

Analysis of Marinated Flavor Evaluation of Different Parts of Cherry Valley Duck Meat

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ABSTRACT

To screen the suitable raw material parts of cherry valley duck for the same brine formula in brined duck products, this study took duck wings, duck necks, duck gizzards, duck heads and duck clavicles as research objects. Volatile components were analyzed by sensory evaluation, solid phase microextraction-gas chromatography-mass spectrometry (SPME-GC-MS) and gas chromatography-ion mobility spectrometry (GC-IMS). The results showed that duck neck had the best sensory evaluation. A total of 54 volatile compounds were identified in five brined duck parts by SPME-GC-MS, while 22 volatile compounds were detected by GC-IMS. Fourteen key volatile compounds were screened out by relative odor activity value (ROAV) and variable importance in projection (VIP). Among them, 1-Nonanal were the key compounds leading to the differences between brined duck neck and other parts, and brined duck neck exhibited more prominent fatty aroma. SPME-GC-MS and GC-IMS showed a synergistic effect, which provided a theoretical basis for the industrial production of brined duck products.

KEYWORDS

Volatile substances; Sensory evaluation; SPME-GC-MS; GC-IMS

1. INTRODUCTION

China is rich in duck breed resources, with distinct differences in growth rate and meat performance among various breeds. The Cherry Valley duck, as the current mainstream meat duck breed in China, offers advantages such as fast growth rate, high feed conversion efficiency, high lean meat percentage, strong disease resistance, and wide geographical adaptability [1]. In industrial production, although a uniform marinating formula is used, the distribution and content of nutrients such as fat and protein vary across different carcass parts. During the marinating process, continuous exchange occurs among spices, seasonings, and meat components [2], leading to significant differences in the adsorption and retention of flavor substances, as well as the formation of new flavor compounds during processing. These variations ultimately result in distinctive flavor profiles. Significant differences in taste and flavor are observed among different parts marinated with the same recipe, and the flavor of marinated duck is a key indicator of its quality. Therefore, this study aims to evaluate the suitability of the same marinade for different duck parts by detecting volatile compounds in various marinated duck parts.

Current methods for flavor component detection include high-performance liquid chromatography(HPLC) [3], electronic nose technology [4], gas chromatography-mass spectrometry(GC-MS) [5], gas chromatography-olfactometry(GC-O) [6], and gas chromatography-ion mobility spectrometry (GC-IMS)[7]. GC-MS, which combines gas chromatography and mass spectrometry, is widely used to detect volatile components in various substances. For example, Zhao Zhihui et al [8]. used headspace solid-phase microextraction combined with GC-MS to determine volatile flavor compounds in beef from Tongliao, Inner Mongolia, identifying 117 volatile substances. GC-IMS is a hyphenated technique that integrates gas chromatography with ion mobility spectrometry, offering advantages such as wide analytical range, high sensitivity, no need for complex sample pretreatment, and rapid detection. It is particularly suitable for the rapid detection of volatile organic compounds. For instance, Wang Limei et al [9]. used GC-IMS to determine the main volatile flavor components in brine and marinated duck necks under different treatment conditions.

In this study, five parts of Cherry Valley duck—duck neck, duck wing, duck head, duck keel, and duck gizzard—were selected as research subjects and processed under uniform marinating formula and conditions. SPME-GC-MS and GC-IMS were used in combination [10, 11] to systematically compare and analyze the composition of volatile flavor compounds. Principal component analysis (PCA) and partial least squares discriminant analysis (PLS-DA) were applied for data analysis. Combined with variable importance in projection (VIP) and relative odor activity value (ROAV) methods, the differential volatile flavor compounds among different parts were identified. Sensory evaluation was also conducted to verify the correlation between flavor chemical analysis results and sensory perception. From a flavor chemistry perspective, this study aims to scientifically elucidate the intrinsic flavor characteristics of different marinated duck parts, reveal the rules governing flavor formation, and provide theoretical basis and data support for the precision processing of Cherry Valley duck by-products, the development of differentiated products, and the targeted regulation of flavor quality.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

2.1.1. Materials

Cherry Valley ducks, provided by Zibo Haiyue Longgong; mixed spices, provided by Zibo Haiyue Longgong; green Sichuan pepper, from Zibo Haiyue Longgong Logistics Port; iodized table salt, China Salt Shanghai Salt Industry Company; chicken essence, Shanghai Tatale Food Co., Ltd.; Monascus red (red yeast rice pigment), Xuchang Yichengde Trading Co., Ltd.; peanut oil, Shandong Longda Commerce Co., Ltd.

2.1.2. Instruments and Equipment

Table 1. Main instruments and equipment

Instrument	Model	Manufacturer
Electronic analytical balance	AL103	Mettler-Toledo Instruments Co., Ltd.
Metal bath solid-phase microextraction probe holder	KL01	Beijing Kanglin Technology Co., Ltd.
Solid-phase extraction fiber	PDMS	Beijing Kanglin Technology Co., Ltd.
Low-temperature refrigerator	BCD-290W	Qingdao Haier Co., Ltd.
Gas chromatography-ion mobility spectrometry (GC-IMS)	FlavourSpec®	G.A.S. mbH, Germany
Gas chromatography-mass spectrometry (GC-MS)	7890A	Agilent Technologies Co., Ltd.

2.2. Experimental Methods

2.2.1. Sample Preparation

(1) Process flow diagram: Spices → Marinade → Pre-treated different duck parts → Marinating → Finished product

(2) Raw material pretreatment: Following the method of Wang Limei[9], 100 g each of duck neck, duck keel (breast plate cartilage), duck gizzard, duck wing, and duck head were taken. The samples were soaked to remove blood, then rinsed with running water. Special attention was paid to cleaning the blood from the nostrils of the duck heads. The samples were drained and set aside.

(3) Marinade recipe: 1.29 g of mixed spices, 1.2 g of green Sichuan pepper, 1.125 g of salt, 2.89 g of monosodium glutamate (MSG), 0.028 g of Monascus red (red yeast rice pigment), 0.75 g of peanut oil, and 500 mL of water.

