one category. After 180 d of storage at room temperature, only the low temperature pretreatment group and the control group (CK) were clustered into one category. The results of relative odor activity value (ROAV) showed that the key flavor compounds of prepared soft-shelled turtle dishes were heptanal, octanal, (*E*)-2-octenal, nonanal, (*E,E*)-2,4-nonadienal, decanal, (*E*)-2-decenal, (*E, E*)-2,4-decadienal, 2-undecanal, 1-octen-3-ol, and 2-pentylfuran. Aldehydes contents in the samples increased after irradiation, which was the main components leading to the off-odor of prepared soft-shelled turtle dishes after irradiation, and the key flavor compounds of the samples decreased after 180 d of storage at room temperature. In conclusion, low temperature or pretreatment of three antioxidants could maintain the flavor of prepared soft-shelled turtle dishes after irradiation, and low temperature had the best effect. This study could provide theoretical reference for the application of irradiation technology in the sterilization and preservation processing of prepared soft-shelled turtle dishes and its flavor control.

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1. Intoduction

Prepared dishes are pre-packaged dishes that are made from one or more edible agricultural products and their processed goods as raw materials, with or without the use of seasoning and other auxiliary materials, and without the addition of preservatives. Through industrial pre-processing methods such as stirring, pickling, rolling, shaping, frying, baking, boiling, steaming, and so on, they are prepared with or without seasoning packets. These dishes meet the storage, transportation, and sales conditions indicated on the product label and are ready to eat after heating or cooking (State Administration for Market Regulation, 2024).

Soft-shelled turtle (*Pelodiscus sinensis*) is a unique rare aquatic economic animal in China, its meat is delicious, high nutritional value, containing a large number of essential amino acids, unsaturated fatty acids and other components, is a traditional food therapy and tonic in China (Wang et al., 2021; Zhao, 2016). Turtle is rich in nutrients, delicious meat, containing many essential amino acids, unsaturated fatty acids and other ingredients (Liang et al., 2018; Rawski et al., 2018). At present, more than 90 % of soft-shelled turtle in China are still sold in fresh form in the market (Zhao, 2019), and the rapid development of Chinese prepared dishes industry has provided a good opportunity for the deep processing of soft-shelled turtle. In 2022, Chinese turtle aquaculture production is up to 373, 700 tons (The fisheries and fisheries Administration Bureau of the Ministry of agriculture and rural affairs, 2023).

However, due to its rich nutrition and high-water content, it is very susceptible to microbial contamination during processing and storage, which may lead to spoilage or even foodborne diseases (Ying et al., 2024). Although the traditional low temperature preservation technology can maintain the freshness of aquatic products to a certain extent, it also has the disadvantages of destroying the internal structure of aquatic products and causing the loss of their nutrients (Jiang, 2023). The quality and freshness preservation of prepared dishes are urgent and difficult problem for the development of the industry, and there is an urgent need to carry out basic research on original physical cold sterilization technology. In recent years, many preservation methods encompass physical and chemical and biological methods have been carried out to control the quality deterioration of foods (Du et al., 2024), among which the irradiation technology, as a typical non-thermal food processing technology, has the advantages of rapid, efficient, low-cost, and pollution-free, etc., which has received the attention of more and more countries and international organizations, and gradually become one of the widely accepted modern food processing methods (Farkas & Mohácsi-Farkas, 2011; Ehlermann, 2016; Yang et al., 2018).

Irradiation technology, especially electron beam irradiation, plays an important role in the sterilization and preservation of aquatic products (Shi et al., 2015; Wei et al., 2022; Yu, Huang, et al., 2022). A certain dose of irradiation can retain the original flavor of aquatic products to the maximum extent while effectively sterilizing them, while a high dose of irradiation can lead to the production of off-odor. Lu et al. (2021) used electron beam irradiation at doses of 1, 3, 5, and 7 kGy (kilogray) to treat the meat of *Lateolabrax japonicus*, and found that the overall flavor of its meat changed slightly after irradiation, and a slight off-odor appeared when the irradiation dose reached 7 kGy. Redults shown that after electron beam irradiation of 5 kGy and below, fine round-toe crab meat (*Ovalipes punctatus*) could better maintain its original olfactory sensation, and 7 kGy and 9 kGy irradiation will lead to slight odor production (Mei et al., 2018). Yang Wenge et al. used electron beam irradiation to treat *Sciaenops ocellatus* meat, and the result showed that the original flavor of the meats were well preserved by irradiation at a dose lower than 5 kGy, while the high dose of irradiation led to the generation of off-odor (Yang et al., 2014). Guo Hongxia et al. (2020) used electron beam irradiation to treat vacuum-packed salmon, and the result showed that the 1 kGy sample basically has no irradiation off-odor, which is similar to the fresh fish (Guo et al., 2020). But the irradiation off-odor was stronger with the increase in irradiation dose, there was a significant difference with the samples of 0 and 4 kGy. Irradiation can negatively affect the flavor of aquatic products and make them produce irradiated off-odor, which is one of the main reasons why consumers find it difficult to accept, and this has become the most important factor restricting the application of irradiation technology in aquatic products.

However, the above studies seldom dealt with the mechanism of odor generation and its control method in the irradiation of aquatic products. In the previous study, the group used 0, 4.7, 7.1, and 9.9 kGy ^{60}Co-γ irradiation to irradiate prepared soft-shelled turtle dishes, and analyzed the changes of flavor before and after irradiation by sensory evaluation, electronic nose combined with HS-SPME-GC–MS, and the results showed that 4.7 kGy irradiation had no significant effect on the flavor of prepared soft-shelled turtle dishes, while 7.1 and 9.9 kGy irradiated samples produced off-odor (Xu et al., 2022). The commonly used analysis methods of food flavor mainly include artificial sense, intelligent sense and instrument analysis, while the combination of various analysis methods, such as electronic nose, e-tongue and GC–MS, has become a hot topic of research in this field (Yin et al., 2021; Yu, Pan, et al., 2022; Peng et al., 2023). The study utilized electronic nose (*E*-nose), electronic tongue (E-tongue), and headspace solid-phase microextraction gas chromatography–mass spectrometry (HS-SPME-GC–MS) analysis techniques to investigate the effects of different pretreatment methods (low temperature, adding 0.1 % rosemary, 0.1 % TBHQ and 0.1 % sesaminol) combined with 6 kGy irradiation on the volatile flavor and taste characteristics of prepared soft-shelled turtle dishes. The aim is to provide theoretical references for the application of irradiation technology in the sterilization, preservation, and processing of prepared soft-shelled turtle dishes, as well as the maintenance of their flavor.

2. Materials and methods

2.1. Materials and equipments

Fresh and healthy purebred Chinese soft-shelled turtle (*Pelodiscus sinensis*), male, weight (2.0 ± 0.25) kg, provided by Hunan Huajia Agricultural Group Co., Ltd. and cultured in the outer pond of Huajia Ecological Soft-shelled Turtle Industrial Park, Hanshou County. Rosemary extract was provided by Changsha HuiRui Biotechnology Co., Ltd.; TBHQ (tertiary butylhydroquinone, food grade) was provided by Henan Ruli Biotechnology Co., Ltd.; and sesamol 98 % was provided by Adamas-Beta (Shanghai) Chemical Reagent Co., Ltd.

The SQ (H) industrial cobalt source irradiation device is from Beijing Sanqiang Nuclear Radiation Engineering Technology Co., Ltd. in China; the 7890B-7000C-GC/MSD gas chromatography–mass spectrometry system is from Agilent in the United States; the PEN3 electronic nose system is from Airsense in Germany; the TS-5000Z taste analysis system is from Insent in Japan; the FSH-2 high-speed dispersion homogenizer is from Changzhou Jintan Youlian Instrument Research Institute in China; the 65 μm CAR/PDMS extraction head is from Supelco in the United States; the TX2202L electronic balance is from SHIMADZ in Japan; and the BCD-328WDPT refrigerator is from Qingdao Haier Co., Ltd. in China.

2.2. Materials and methods

2.2.1. Sample preparation

Fresh and live soft-shelled turtles are slaughtered, gutted, peeled of outer membranes and toenails, cut into blocks, washed, scalded (at 100 °C for 3–5 min), cooled, removed impurities, packed into cans (500 g), filled with soup, sealed, cooked (in a sterilization kettle at 121 °C and 103 kPa for 20 min), and then cooled in a water bath to obtain prepared soft-shelled turtle dishes. Prior to sealing the cans, rosemary extract, TBHQ, and sesamol extract with a mass fraction of 0.1 % are respectively added into the cans. Additionally, the other cans are pretreated by freezing. After sample preparation is completed, the samples are immediately sent for irradiation.

2.2.2. Sample irradiation

The irradiation was carried out at Hunan Irradiation Center, Hunan Institute of Nuclear Agricultural Science and Space Breeding, Hunan Academy of Agricultural Sciences, with a radioactive source of ^{60}Co, activity of 3.14×10^{16} Bq, and a single plate source. The irradiation was carried out in a dynamic stepwise manner, with automatic surface change during irradiation, and the average dose rate was about 83.33 Gy-min^{-1}. The irradiation dose was tracked using a potassium dichromate (silver) dosimeter (deviation <5 %), which was calibrated by the National Dosage Assurance Service (NADS) of the China Academy of Measurement and Science (CAMS), and three parallels were set up. The irradiation dose was set at 0 and 6 kGy, and the measured values were 0 and 6.3 kGy. The samples were labeled as CK (0 kGy), A (6 kGy), B (low temperature + 6 kGy), C (0.1 % rosemary extract +6 kGy), D (0.1 % TBHQ +6 kGy), and E (0.1 % sesamol extract +6 kGy), respectively. The determinations were performed at 0 d (CK1, A1, B1, C1, D1, E1) and 180 d (CK2, A2, B2, C2, D2, E2) of ambient storage, and three parallels were set for each treatment group.

2.2.3. Sample pre-treatment

The hard tissues such as the back shell, bones, and toenails of the prepared soft-shelled turtle dishes are removed, and the remaining fleshy parts of the turtle are minced into a paste using a homogenizer. The paste is then mixed evenly and packaged in sample bags, which are stored in a refrigerator at 4 °C for future use.

2.2.4. Electronic nose (E-nose) determination

The sample was accurately weighed 3.00 ± 0.01 g of soft-shelled turtle paste into a 15 mL headspace bottle, sealed with a cap, placed in a water bath at 80 °C for 30 min, removed, and allowed to stand at room temperature. The electronic nose injection needle was inserted directly into the headspace bottle for the determination of volatile compounds, and the determination was repeated 4 times for each sample. Measurement conditions: sampling time 1 s/group; cleaning time 120 s; zeroing time 10 s; sample preparation time 5 s; injection flow rate 400 mL/min; analysis of the sampling time 120 s. The performance description of the electronic nose sensors is shown in Table 1 (Liu et al., 2023).

Table 1
Description of electronic tongue and electronic nose sensor performance.

Electronic Tongue		
Sensor serial name	**Evaluable flavor Basic flavor (relative value)**	**Aftertaste (CPA value)**
Umami Sensor (AAE)	Umami (Umami caused by amino acids, nucleic acids)	Umami richness (Sustained perceived freshness)
Saltiness Sensor (CT0)	Saltiness (Saltiness caused by inorganic salts such as table salt)	–
Sourness Sensor (CA0)	Sourness (Sourness caused by acetic acid, citric acid, tartaric acid, etc.)	–
Bitterness sensor (C00)	Bitterness (Bitterness caused by bitter substances, perceived as richness at low concentrations)	Bitter aftertaste (Bitter taste of beer, coffee, and other general foods)
Astringency sensor (AE1)	Astringency (Astringency caused by astringent substances, perceived as an irritating aftertaste at low concentrations)	Astringency aftertaste (Astringency presented by tea, wine, etc.)
Sweetness sensor (GL1)	Sweetness (Sweetness caused by sugar or sugar alcohols)	–
Electronic Nose		
Sensor serial name	**Performance description**	
1(W1C)	Sensitive to aromatic compounds	
2 (W5S)	Sensitive to nitrogen oxides	
3 (W3C)	Sensitive to ammonia and aromatic compounds	
4 (W6S)	Sensitive to hydrogen	
5 (W5C)	Sensitive to alkanes, aromatic compounds	
6 (W1S)	Sensitive to short-chain alkanes such as methane	
7 (W1W)	Sensitive to inorganic sulfides	
8 (W2S)	Sensitive to alcohols, aldehydes, ketones and ethers	
9 (W2W)	Sensitive to aromatic compounds and organic sulfides	
10 (W3S)	Sensitive to alkanes	

2.2.5. Electronic tongue (E-tongue) determination

The sample was accurately weighed 20.00 g ± 0.01 g of soft-shelled turtle paste into a 200 mL beaker, add 150 mL of purified water, stirring magnetically for 30 min to make the samples fully mixed, and then centrifuged in a 4 °C freezing centrifuge at 9000 r/min for 5 min, and then the supernatant was taken for the determination, and the determination was repeated three times for each sample. The performance description of the electronic tongue sensors is shown in Table 1 (Chen et al., 2022).

2.2.6. HS-SPME-GC–MS determination

The sample was accurately weighed 2.00 ± 0.01 g of soft-shelled turtle paste into a 20 mL headspace bottle, sealed with a cap, and then inserted into the 65 μm CAR/PDMS extraction head, and then removed after adsorption at 85 °C under the condition of water-bath temperature for 40 min, and inserted into the GC injection port, desorbed at 250 °C for 5 min, and then removed the extraction head, and then used for the determination of GC–MS analysis, and each sample was repeated for three times (Xu et al., 2022).

GC conditions: HP-5MS column (30 m × 250 μm, 0.25 μm); injection mode was non-split, the flow rate of carrier gas (He) was 1.2 mL/min; the temperature of the injection port was 250 °C; the initial temperature was 40 °C, held for 2 min, and then increased to 90 °C at 5 °C/min, then to 170 °C at 8 °C/min, and finally to 250 °C at 10 °C/min. Hold for 5 min.

MS conditions: electron ionization source; electron energy 70 eV; temperature 250 °C; scanning mass range m/z 33–450.

Matching was performed through computer retrieval with the NIST11 standard spectral library. Compounds were qualitatively analyzed based on a match score greater than 80, and quantitative analysis was conducted using the peak area normalization method to calculate the relative content of each volatile compound.

2.2.7. Relative odor activity value (ROAV) analysis

Referring to the relative odor activity value evaluation method of Liu et al. (2008). The ROAV ranges from 0 to 100, volatile compounds with ROAV ≥1 are considered as key flavor compounds in the overall flavor of the samples, of which 0.1 ≤ ROAV <1 play an embellish role, of which <0.1 are potential flavor compounds. The ROAVs of the volatile compounds were calculated as folllows:

$$ROAV_i = \frac{C_i}{T_i} \times \frac{T_{\max}}{C_{\max}} \times 100$$

In the formula, $ROAV_i$ is the relative odor activity value of the volatile compound, C_i is the relative c ontent (%) of the volatile flavor compound to be measured, T_i is its sensory threshold (μg/kg), and T_{max}, C_{max} are the maximum of C_i, T_i among all the compounds in the sample.

2.3. Data analysis

GC–MS data processing: matching with NIST11 standard spectral library through computer search, and only the identification results with similarity greater than 80 were reported. Quantitative analysis by area normalization, the percentage of peak area was calculated by Office Excel, 2023 software, the relative content of each volatile compound, and the ROAV of each volatile compound was obtained according to formula (1). Cluster heat map of the relative content of samples with different treatments using Origin 2021b software.