(4) Marinating: 500 mL of water was added to the pot, and the induction cooker was set to maximum power for heating. After the water came to a boil, the weighed mixed spices, salt, MSG, Monascus red, and peanut oil were added. The raw materials were then added for marinating. During the marinating process, the marinade was kept boiling. The marinating time was uniformly set to 30 min. After turning off the heat, the samples were promptly removed to prevent the duck products from disintegrating in the pot.

(5) Sample packaging: The meat from different duck parts was separately chopped, mixed thoroughly, placed into vacuum bags, and stored frozen at low temperature until further use.

2.2.2. Sensory Evaluation

The method was slightly modified based on the method of Tan Qingling [12] and the national standard GB/T 23586-2022 [13]. Fifteen sensory panelists who have long been engaged in the quality research of marinated duck were invited. They received training in olfactory sensitivity and comprehensive sensory evaluation professionalism. The color, aroma, taste, mouthfeel, and tissue structure of different marinated duck parts after cooling were evaluated. The evaluation results were classified into three grades: excellent, medium, and poor. Excellent corresponded to 9-10 points, medium to 7-8 points, and poor to 0-6 points. The sensory evaluation criteria are shown in Table 2.

Table 2. Sensory quality evaluation criteria for marinated duck

Score	Color	Aroma	Taste	Mouthfeel	Tissue structure
Excellent (9-10 points)	Uniform and consistent color, bright and glossy, with the inherent color of the product	Rich aroma, no off-flavor, with the inherent odor of the product	Moderate saltiness, rich marinating flavor, with the inherent taste of the product	Easy to chew, tender and elastic meat with chewiness	Regular shape, compact and elastic structure, with the inherent tissue structure of the product
Medium (7-8 points)	Relatively uniform color, glossy but not pronounced, with the inherent color of the product	Light aroma, no off-flavor, with the inherent odor of the product	Moderate saltiness, coordinated marinating flavor, with the inherent taste of the product	Relatively easy to chew, slightly tough texture	Basically regular shape, relatively compact structure, average elasticity, with the inherent tissue structure of the product
Poor (0-6 points)	Uneven color, no gloss, deviating from the inherent color of the product	No aroma, presence of off-flavor, deviating from the inherent odor of the product	Excessively salty or bland, uncoordinated marinating flavor, deviating from the inherent taste of the product	Difficult to chew, dry and hard or soft and mushy texture	Deformed and damaged shape, loose and inelastic structure, deviating from the inherent tissue structure of the product

2.2.3. Solid-Phase Microextraction Gas Chromatography-Mass Spectrometry

SPME conditions: The method of He Xufeng et al. [5] was referenced with slight modifications. A 2 g (accurate to 0.001 g) portion of duck meat was weighed and placed into a 20 mL headspace vial. After sealing, the vial was placed on a solid-phase microextraction instrument and heated at 60 °C. The extraction fiber was then inserted into the headspace vial, and the fiber head was extended to

adsorb volatile compounds for 30 min. Finally, the extraction fiber was withdrawn and inserted into the GC-MS injection port.

GC conditions: The method of Gong Yaoqian et al. [14] was referenced. The injection port temperature was 250 °C. The injection mode was splitless. The carrier gas was helium (purity 99.999%) at a flow rate of 0.6 mL/min. The column was an HP-5MS fused silica capillary column (30 m × 0.25 mm, 0.25 μm). The temperature program was as follows: initially held at 40 °C for 2 min, then increased to 60 °C at 5 °C/min, then to 100 °C at 10 °C/min, then to 250 °C at 18 °C/min, and finally held at 250 °C for 10 min.

MS conditions: The method of Gong Yaoqian et al. [14] was referenced. An electron impact (EI) ion source was used with an ionization voltage of 70 eV. The transfer line temperature was 280 °C, and the ion source temperature was 230 °C. The mass scan range was 50–500 u.

2.2.4. Gas Chromatography-Ion Mobility Spectrometry

The method of Yao Wensheng et al. [7] was referenced with slight modifications. A 2 g sample was placed into a 20 mL headspace vial. The sample was incubated at 50 °C for 20 min with an injection needle temperature of 80 °C. The incubation rotation speed was 500 r/min. The FlavourSpec® conditions were as follows: column type: MXT-5 (15 m, 0.53 mm ID, 1 μL); analysis time: 20 min; column temperature: 60 °C; carrier/drift gas: N₂.

2.2.5. Calculation of Relative Content of Volatile Compounds

The relative content of each detected component was calculated using the peak area normalization method [15]. The calculation formula is shown in Equation (1):

$$\text{Relative content(\%)} = \frac{\text{Peak area of individual component}}{\text{Sum of peak areas of all components}} \times 100 \quad (1)$$

2.2.6. ROAV Calculation

In this study, the ROAV (Relative Odor Activity Value) method was used to identify the key aroma compounds in different parts of marinated Cherry Valley duck. The ROAV of the aroma component that contributed the most to the flavor of marinated duck was defined as 100. The ROAVs of the remaining aroma compounds were calculated according to Equation (2):

$$ROAV = \frac{C_i}{C_{\max}} \times \frac{T_{\max}}{T_i} \times 100 \quad (2)$$

Where C_i and T_i represent the relative content (%) and odor threshold (μg/kg) of each aroma component, respectively; and C_{\max} and T_{\max} represent the relative content (%) and odor threshold (μg/kg) of the aroma component that contributed the most to the flavor of marinated duck [16].

2.2.7. Data Processing

Origin 2024 software and SIMCA 14.1 were used for graphing. Key flavor compounds were screened based on ROAV and VIP values. Two-dimensional spectra, three-dimensional spectra, and fingerprints were generated using Gallery Plot software.

3. RESULTS AND DISCUSSION

3.1. Sensory Evaluation of Different Marinated Duck Parts

Sensory evaluation is the most intuitive indicator for describing and judging food quality, and it is also an important component of the quality control system. Based on the data presented in Appendix

C, systematic processing was performed to calculate the mean and standard deviation of each indicator. The sensory evaluation results of the five marinated duck parts are shown in Table 3.

Table 3. Sensory Evaluation Results of Five Parts of Marinated Duck

Sample	Color	Aroma	Taste	Mouthfeel	Tissue
MDW	7.90±0.15 ^a	7.50±0.22 ^b	8.20±0.23 ^b	7.80±0.20 ^a	7.90±0.15 ^b
MDN	7.20±0.21 ^b	9.10±0.13 ^a	8.80±0.24 ^a	7.40±0.22 ^b	7.20±0.21 ^d
MDH	6.20±0.24 ^d	6.90±0.18 ^c	6.50±0.25 ^d	6.40±0.23 ^d	7.40±0.19 ^c
MDG	8.20±0.23 ^a	6.40±0.24 ^d	5.00±0.26 ^e	5.70±0.25 ^e	8.60±0.22 ^a
MDC	6.60±0.22 ^c	7.10±0.19 ^c	7.40±0.21 ^c	6.70±0.20 ^c	7.20±0.18 ^d

Note: MDH: Marinated duck head; MDN: Marinated duck neck; MDC:Marinated duck clavicle; MDW: Marinated duck wing; MDG:Marinated duck gizzard.

Significant differences ($p < 0.05$) were observed among the different marinated duck parts in terms of color, aroma, taste, mouthfeel, and tissue structure. Among them, MDN scored significantly the highest in aroma and taste, exhibiting a rich marinated aroma and good palatability. MDW showed outstanding performance in mouthfeel and tissue structure, with a balanced overall sensory profile. Although MDG received relatively high scores for color and tissue structure, its scores for taste and mouthfeel were low. MDH and MDC exhibited moderate levels across all indicators. In summary, MDN possessed the best overall sensory quality and was more preferred by consumers.

According to the sensory evaluation criteria described in section 2.2.2, five different samples—MDW, MDN, MDH, MDG, and MDC—were evaluated based on five attributes: color, aroma, taste, mouthfeel, and tissue structure. The results are shown in the figure, where the data represent the mean scores from 15 sensory panelists.

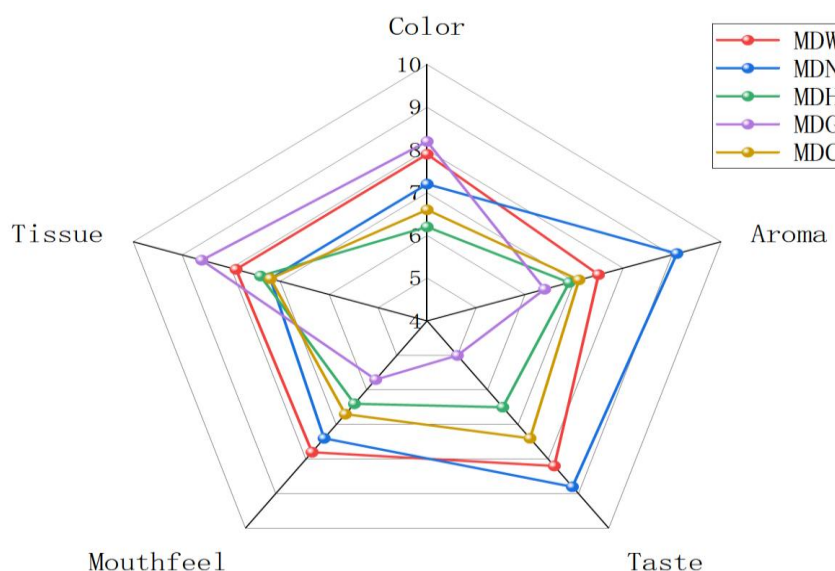


Figure 1. Radar Chart of Sensory Evaluation of Five Parts of Marinated Duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

As shown in Figure 1, analysis of the aroma and taste of marinated duck revealed the following order: MDN > MDW > MDC > MDH > MDG. Except for mouthfeel, where MDN was slightly lower than MDW, MDN was superior to the other marinated duck parts in all other aspects. Considering all factors comprehensively, MDW exhibited the best mouthfeel, with tender, elastic, and chewy meat, while maintaining relatively high levels in the other four aspects. Overall, MDW was second only to MDN in popularity. MDN showed uniform but not pronounced color and was the product with the

highest overall sensory evaluation score. MDH had poor color and a light aroma, but its tissue shape was intact and compact. MDG exhibited the best color and tissue structure; however, its mouthfeel was difficult to chew, with excessive saltiness and an uncoordinated marinating flavor. MDC was moderate in all aspects, with a tissue structure similar to that of MDN. Overall, MDN was more preferred by consumers. Based on the above observations, MDN had the optimal sensory evaluation.

3.2. GC-IMS Analysis of Different Marinated Duck Parts

3.2.1. GC-IMS 2D and 3D Spectral Analysis

GC-IMS technology was used to analyze the volatile organic compounds in five types of marinated duck parts: MDH, MDN, MDC, MDW, and MDG. The results are shown in Figure 2 (a-b). Figure 2 (a) presents the three-dimensional spectra of the five marinated duck parts, showing differences in the intensity of characteristic peaks of volatile compounds. MDG exhibited the highest signal intensity of volatile compounds, indicating the highest concentration of released volatile compounds, followed by MDH, MDW, and MDC, while MDN showed the lowest signal peak intensity, suggesting the lowest content of volatile compounds. Projection of the three-dimensional spectra yielded a bottom-up two-dimensional spectrum. As shown in Figure 2 (b), the background of the entire two-dimensional spectrum is blue. The red vertical line at a drift time of approximately 4.0 ms represents the reactant ion peak (RIP). Each point on either side of the RIP represents a signal of a volatile organic compound (VOC) [17]. The color gradient intuitively represents the concentration of substances, where red indicates high-concentration components and white indicates low-concentration components. The study found that the signal peaks of the five marinated duck samples were mostly distributed between retention times of approximately 200 s and 600 s. Among them, MDG had the highest number of red signal peaks, followed by MDH, MDW, and MDC, while MDN exhibited the weakest overall signals, with most areas showing blue signals. These results reveal the overall polarity distribution of volatile substances in different marinated duck parts and also confirm the good separation ability of the GC-IMS method for small-molecule compounds with different properties.