Results of electronic nose and electronic tongue measurement: The response values of electronic nose and electronic tongue sensors were sorted by Office Excel, 2023 software and SPSS 26.0 software. Analysis of variance and significance analysis were conducted by Duncan's

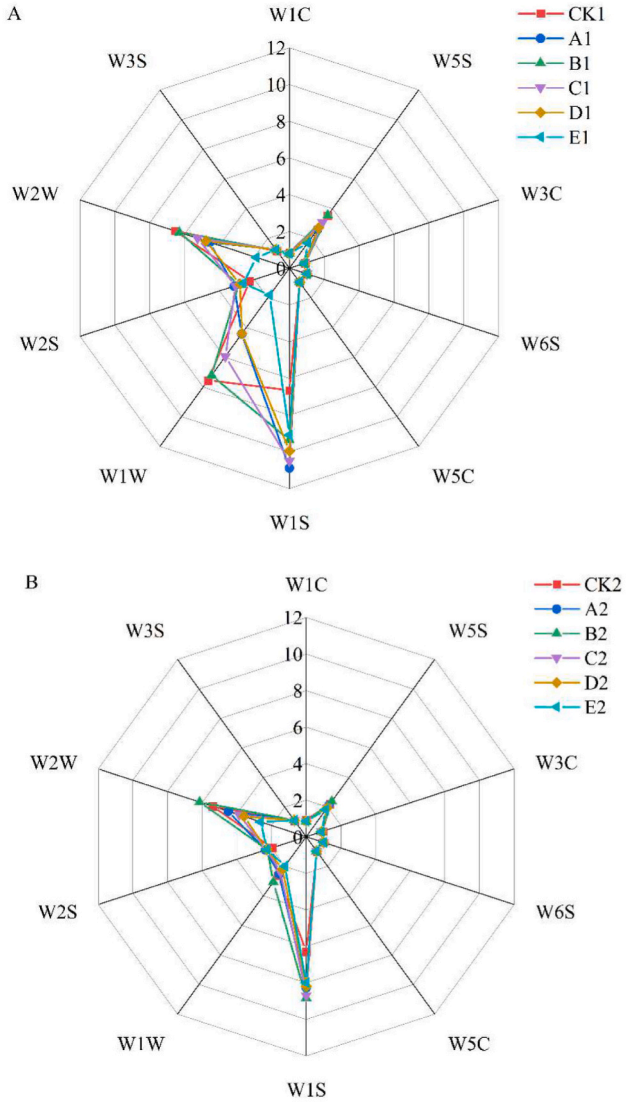
multiple comparisons, and $P < 0.05$ showed significant difference. Principal component analysis (PCA) and radar map and PCA map were performed using Origin 2021b software.

3. Results

3.1. E-nose analysis

3.1.1. E-nose radar fingerprint analysis

The electronic nose technology was used to detect the volatile flavor compounds in the prepared soft-shelled turtle dishes of different treatments and to analyze the changes of the overall flavor of them from a macroscopic perspective. As shown in Fig. 1A, the odor profile curves of prepared soft-shelled turtle dishes with different treatments differed significantly at 0 d of storage at room temperature, in which the response values of the electronic nose sensors W1C (aromatic compounds), W3C (ammonia and aromatic compounds), W6S (hydrogens), W5C (alkanes, aromatic compounds), and W3S (alkanes) of the samples with different treatments were always in the vicinity of 1, which indicated that the volatile flavor compounds corresponding to the five sensors were low and less variable in the samples. The response values of W5S (nitrogen oxides), W1S (short-chain alkanes), W1W (inorganic sulfides), W2S (alcohols, aldehydes, ketones, and ethers), and W2W (aromatic compounds and organic sulfides) for the samples were all significantly greater than 1, suggesting that volatile compounds corresponding to the five sensors were important volatile flavor compounds in prepared soft-shelled turtle dishes. Compared with the control group (CK1), the W1S response values of the samples in each treatment group were significantly larger, followed by W2S, which indicated that the contents of short-chain alkanes, alcohols, aldehydes, ketones and ethers in the samples might increase after irradiation. However, the W1S and W2S response values of B1, C1, D1 and E1 were significantly lower than that of A1, which indicated that both low temperature pretreatment and addition of antioxidants (0.1 % rosemary, 0.1 % TBHQ, 0.1 % sesamol) inhibited the content increase of short-chain alkanes, alcohols, aldehydes, ketones, and ethers in irradiated samples. The response values of W5S, W1W, and W2W of B1 were similar to that of CK1, whereas the W5S, W1W and W2W response values of the other treatment groups



A.0 kGy irradiation (CK); B. 6 kGy irradiation; C. low temperature + 6 kGy irradiation; D. 0.1% rosemary + 6 kGy irradiation; E. 0.1% TBHQ + 6 kGy irradiation; F. 0.1% sesamol + 6 kGy irradiation

Fig. 1. Radar fingerprint of electronic nose in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d (A) and 180 d (B).

were significantly lower than that of CK1. In addition, the response values of these three sensors for C1 were significantly higher than that of A1, D1 was similar to it, and E1 was significantly lower than that of A1. It is indicated that the pretreatments of low temperature and adding 0.1 % rosemary extract have a significant maintenance effect on the content of nitrogen oxides, inorganic sulfides, aromatic compounds, and organic sulfides in irradiated prepared soft-shelled turtle dishes.

As shown in Fig. 1B, the odor profile curves of the prepared soft-shelled turtle dishes samples of different treatments tended to be similar after 180 d of storage at room temperature, indicating that the differences in volatile flavor compounds among the samples from different treatments became smaller after 180 d of storage at room temperature. The response values of W1S and W2S of the samples were still significantly higher than those of the control group (CK2), and both of them were lower than those of the samples stored for 0 d. The response values of W5S, W1W and W2W of all samples decreased after 180 d of storage at room temperature, with W1W being the most obvious. The response values of W5S, W1W and W2W to B2 were significantly higher than that of CK2, and the response values of W5S, W1W and W2W of all other groups of samples were significantly lower than that of CK2. In addition, the response values of the three sensors to C2, D2 and E2 were also significantly lower than that of A2. Therefore, the low-temperature pretreatment had a significant effect on the retention of volatile flavor characteristics of irradiated prepared soft-shelled turtle dishes.

3.1.2. *E-nose PCA*

PCA can extract information from the main variables affecting the spatial distribution of the samples to explain the variance between the samples (Dong et al., 2019). PCA was used to analyze the electronic nose response value of prepared soft-shelled turtle dishes samples at 0 d after 180 d of storage at room temperature, and the results are shown in Fig. 2A. PC1 and PC2 explained 61.7 % and 25.1 % of the total variance, respectively, and the two principal components together accounted for 86.8 % (greater than 85 %) of the total variance, indicating that the two principal components covered the majority of the sample information, and they can be used to characterize the flavor characteristics of the different treatments of prepared soft-shelled turtle dishes. In the PCA model, the control group (CK1) was clearly distinguished from the samples of each treatment group, with CK1 located in the first and fourth quadrants, B1 in the first and second quadrants, A1, C1, D1, and E1 mainly located in the second and third quadrants, and W5S, W1W, and W2W contributing more to the sample grouping. In the PC1 direction, B1 was closest to CK1, followed by C1, D1, and E1, with A1 being the furthest away, indicating that volatile flavor compounds in A1 had the greatest difference compared to CK1, followed by C1, D1, and E1, whereas B1had the least difference with CK1, which was consistent with the results of radargram analysis. Feng et al. (2019) investigated the "irradiation odor" of irradiated meat duck products and used an electronic nose to detect irradiated roast duck and brine duck. The results showed that the response values of the electronic nose sensors for the two types of meat duck products changed after irradiation, but the main categories of volatile flavor compounds before and after irradiation were ammonia and aromatic compounds, hydrogen sulfide, aromatic compounds, and organic sulfides. And effective differentiation was also achieved between roasted duck and brine duck treated with different doses of irradiation using linear discriminant analysis (LDA) analysis.

The results of PCA analysis of *E*-nose response value for each group of samples after 180 storage at room temperature are shown in Fig. 2B. PC1 and PC2 explained 60.0 % and 25.5 % of the total variance, respectively, for a total of 85.5 %, suggesting that the first 2 principal components were sufficient to explain the total variance of the data set. The control group (CK2) was located on the right side of the Y-axis, while the other groups of samples were mainly located on the left side of the Y-axis, and there were intersections between B2, C2, and D2 and CK2, suggesting that the odor differences between the four groups of samples were relatively small. A2 and E2 were relatively far away from the CK2 samples, suggesting that there were significant differences between A2 and E2 and CK2. The results further indicated that the low-temperature pretreatment had a better retention effect on the volatile flavor compounds in irradiated prepared soft-shelled turtle dishes.

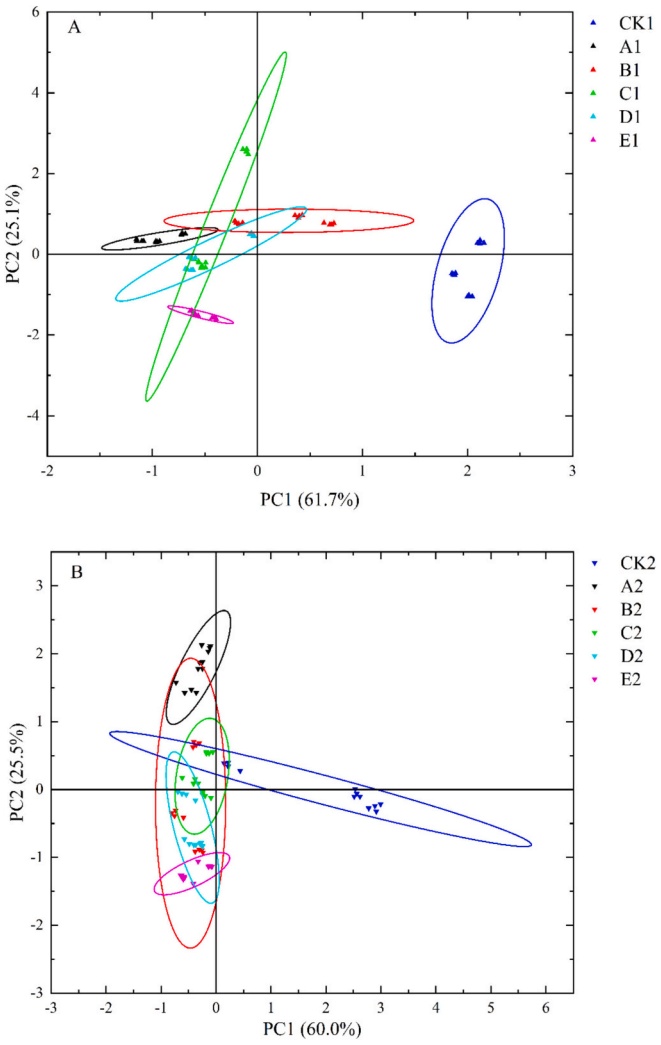


Fig. 2. PCA chart of electronic nose in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d (A) and 180 d (B).

3.2. *E-tongue analysis*

3.2.1. *E-tongue radar fingerprint analysis*

As shown in Fig. 3A, the electronic tongue radar fingerprint profiles of prepared soft-shelled turtle dishes samples with different treatment are similar. The response values of the six electronic tongue sensors to each group of samples are similar, indicating that there are little differences in the taste characteristics among the prepared soft-shelled turtle dishes samples with different treatment. The relatively large response values of each group of samples on the bitterness, umami and saltiness sensors indicated that bitterness, umami and saltiness were effective and important taste indicators of prepared soft-shelled turtle dishes, while the response values on the sourness, astringency, bitterness aftertaste, astringency aftertaste, umami aftertaste (richness) and sweetness sensors were all close to or below the point of tastelessness (0). Amino acids in soft-shelled turtle are rich in variety and high in content, and different types of amino acids have different flavor presenting properties and contribute differently to the taste of prepared

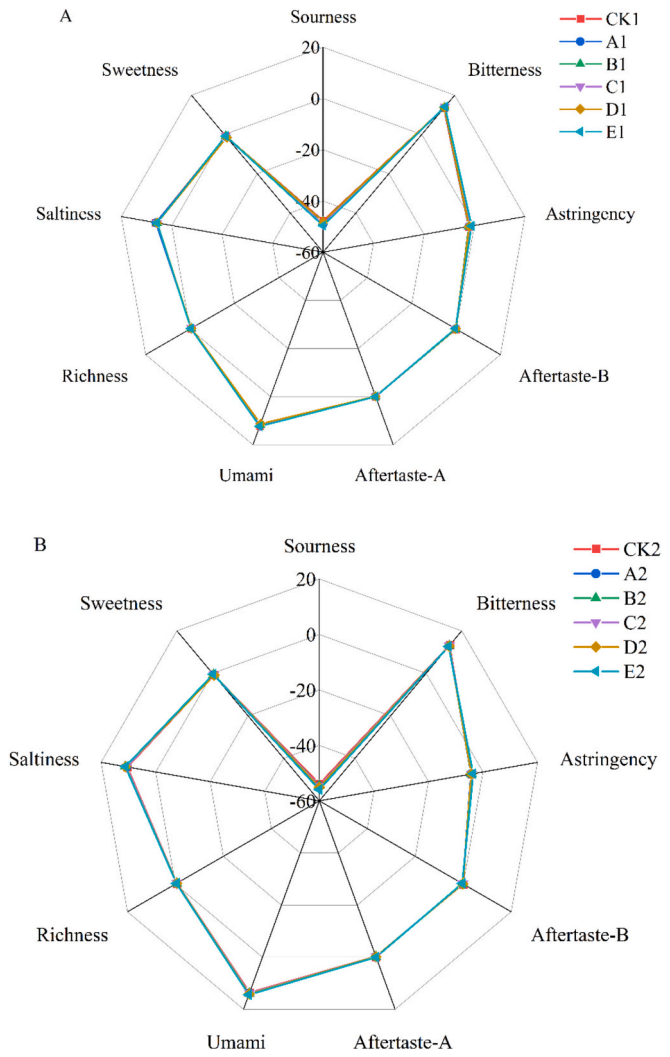


Fig. 3. Radar fingerprint of electronic tongue in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d (A) and 180 d (B).

soft-shelled turtle (Huang et al., 2021). The umami taste of the prepared soft-shelled turtle mainly originated from its umami amino acids (aspartic acid, glutamic acid), while the bitter taste was mainly formed figure by bitter amino acids (valine, methionine, etc.) and the added seasonings (Chen et al., 2022).

Fig. 3B shows the radar fingerprint profiles of the electronic tongue response values of the prepared soft-shelled turtle dishes samples with different treatments after 180 d of storage at room temperature, and the electronic tongue response characteristics of the samples in each group were similar, indicating that the differences in the flavors of the samples of prepared soft-shelled turtle dishes with different treatments were still relatively small. However, compared with the 0 d samples, the umami and saltiness of all the samples were significantly enhanced and the bitterness decreased after 180 d of storage at room temperature, and the samples of each treatment group showed the same changes in umami, saltiness, and bitterness compared with the control group (CK2). This may be due to the protein degradation of soft-shelled turtle during storage to produce free amino acids, while irradiation accelerates the oxidative decomposition of proteins to produce some flavor amino acids. In addition, salt penetrates into the flesh of soft-shelled turtle during storage, which may lead to an increase in the saltiness of prepared soft-shelled turtle (Liu et al., 2022).