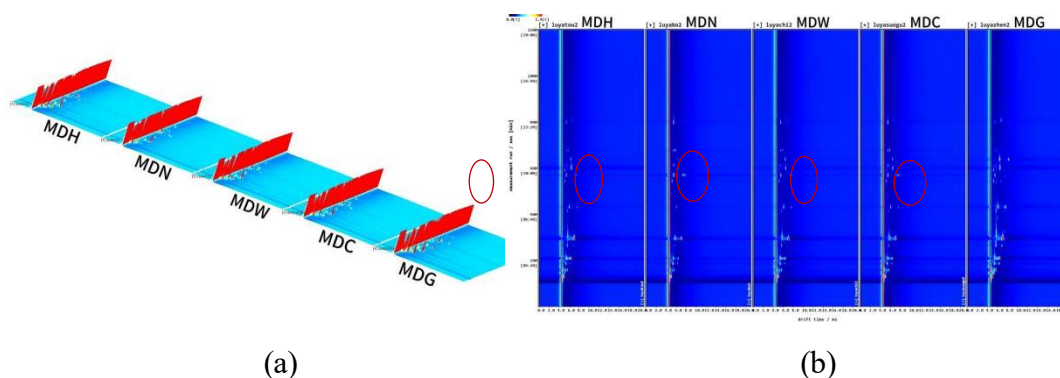


Figure 2. 3D spectrum (a) and 2D spectrum profiles of VOCs in five parts Marinated duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

3.2.2. Comparative Analysis of GC-IMS Aroma Component Fingerprints

Based on the retention times and ion drift times of volatile substances in Appendix B, qualitative analysis of volatile compounds was performed by matching against the GC-IMS database. A total of 22 volatile compounds were detected across the five types of marinated duck parts, including 6 esters, 2 pyrazines, 3 aldehydes, 3 alkenes, 1 terpene, 4 alcohols, and 3 ketones. Among them, esters and alcohols accounted for the highest proportions, followed by aldehydes, alkenes, and ketones, then pyrazines, with terpenes being the least abundant. These aroma components collectively contributed to the characteristic flavor of marinated duck.

To identify the differences in flavor characteristics among the five duck parts processed with the same marinade, a fingerprint was generated using the Gallery Plot plugin within the GC-IMS system (Figure 3). As shown in Figure 3, the five marinated duck parts exhibited both common and characteristic volatile components. The fingerprint was divided into four regions: red, orange, yellow, and green. Five VOCs (red region) were commonly detected across all five marinated duck samples, including 2-ethyl-3,5-dimethylpyrazine (burnt odor), β -pinene (resinous odor), 2-methoxy-3-methylpyrazine (roasted nutty odor), ethyl butyrate (pineapple-like odor), and benzaldehyde (bitter almond odor). These compounds collectively formed the basic flavor profile of marinated duck. The orange region represents the specific aroma signal peaks of MDN, including limonene, 4,5-dihydro-2-methyl-3(2H)-thiophenone, and 1-octen-3-ol, which together formed a complex flavor combining fruity and mushroom-like notes. The green region represents the specific aroma signal peaks of MDC, including ethyl acetoacetate, which imparted a fruity characteristic flavor to MDC. MDG exhibited 11 specific aroma components in the yellow region, showing significant flavor diversity: esters (e.g., hexyl acetate, propyl butanoate) contributed fruity and grassy notes to MDG; aldehydes (e.g., heptanal, 2-methylpentanal) imparted fatty notes; alkenes (e.g., β -myrcene) brought spicy and balsamic notes; ketones (e.g., 2-heptanone) provided fruity and slightly medicinal notes; and alcohols (e.g., 1-hexanol, 1-pentanol) imparted fresh green notes to MDG. Apart from the volatile compounds commonly detected, MDC and MDH exhibited no other characteristic volatile substances.

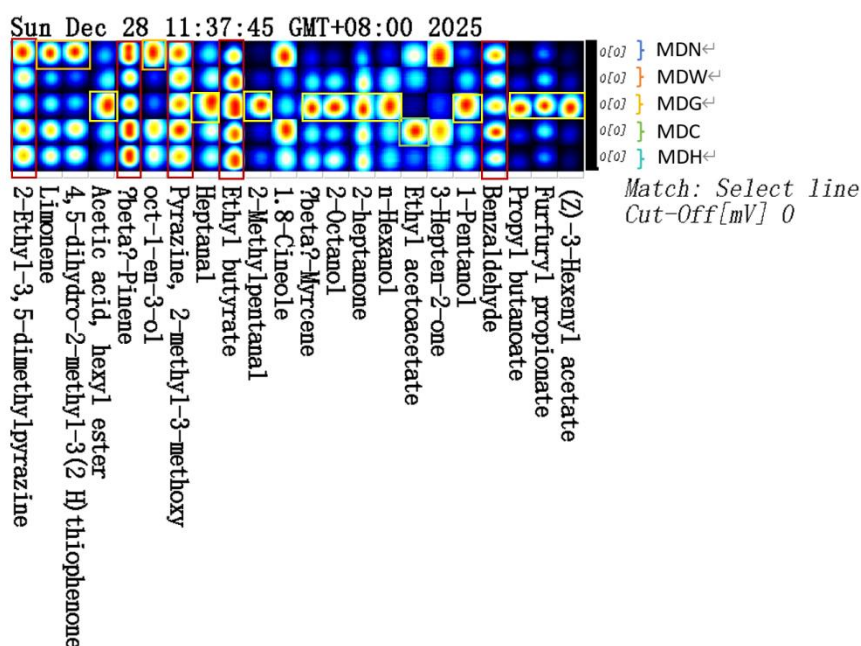


Figure 3. Fingerprint of VOCs in five parts Marinated duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

3.3. SPME-GC-MS Analysis of Different Marinated Duck Parts

SPME-GC-MS technology was used to analyze the five types of marinated duck parts, and a total of 54 volatile components were identified (see Appendix A). On this basis, statistical analysis was performed on the types and quantities of volatile substances in each part. The results are shown in Table 4. The volatile substances detected from the five marinated duck parts included aldehydes, ketones, alkenes, and others. Among them, MDW exhibited the highest number of volatile compounds, with a total of 30 components, including 6 aldehydes, 5 alcohols, and 14 alkenes. MDH showed the lowest number of detected volatile compounds, with a total of 17 components, including 3 aldehydes, 6 alkenes, and 4 hydrocarbons.