3.2.2. *E-tongue PCA*

To further investigate the differences in taste characteristics of prepared soft-shelled turtle dishes samples with different treatment, PCA analysis was conducted on the electronic tongue response values of each group of samples. The results are shown in Fig. 4A. It could be seen in the figure that PC1 and PC2 explained 49.3 % and 18.5 % of the total variance, respectively, and the total of the two was 67.8 %, which had a high degree of reliability. The samples of prepared soft-shelled turtle dishes with different treatments could be divided into two groups, and there was a significant distance between the two groups in the direction of PC1, which indicated that there was a difference between the two groups of sample tastes on PC1, which might be produced by the added rosemary and sesamol. Bitterness and umami contributed more to PC1, indicating that bitterness and umami were the main factors affecting the distribution of samples of prepared soft-shelled turtle dishes with different treatments. CK1, A1, B1 and D1 were in the second and third quadrants and overlapped each other among the 4 groups of samples, which indicated that the 4 groups of samples were relatively similar in terms of taste characteristics. While C1 and E1 were located in the first and fourth quadrants and crossed each other, with a larger distance from the other 4 groups of samples. This indicates that C1 and E1 are significantly different from the other 4 groups of samples in terms of taste characteristics, which suggests that the addition of 0.1 % rosemary and 0.1 % sesamol may have some effects on the taste characteristics of prepared soft-shelled turtle dishes.

After 180 days of storage at room temperature, the PCA analysis results of the electronic tongue response values for each group of

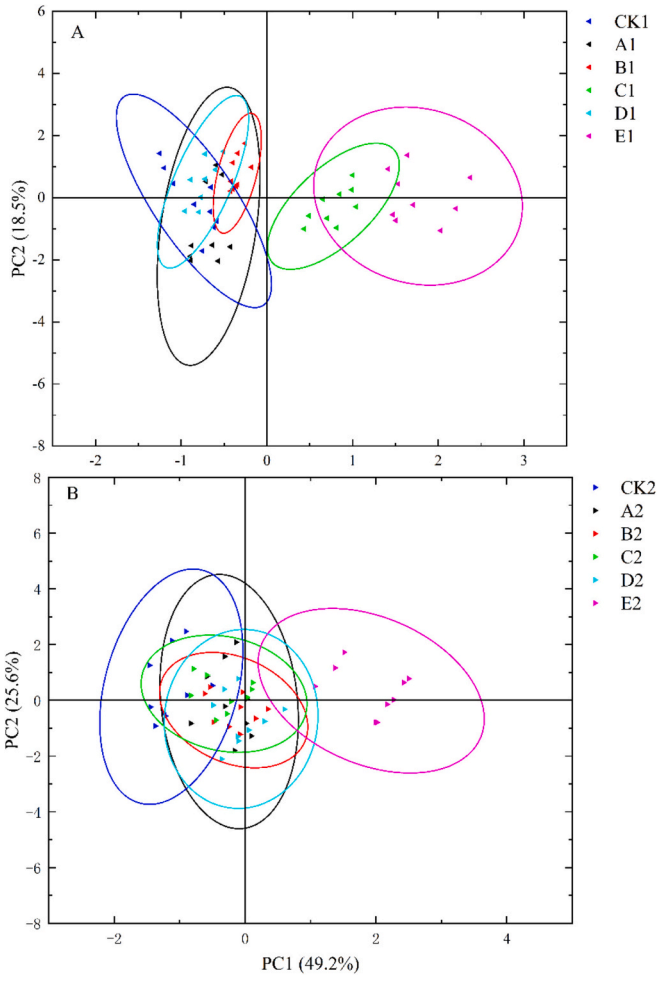


Fig. 4. PCA chart of electronic tongue in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d (A) and 180 d (B).

samples are shown in Fig. 4B. PC1 and PC2 explain 49.2 % and 25.6 % of the total variance, respectively, totaling 74.8 %, indicating that the two principal components cover most of the sample information. Among them, umami and saltiness contributed more to PC1, and bitterness contributed more to PC2. It can be seen in the figure that C2 overlapped with the other four groups of samples, and the relative distance of E2 was also close, but there was no crossover with the control group (CK2), which indicated that, except for E2, the differences in the taste characteristics between the samples of prepared soft-shelled turtle dishes in each treatment group and the control group were small after 180 d of storage at room temperature.

3.3. HS-SPME-GC–MS analysis

3.3.1. Analysis of volatile compounds

Results of the relative content and quantity of volatile compounds in different treatments are shown in Table 2. At 0 d, 46,47,53,43,44, and 36 volatile compounds were detected in controls (CK1), A1, B1, C1, D1, and E1, respectively, including aldehydes, ketones, alcohols, acids, esters, hydrocarbons, and furans. The volatile compounds were obviously different, and the relative content of A1 aldehydes and other substances were not different from CK1, while the relative content of ketones, alcohols and esters increased, while that of acids and hydrocarbons decreased. The relative content of B1, C1 and D1 aldehydes increased significantly compared with CK1, while the relative content of other substances was significantly reduced, but the relative content of other substances in E1 increased significantly, while aldehydes, ketones, alcohols, acids, esters and hydrocarbons all decreased. Previous studies used different doses of cold squab, and the results showed that the aldehyde content of squab radiated with 3,6,9,12 kGy increased from 1.91 mg/kg to 3.47,5.99,6.89 and 8.67 mg / kg, respectively. This is similar to the results of this study, indicating that irradiation accelerates lipid oxidation in turtle preformed vegetables, thus producing more aldehydes.

After 180 days of storage at room temperature, 33, 35, 41, 33, 36 and 41 volatile compounds were detected in control (CK2), A2, B2, C2, D2 and E2, respectively. The amount of aldehydes in each group of samples decreased significantly, but the relative content did not change much, in which the relative content of CK2, C1 and D1 aldehyde decreased, while the samples in other groups increased. The relative content of hydrocarbons were significantly increased in all groups of samples except C2. The relative content of other groups of compounds were significantly decreased in A2, B2 and E2. The relative content of acids were significantly decreased in B2, esters were significantly decreased in A2, and esters were increased in C2 and E2. The results indicated that different treatments had significant effects on the composition and relative content of volatile compounds in the prepared soft-shelled turtle dishes, and the quantity and relative contents of volatile compounds in the different treatments of prepared soft-shelled turtle dishes changed significantly after 180 d of storage at room temperature.

The heat map could reflect the data information in the one-dimensional table by color change. The red the color, the less the volatile compounds, while the bluer the color, the more the content. The heat map results of each volatile compound in the prepared turtle vegetables with different treatments were shown in Fig. 5.

Aldehydes were the main products of lipid oxidative degradation, with high relative contents and low odor thresholds, contributing to the overall flavor of the prepared soft-shelled turtle dishes (Ding et al., 2021). The relative contents of aldehydes in prepared soft-shelled turtle dishes were relatively abundant, except for E1, the relative contents of heptanal, benzaldehyde, (*E*)-2-octenal, nonanal and (*E*)-2-decenal in all groups of samples were significantly increased compared with that of CK1. Phenylacetaldehyde was detected in all irradiated samples, indicating that more aldehydes were produced in the prepared soft-shelled turtle dishes after irradiation. After 180 d of storage at room temperature, the number of aldehydes decreased significantly in all groups of samples, and the relative contents were still significantly higher than that of CK2, except for E2. The quantity of aldehydes in B2 was relatively close to that of CK2, but (*E*)-2-decenal, (*E,E*)-2,4-decadienal, and (*E*)-2-octadienal were detected only in B2, in which (*E,E*)-2,4-decadienal was the fishy odor producing important compound (Kang et al., 2017). Ketones were another major product of oxidative degradation of lipids (Ding et al., 2021), but there were fewer types and lower relative contents of ketones in each group of samples. It is suggested that irradiation can induce the oxidation of lipids to produce low molecular aldehydes and ketones, which are likely to be the main factors in the production of "Irradiation odor" (Lu et al., 2021), and it is assumed that the off-odor of the prepared soft-shelled turtle dishes after high-dose irradiation may be related to the change in the relative content of aldehydes.

Alcohols originate from lipid oxidation and most of them have high thresholds and contribute less to the overall flavor, but a few unsaturated alcohol thresholds such as enols have low thresholds and contribute more to the overall flavor (Lu et al., 2021). 1-octen-3-ol, a degradation product of linoleic acid hydroperoxides, was detected in all groups of samples with a high relative content and a low threshold, with a mushroomy and earthy odor, which is thought to be associated with the light flavor of fresh fish (Jin et al., 2016). Iglesias and Medina (2008) confirmed that the content of 1-octen-3-ol is highly correlated with

Table 2
Comparison of the classification of volatile compounds in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d and 180 d.

Component	Day	CK		A		B		C		D		E	
		Relative content/ %	Quantity	Relative content/ %	Quantity	Relative content/ %	Quantity	Relative content/ %	Quantity	Relative content/ %	Quantity	Relative content/ %	Quantity
Aldehydes	0	32.27	16	32.66	16	48.73	19	58.55	16	63.73	16	9.67	7
	180	29.66	7	53.04	9	51.69	12	53.59	8	51.74	6	26.09	7
Ketones	0	1.88	2	2.33	3	1.69	2	0.00	0	0.00	0	1.24	0
	180	1.28	1	0.33	1	1.13	1	0.00	0	0.00	0	3.73	5
Alcohols	0	6.77	4	9.87	4	10.83	5	7.19	5	10.53	5	0.89	3
	180	7.37	3	7.83	5	16.19	5	9.32	3	9.89	5	3.84	3
Acids	0	4.39	3	2.69	3	8.69	3	0.77	1	1.23	2	0.65	2
	180	2.56	2	0.92	1	0.95	1	1.02	1	0.79	1	0.70	1
Esters	0	1.70	3	4.97	5	1.16	3	1.54	3	1.47	3	0.69	3
	180	2.93	5	0.92	2	1.66	5	12.06	5	1.51	3	10.74	3
Hydrocarbons	0	7.24	9	2.84	8	5.86	13	13.36	9	7.57	11	6.77	10
	180	14.02	9	14.23	12	17.58	12	8.93	10	14.36	12	18.71	12
Others	0	45.76	9	44.64	8	23.04	8	18.59	9	15.47	7	80.09	11
	180	42.19	6	22.74	5	10.79	5	15.08	6	21.71	9	36.20	10

Note: Different treatments mean CK (0 kGy), A (6 kGy), B (low temperature + 6 kGy), C (0.1 % rosemary extract +6 kGy), D (0.1 % TBHQ +6 kGy), and E (0.1 % sesamol extract +6 kGy). The determinations were performed at 0 d (CK1, A1, B1, C1, D1, E1) and 180 d (CK2, A2, B2, C2, D2, E2) of ambient storage.

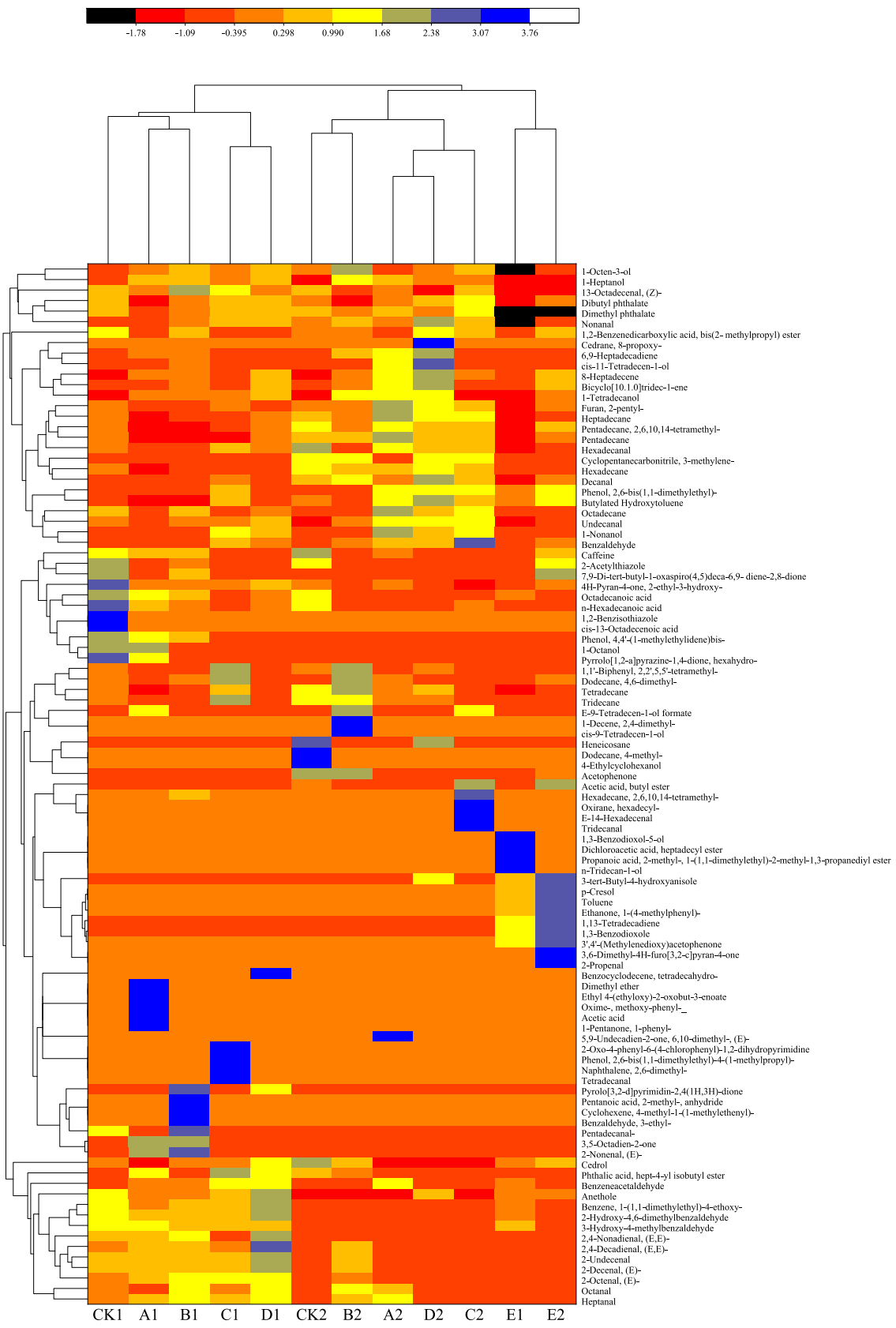


Fig. 5. Clustering heat map of volatile compounds in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d and 180 d.

peroxide value and thiobarbituric acid value. Therefore, the change of the relative content of 1-octen-3-ol can reflect the degree of lipid oxidation in irradiated prepared soft-shelled turtle dishes. Except for E1, the relative content of 1-octen-3-ol in each group of samples increased significantly after irradiation treatment, which may be related to the occurrence of off-odor in prepared soft-shelled turtle dishes after high-dose irradiation.

Acids are mainly derived from lipid oxidation and hydrolysis, which have a high threshold but play a non-negligible basal role in the formation of overall flavor (Li et al., 2020). The quantity of acids in the samples was relatively small, palmitic acid, stearic acid and (*Z*)-13-octadecenoic acid were detected in the control group, and the relative quantity of palmitic acid was significantly decreased in all treatment groups, and (*Z*)-13-octadecenoic acid was not detected, which may be oxidized and changed to other compounds in the irradiation process. After 180 d of storage at room temperature, palmitic acid and stearic acid were detected in the control group, while only palmitic acid was detected in the other groups.