Table 4. Types of VOCs in five parts Marinated duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

Category	Number				
	MDW	MDN	MDH	MDG	MDC
Aldehydes	6	7	3	3	3
Alcohols	5	2	1	2	3
Ketones	2	1	1	-	1
Alkenes	14	8	6	12	17
Hydrocarbons	2	2	4	2	3
Esters	1	-	1	1	-
Ethers	-	-	1	1	1
Total	30	20	17	21	28

Note: "-" in the table indicates that no volatile substance was detected.

As shown in the Venn diagram in Figure 4, the composition of volatile compounds in the five types of marinated duck parts exhibited certain differences. A total of six volatile compounds were commonly identified across the five marinated duck samples. MDW contained four specific volatile substances, including α -terpineol, 6-epi-shyobunol, (-)- α -thujone, and estragole, which contributed piney and herbal, medicinal notes. MDN contained two specific volatile substances, namely nonanal and pentanal, which together imparted fatty aldehyde notes to the sample. MDH contained five specific volatile substances, namely (E)- β -ocimene, (-)- β -pinene, 3-carene, n-heptadecane, and vinyl hexanoate, which collectively contributed fresh herbal, piney, and sweet fruity notes to MDH, along with a subtle waxy fatty undertone. MDG contained three specific volatile substances, including trans-2-undecenal, p-cymene, and β -copaene, presenting overall fatty aldehyde and spicy notes. MDC contained two specific volatile substances, including α -acorenenol and α -selinene, which together imparted woody, herbal/medicinal, and spicy notes to MDC.

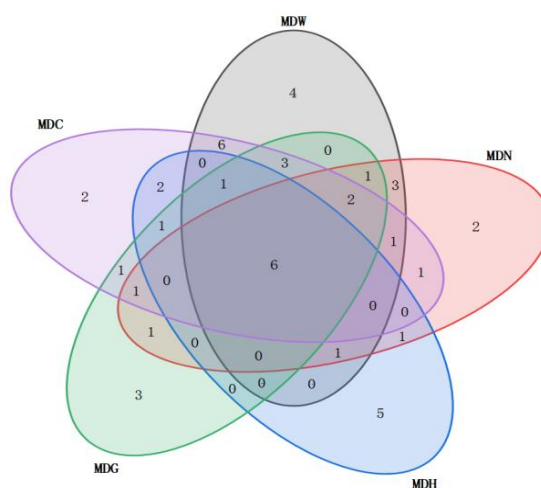


Figure 4. Venn Diagram of VOCs in five parts Marinated duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

3.4. Comprehensive Analysis of SPME-GC-MS and GC-IMS

The volatile organic compounds (VOCs) detected by SPME-GC-MS and GC-IMS were plotted in a Venn diagram, as shown in Figure 5. The results indicated that five volatile substances were

commonly detected by both techniques, namely heptanal, benzaldehyde, eucalyptol, β -pinene, and myrcene, suggesting considerable differences between the two detection and analysis techniques. The combined use of SPME-GC-MS and GC-IMS, through technical complementarity, significantly expanded the analytical range of VOCs in complex systems. This hyphenated technique integrated the high-throughput, rapid screening capability of GC-IMS with the precise lipid-oriented analysis of SPME-GC-MS, offering a distinct advantage for analyzing the volatile components of samples.

The detection results from both SPME-GC-MS and GC-IMS were predominantly characterized by ketones, aldehydes, alcohols, and esters. Ketones are mainly generated through the Maillard reaction, oxidation or degradation of unsaturated fats, and amino acid degradation. They typically possess high odor thresholds and therefore contribute relatively little to the flavor of marinated duck meat, imparting diverse aromas such as musty, buttery, fruity, and floral notes to the product [18]. Aldehydes originate from amino acid and fatty acid metabolism [11], generally have low thresholds and strong odors, contributing fatty, roasted, and nutty notes to the product. Esters are mainly derived from the esterification reaction between alcohols and acids, typically have low thresholds, and primarily exhibit green, honey-like aromas. Alcohols mainly originate from lipid oxidation, amino acid degradation, and carbohydrate formation [19], generally have high thresholds, and often present rancid, aromatic, apple-like, and caramel-like notes. The synergistic effects of these components collectively constitute the flavor profile of marinated duck meat [20, 21].

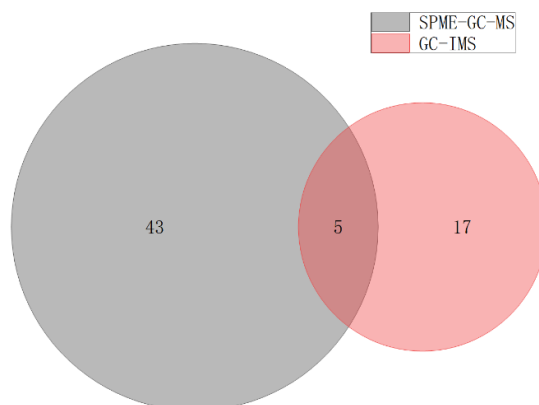


Figure 5. Venn Diagram of VOCs from two analytical techniques

3.5. Screening of Differential Volatile Compounds in Different Marinated Duck Parts

3.5.1. PCA Analysis of Key Flavor Compounds in Different Marinated Duck Parts

To reveal the differences in volatile compounds among the five types of marinated duck parts, the volatile compound data obtained from SPME-GC-MS and GC-IMS were processed separately.

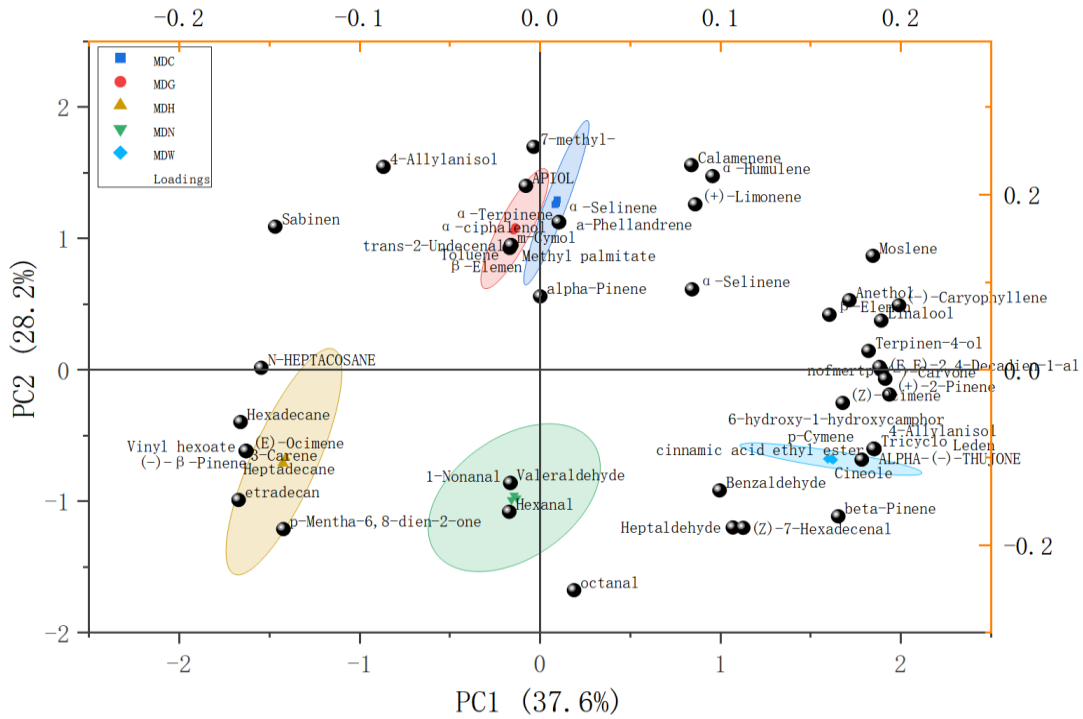


Figure 6. PCA plots of VOCs in five parts Marinated duck by SPME-GC-MS

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

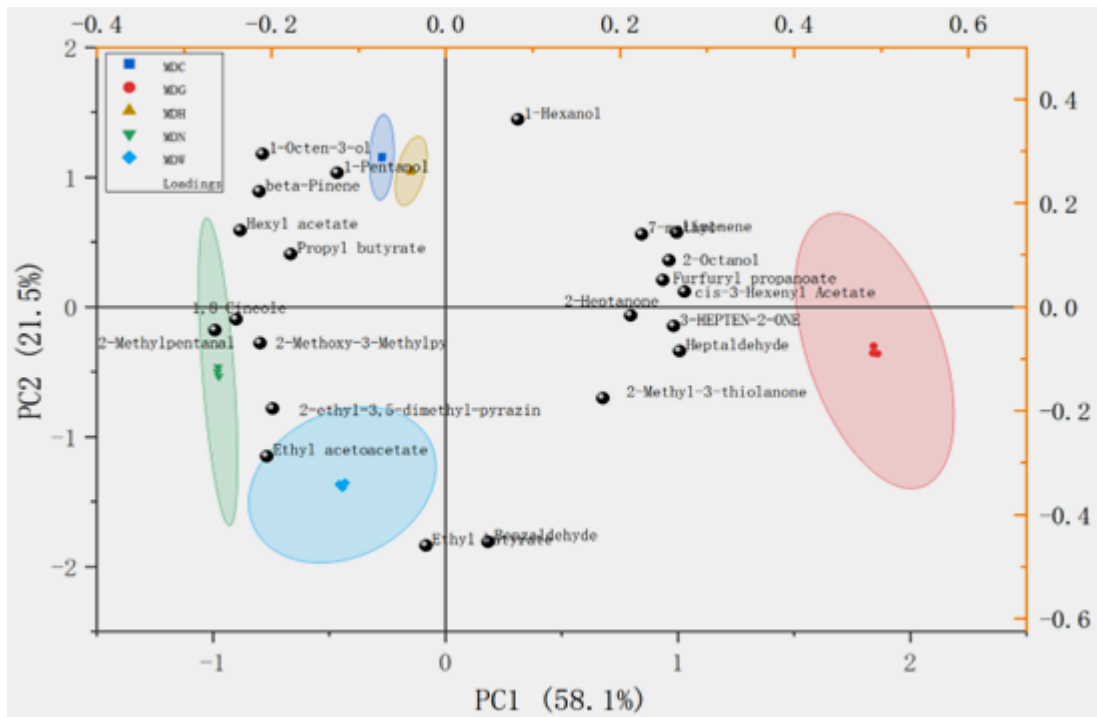


Figure 7. PCA plots of VOCs in five parts Marinated duck by GC-IMS

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

As shown in Figures 6 and 7, the contribution rates of the first and second principal components in SPME-GC-MS were 37.6% and 28.2%, respectively, with a cumulative contribution rate of 65.8%.