Esters have a sweet, creamy, fruity or floral aroma that can enhance the odor of other flavor compounds and acts as a rich and soft base (Mei et al., 2018). The quantity and relative content of esters in the samples were small, three esters were detected in the control group (CK1), and except for A1, there was little difference between the samples in each treatment group and the control group (CK1). After 180 d of storage at room temperature, the composition of aldehydes in each group of samples changed significantly, butyl acetate was detected in the control group (CK2), and the relative content of butyl acetate was higher in C2 and E2.

Hydrocarbons are a group of compounds with high variety and relative content in prepared soft-shelled turtle, including alkanes, olefins and aromatic hydrocarbons. Hydrocarbons mainly originate from homolytic cleavage of fatty acid alkoxy radicals, and their thresholds are generally high, contributing less to the overall flavor. However, olefins may form aldehydes, ketones, and other compounds under certain conditions, which have a potential impact on flavor formation (Liu et al., 2022). Aromatic hydrocarbons may be produced by the oxidation of free amino acids of the aromatic group, and some aromatic hydrocarbons, such as toluene and naphthalene, usually have undesirable flavors and may contribute to the development of off-odor in prepared soft-shelled turtle dishes (Lv et al., 2016).

Other compounds mainly include some phenols, ethers, and nitrogenous oxygenated heterocyclic compounds. 2-pentylfuran, anethole, 1-tert-butyl-4-ethoxybenzene, caffeine and ethyl maltol were detected in all groups of samples, with significant differences in the other compounds. 2-pentylfuran is an oxygenated heterocyclic compound, which is usually used as an indicator of lipid oxidation in meat products, and its high relative content and low threshold value play an important role in the overall flavor of meat products (Shan et al., 2022). The relative content of 2-pentylfuran was slightly lower in the samples of different treatments compared to the control (CK1), except for C1. The high relative content of caffeine and ethyl maltol in CK1 may be originated from the ingredients added during the processing of prepared soft-shelled turtle, and the relative content of sesamal was also high at 64.49 % in E1. The relative contents of caffeine and ethyl maltol in the samples of different treatments were significantly reduced compared with CK1, which indicated that irradiation treatment would cause oxidative degradation of these two compounds. After 180 d of storage at room temperature, the compounds of the samples with different treatments changed significantly, and the relative content of 2-pentylfuran was higher than that of the control group (CK2), of which A2 was the most obvious, indicating that irradiation treatment accelerated the oxidation of lipids in the prepared soft-shelled turtle dishes, and that the low temperature and pretreatment with antioxidants had a certain inhibition effect on the oxidation of lipids in the prepared soft-shelled turtle dishes after irradiation. It is consistent with the findings of both domestic and international scholars regarding the inhibitory effects of antioxidants on lipid oxidation in food (Li et al., 2023).

3.3.2. Cluster analysis (CA)

The volatile compounds of different vegetables were clustered using the "inter-group association method" as the group merging criterion and the "square European distance" as the metric criterion. The results are shown in Fig. 5. According to the results of the cluster heat map, different treatments can be clearly distinguished when the samples were stored at room temperature for 0 d and 180 d. When the Manhattan distance was 80.05, the 12 groups of samples could be classified into three categories, the first category consisted of samples stored at room temperature for 0 d except E1, the second category consisted of samples stored at room temperature for 180 d except E2, and E1 and E2 were clustered into one category alone, which indicated that the volatile compounds compositions and relative contents of the two samples differed greatly from those of the other groups of samples. When stored at room temperature for 0 d with a Manhattan distance of 77.97, the remaining 5 groups of samples were divided into 2 categories, the first category was composed of CK1, A1 and B1, of which A1 and B1 were divided into a category and relatively close to CK1, indicating that the volatile compounds compositions of A1 and B1 differed from that of the control group (CK1) to a certain extent, which was similar to the results of the PCA by the electronic nose; C1 and D1 were clustered into a category and relatively far away from CK1, indicating that they are relatively different from CK1. When the samples were stored at room temperature for 180 d and the Manhattan distance was 69.02, the five groups of samples were still classified into two groups, in which the control group (CK2) and B2 were clustered into one category, indicating that the composition of volatile compounds between B2 and CK2 was similar. A2, C2 and D2 were classified into one group, in which C2 was classified into one group and was relatively close to CK2, and A2 and D2 were classified into one group and were relatively far away from CK2. The results showed that there were some differences in the composition of volatile compounds in prepared soft-shelled turtle dishes by different pretreatment combined with irradiation, and the low-temperature pretreated samples had the highest degree of similarity with the control group after 180 d of storage at room temperature, so the low-temperature pretreatment had obvious effect on the retention of volatile compounds in irradiated prepared soft-shelled turtle dishes.

3.3.3. ROAV analysis

The contribution of volatile compounds to the overall flavor was determined by their relative contents and sensory thresholds in food (Kang et al., 2017). The relative odor activity value (ROAV) is used to evaluate the contribution of each compound to the overall flavor of the prepared soft-shelled turtle dishes, the larger the ROAV, the greater the contribution (Zhang et al., 2019). The ROAVs of the volatile flavor compounds not less than 0.1 were calculated in Tables 3 and 4. Heptanal, octanal, (*E*)-2-octenal, nonanal, (*E,E*)-2,4-nonadienal, decanal, (*E*)-2-decenal, (*E,E*)-2,4-decadienal, 2-undecylenal, 1-octen-3-ol, and 2-pentylfuran were identified to the key flavor compounds in the prepared soft-shelled turtle at 0 d of storage at room temperature, it could be seen that aldehydes are the most abundant key flavor compounds. Benzaldehyde, undecanal, phenylacetaldehyde, *p*-methylacetophenone, octanol, toluene and anethole were the compounds with important modifying effects. The ROAVs of heptanal and (*E*)-2-octenal in all groups of samples except E1 became larger compared with CK1, and the ROAVs of (*E,E*)-2,4-nonadienal, (*E,E*)-2,4-decadienal, and 1-octen-3-ol in A1, B1, and D1 also increased. The ROAV of decanal, 2-undecadienal and 2-pentylfuran became smaller in all groups of samples compared with the control (CK1), while the ROAV of phenylacetaldehyde was greater than 0.1, which became an important modifying effect or key flavor compound in the samples. Studies have shown that irradiation can induce the oxidation of lipids to produce low molecular aldehydes and ketones, and such substances are likely to be the main factors for the "irradiation taste". Therefore, the off-odor of turtle prepared vegetables after high-

Table 3
ROAV of volatile flavor compounds in different treatments of prepared soft-shelled turtle stored at room temperature for 0 d.

Compound name	Threshold /(μg/kg)	Flavor description	CK1	A1	B1	C1	D1	E1
heptanal	3.00	Fruity Scent	4.22	7.81	9.69	4.67	5.76	0.00
benzaldehyde	350.00	Bitter almond flavor, aromatic odor	0.04	0.06	0.04	0.13	0.07	0.05
nonanal	1.00	Floral flavor	100.00	100.00	100.00	100.00	100.00	100.00
decanal	0.10	–	55.78	51.83	41.01	53.53	35.58	53.52
octanal	0.70	Waxy flavor, sweet orange aroma	31.31	0.00	53.73	13.56	35.95	0.00
(*E*)-2-octenal	3.00	Grassy flavor, baking flavor	1.16	2.00	2.00	1.37	1.62	0.00
(*E*)-2-decenal	0.30	–	22.33	21.17	22.65	15.67	30.74	0.00
(*E,E*)-2,4-decadienal	0.07	Citrus fruit flavor, nutty flavor	48.64	51.93	50.77	13.14	92.28	0.00
undecanal	5.00	–	0.77	0.50	0.58	0.47	0.55	0.00
2-undecenal	0.78	Waxy flavor, faint scent	10.59	8.68	6.44	4.96	10.51	0.00
benzeneacetaldehyde	4.00	Honey scent	0.00	0.61	0.64	0.92	1.01	1.80
(*E,E*)-2,4-nonadienal	0.10	Fatty, waxy, greenish flavor	37.58	40.29	45.72	0.00	44.00	0.00
1-(4-methylphenyl)-ethanone	21.00	–	0.00	0.00	0.00	0.00	0.00	0.27
1-octen-3-ol	1.00	Mushroom flavor, earthy flavor	22.45	38.36	39.87	16.74	25.28	2.13
1-octanol	110.00	–	0.13	0.12	0.00	0.00	0.00	0.00
toluene	200.00	Benzene-like aroma	0.00	0.00	0.00	0.00	0.00	0.26
2-pentyl-furan	6.00	Green bean flavor, sweetness	2.48	1.63	1.41	1.52	1.15	2.14
anethole	15.00	Licorice flavor, fennel flavor	0.24	0.12	0.11	0.12	0.17	0.20