In GC-IMS, the contribution rates of the first and second principal components were 58.1% and 21.5%, respectively, with a cumulative contribution rate of 79.6%. These results indicate that the first two principal components could effectively reflect the overall characteristics of the volatile compounds in the five marinated duck parts. The PCA plots generated based on SPME-GC-MS and GC-IMS techniques showed that the five marinated duck parts exhibited a clear separation trend spatially, with significant inter-group distribution distances, indicating certain differences in the composition and content of volatile compounds among different marinated duck parts. This result further confirms that the PCA model can effectively distinguish the flavor characteristics of different marinated duck parts, providing scientific support for the selection of duck parts and flavor quality evaluation.

3.5.2. PLS-DA Analysis of Key Flavor Compounds in Different Marinated Duck Parts

PLS-DA is a supervised multivariate statistical analysis method that maximizes inter-group differences based on predefined classifications (Y variables), achieving better separation than PCA. PLS-DA discriminant models were established using the relative contents of VOCs obtained by the two detection techniques as dependent variables and the five marinated duck parts as independent variables (Figure 8a-b). Points of different colors represent marinated duck samples from different parts. The model evaluation results were as follows: for SPME-GC-MS data, the explained variance RX^2 was 0.619, RY^2 was 0.998, and the predictive ability Q^2 was 0.991; for GC-IMS data, the explained variance RX^2 was 0.796, RY^2 was 0.999, and the predictive ability Q^2 was 0.999. The R^2 and Q^2 values of all models were significantly close to 1, indicating good model fit and strong predictive ability. To determine whether the models suffered from overfitting, permutation tests were performed (Figure 9a-b). The results showed that the intercepts of R^2 and Q^2 were 0.275 and -0.989 for SPME-GC-MS, and 0.054 and -0.82 for GC-IMS, respectively. All validation parameter intercepts were close to 0, and the Q^2 intercepts were negative, fully demonstrating that the models had good stability and no overfitting issues. With excellent predictive performance ($Q^2 > 0.99$), the models can not only clearly distinguish the flavor characteristics of different marinated duck parts but also provide solid technical support for product quality control and precise flavor regulation.

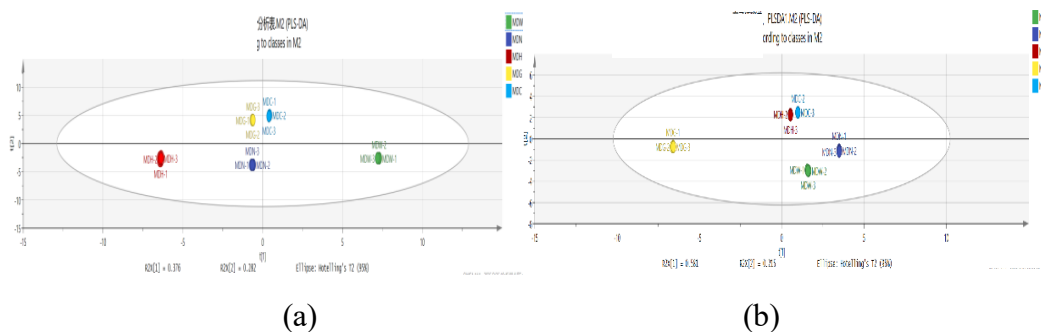


Figure 8. PLS-DA analysis of VOCs in five parts Marinated duck a: SPME-GC-MS b: GC-IMS
 MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

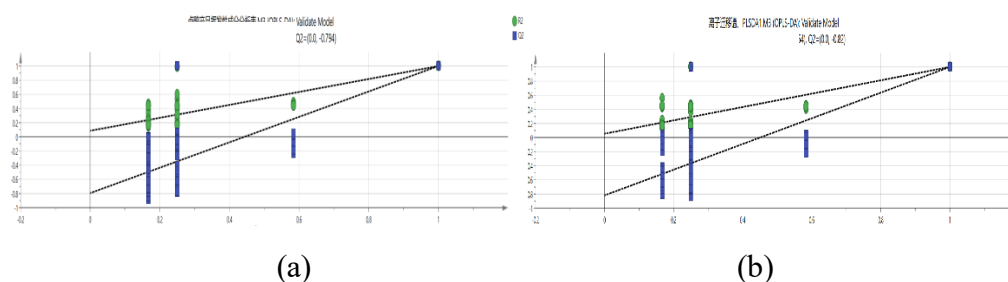


Figure 9. Replacement test of VOCs in five parts Marinated duck a: SPME-GC-MS b: GC-IMS

To thoroughly evaluate the contribution of each variable to the classification model, the VIP (Variable Importance in Projection) values of each volatile component were calculated based on the PLS-DA model. Volatile substances with VIP scores > 1 were considered to have a significant impact on the samples, with higher VIP values indicating greater influence. As shown in Figure 6, a total of 23 significant volatile substances with $VIP > 1$ were identified by SPME-GC-MS, including 13 alkenes, 4 aldehydes, 4 hydrocarbons, 1 alcohol, and 1 ester. Ranked by VIP value, these were nonanal, α -pinene, hexanal, heptanal, β -copaene, trans-2-undecenal, methyl palmitate, toluene, p-cymene, phellandrene, sabinene, (Z)-7-hexadecene, n-heptacosane, n-hexadecane, (-)- β -pinene, n-heptadecane, vinyl hexanoate, (E)- β -ocimene, 3-carene, and sabinene (note: sabinene appears twice in the original list; please verify). A total of 10 significant volatile substances with $VIP > 1$ were identified by GC-IMS. Ranked by VIP value, these were 1-pentanol, propyl butyrate, 1-hexanol, 4, 5-dihydro-2-methyl-3(2H)-thiophenone, 2-methoxy-3(5)-methylpyrazine, 2-heptanone, 2-ethyl-3, 5-dimethylpyrazine, ethyl butyrate, benzaldehyde, β -pinene, and β -myrcene.