Note: The value of Threshold is derived from Reference (Chen et al., 2022; Dang et al., 2023; Liu et al., 2023; Wang et al., 2020; Wu et al., 2023; Zhang et al., 2019). Different treatments mean CK (0 kGy), A (6 kGy), B (low temperature + 6 kGy), C (0.1 % rosemary extract +6 kGy), D (0.1 % TBHQ +6 kGy), and E (0.1 % sesamol extract +6 kGy).

Table 4
ROAV of volatile flavor compounds in different treatments of prepared soft-shelled turtle stored at room temperature for 180 d.

Compound name	Threshold /(μg/kg)	Flavor description	CK2	A2	B2	C2	D2	E2
heptanal	3.00	Fruity Scent	0.43	7.29	4.12	0.00	0.00	0.00
benzaldehyde	350.00	Bitter almond flavor, aromatic odor	0.04	0.15	0.05	0.24	0.09	0.10
nonanal	1.00	Floral flavor	100.00	100.00	100.00	100.00	100.00	100.00
decanal	0.10	–	87.03	59.49	73.56	67.09	76.98	69.46
octanal	0.70	Waxy flavor, sweet orange aroma	0.00	30.05	38.59	0.00	0.00	0.00
(*E*)-2-octenal	3.00	Grassy flavor, baking flavor	0.00	0.00	0.72	0.00	0.00	0.00
(*E*)-2-decenal	0.30	–	0.00	0.00	13.19	0.00	0.00	0.00
(*E,E*)-2,4-decadienal	0.07	Citrus fruit flavor, nutty flavor	0.00	0.00	82.23	0.00	0.00	0.00
undecanal	5.00	–	0.00	0.84	0.35	0.82	0.61	0.51
2-undecenal	0.78	Waxy flavor, faint scent	2.37	0.00	4.96	0.00	1.19	0.00
benzeneacetaldehyde	4.00	Honey scent	0.00	1.21	0.00	0.00	0.00	0.32
acetophenone	65.00	Fruity aroma	0.11	0.00	0.06	0.00	0.00	0.03
1-octen-3-ol	1.00	Mushroom flavor, earthy flavor	30.53	13.67	41.04	31.04	16.14	15.57
acetic acid, butyl ester	66.00	–	0.13	0.00	0.00	0.62	0.00	0.90
toluene	200.00	Benzene-like aroma	0.00	0.00	0.00	0.00	0.00	0.33
2-pentyl-furan	6.00	Green bean flavor, sweetness	2.49	4.51	1.81	2.21	2.21	2.96
anethole	15.00	Licorice flavor, fennel flavor	0.00	0.00	0.00	0.00	0.09	0.12

Note: The value of Threshold is derived from Reference (Chen et al., 2022; Feng et al., 2019; Liu et al., 2023; Mao et al., 2021; Wang et al., 2020; Zhang et al., 2019). Different treatments mean CK (0 kGy), A (6 kGy), B (low temperature + 6 kGy), C (0.1 % rosemary extract +6 kGy), D (0.1 % TBHQ +6 kGy), and E (0.1 % sesamol extract +6 kGy).

dose irradiation may be related to the change of the relative content of aldehydes.

After 180 d of storage at room temperature, the volatile flavor substances and their ROAV in each group of samples changed. Except for E2, the types of key flavor substances, especially aldehydes, in each group of samples decreased significantly, which may be due to the further oxidation of some aldehydes in turtle prepared vegetables in normal temperature storage conditions to form acids and other components. The amount of B2 aldehydes is relatively close to the CK1 sample. Nonanal, decanal, 1-octen-3-ol and 2-pentylfuran were still the key flavor compounds common to all groups of samples, and the ROAVs of the other volatile compounds varied considerably among the groups of samples, e.g., the ROAVs of (*E*)-2-octenal were greater than 0.1 and those of (*E*)-2-decenal and (*E,E*)-2,4-decadienal were greater than 1.0 in B2, and were less than 0.1 in all the other groups. The results indicated that there were differences in the key flavor compounds in the prepared soft-shelled turtle dishes with different treatment, and the key flavor compounds decreased in the samples after 180 d of storage, which was consistent with the results that the response value of the electronic nose became smaller.

4. Conclusions

In the process of irradiation, proteins, lipids and other components in food are easy to interact with the free radicals and ions produced during irradiation, and the flavor is also changed (Brewer, 2009). In this experiment, the *E*-nose odor profile of prepared soft-shelled turtle dishes had obvious difference with each treatment, indicating that the composition of volatile compounds of the samples changed significantly after irradiation. The samples before and after irradiation were significantly distinguished by PCA, among which the difference between the low temperature pretreatment group and the control group of the control group (CK) was the minimum. After 180 d of storage at room temperature, the odor profile of different treatment was similar. PCA results showed that the low temperature, 0.1 % rosemary and 0.1 % TBHQ pretreatment groups overlapped with the control group (CK2). Different

treatment have no obvious effect on the taste outline of the *E*-tongue of prepared soft-shelled turtle dishes. GC–MS volatile compounds of prepared soft-shelled turtle dishes with different treatment have obvious differences, cluster analysis results show that 6 kGy irradiation group, low temperature pretreatment and control group (CK) into a category, after 180 d of storage at room temperature, only low temperature pretreatment group and control group (CK) into a category, indicating that the volatile compounds composition of low temperature pretreatment group was the closest to the control group. The results of ROAV showed that the key flavor compounds in prepared soft-shelled turtle dishes were heptanal, octanal, (*E*)-2-octenal, nonanal, (*E,E*)-2,4-nonadienal, decanal, (*E*)-2-decenal, (*E,E*)-2,4-decadienal, 2-undecanal, 1-octen-3-ol, and 2-pentylfuran, indicating that the aldehydes are the most important flavor substances in prepared soft-shelled turtle dishes. At present, international research believes that the source of irradiation flavor of meat products mainly has two aspects: firstly, the irradiation will decompose sulfur amino acids in meat products to produce such as NH_3 and H_2S; secondly, the irradiation will produce off-odor compounds (Nam & Ahn, 2003) such as aldehydes and ketones. No sulfur-containing volatile compounds were identified in the GC–MS analysis, and the response values of the E-nose sensor W2W (aromatic compound and organic sulfide) were significantly lower than that of the unirradiated sample (CK1), indicating that the content of sulfur compounds didn't increase significantly after irradiation. However, the relative contents of key aldehydes in prepared soft-shelled turtle dishes increased significantly after irradiation, which may be the main component that leads to the off-odor of prepared soft-shelled turtle dishes after irradiation. Low temperature or the addition of three kinds of antioxidants pretreatment has a certain effect on maintaining the flavor of prepared soft-shelled turtle dishes after irradiation, among which the low temperature effect is the best, which provides ideas for the control of the odor of prepared soft-shelled turtle dishes irradiation. This study can provide theoretical reference for the application of irradiation technology in the sterilization and preservation processing of prepared soft-shelled turtle dishes and its flavor control.

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CRediT authorship contribution statement

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Declaration of competing interest

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

Data availability

Data will be made available on request.

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