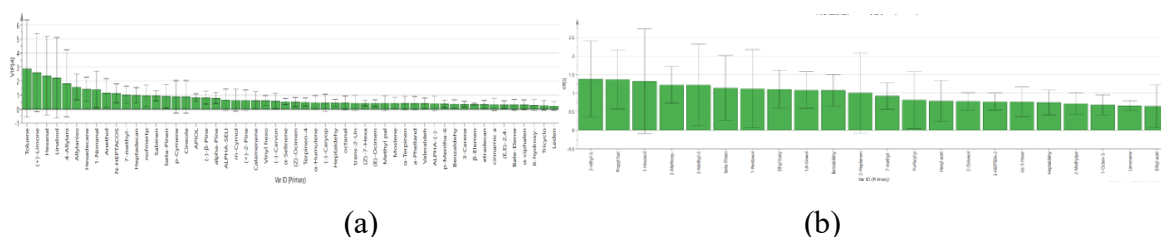


Figure 10. VIP plot of VOCs in five parts Marinated duck a: SPME-GC-MS b: GC-IMS

3.6. Identification of Key Aroma Attributes

Marinated duck contains numerous flavor compounds, but not every substance contributes significantly to its flavor. The contribution of a substance to flavor depends not only on its relative content but also on its odor threshold. Studies have shown that the ROAV (Relative Odor Activity Value) is an effective method for scientifically screening key flavor compounds, and the contribution of a single volatile compound to the overall flavor is positively correlated with its ROAV. Generally, $ROAV \geq 1$ indicates a key flavor compound that plays a decisive role in the overall flavor of the sample; $ROAV < 0.1$ indicates that the substance has no significant effect on the overall flavor; and $0.1 \leq ROAV < 1$ indicates a secondary flavor compound that plays a modifying role in the overall flavor of the sample [22].

Octanal exhibited a relatively high content in both SPME-GC-MS and GC-IMS detections, along with a low odor threshold, indicating that it contributed the most to the overall flavor of the samples. Therefore, its $ROAV_{max}$ was defined as 100. Based on the known odor thresholds of each volatile component, the ROAV values of all volatile substances were calculated according to methods 2.2.5 and 2.2.6. As shown in Table 5, The two techniques collectively identified 22 key volatile substances with $ROAV > 1$, including 1,8-cineole, 2-octanol, 7-methyl-, 1-octen-3-ol, 2-methoxy-3-methylpyrazine, benzaldehyde, propyl butyrate, 2-heptanone, 1-hexanol, ethyl butyrate, 1-pentanol, 2-methylpentanal, hexanal, 1-nonanal, linalool, beta-Pinene, (E)-Ocimene, Moslene, m-Cymol, Sabinen, APIOL and Toluene. The two techniques collectively identified 11 minor volatile substances with $0.1 < ROAV < 1$, including Hexyl acetate, cis-3-Hexenyl Acetate, Valeraldehyde, (Z)-Ocimene, nofmertp, (-)-Caryophyllene, α -Humulene, alpha-Pinene, a-Phellandrene and cinnamic. The volatile substance unique to MDW was cinnamic acid ethyl ester, a secondary volatile compound that provides fruity and sweet notes to MDW. The key volatile substance unique to MDH was Sabinen, which imparts grassy and floral notes to MDH. The volatile substance unique to MDC was a-Phellandrene, a secondary volatile compound that imparts a mixed aroma of black pepper and mint to MDC. MDG Methyl palmitate. Valeraldehyde and 1-Nonanal were the volatile substances unique to MDN, originating from the oxidative decomposition of lipids, accompanied by synergistic generation through the Maillard reaction.

To more precisely identify the key flavor substances, volatile flavor compounds satisfying both conditions of $VIP > 1$ and $ROAV \geq 1$ were comprehensively analyzed and compared. A total of 12 core volatile compounds were identified: beta-Pinene, 2-methoxy-3-methylpyrazine, benzaldehyde, propyl butyrate, 2-heptanone, 1-hexanol, 1,8-cineole, 7-methyl-, hexanal, 1-nonanal, linalool and Toluene.

Table 5. ROVA of aroma components in five parts Marinated duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC:Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard.

Compound Name	CAS No.	Threshold (mg/kg)	Aroma Attribute	ROAV (%)				
				MDW	MDN	MDH	MDG	MDC
Limonene	138-86-3	0.7	Spices	0.29	0.105	0.463	0.726	0.754
1,8-Cineole	470-82-6	0.084	Spices	3.912	2.37	2.741	1.334	8.929
Hexyl acetate	142-92-7	1.04	Fruity	0.392	0.191	0.535	0.281	0.73
cis-3-Hexenyl Acetate	3681-71-8	0.75	Fruity	0.173	0.077	0.297	0.79	0.53
2-Octanol	123-96-6	0.1	Meaty	2.523	0.763	3.727	4.82	4.747
7-methyl-	123-35-3	0.063	Spices	4.373	1.265	6.65	7.506	8.126
1-Octen-3-ol	3391-86-4	0.034	Meaty	14.261	7.22	18.932	13.618	31.876
2-Methoxy-3-Methylpy	2847-30-5	0.007	Burnt	68.126	21.842	70.59	10.357	56.421
Benzaldehyde	100-52-7	0.19	Spices	2.498	0.839	1.129	2.545	1.876
Propyl butyrate	105-66-8	0.15	Meaty	2.825	0.699	1.952	0.45	6.445
2-Heptanone	110-43-0	0.3	Meaty	1.435	0.329	1.454	1.804	2.256
1-Hexanol	111-27-3	0.4	Meaty	0.498	0.52	1.662	1.549	2.384
Ethyl butyrate	105-54-4	0.03	Fruity	16.211	5.507	6.552	12.77	9.929
1-Pentanol	71-41-0	0.47	Meaty	0.425	0.16	0.445	0.27	1.604
2-Methylpentanal	123-15-9	0.163	Meaty	2.056	0.959	1.624	0.92	3.81
Hexanal	66-25-1	0.005	Meaty	100	100	100	100	100
Valeraldehyde	110-62-3	0.012	Meaty	0	0.764	0	0	0
1-Nonanal	124-19-6	0.0011	Meaty	0	94.388	0	0	0
Linalool	78-70-6	0.037	Spices	64.947	17.588	37.906	65.775	83.665
beta-Pinene	7785-70-8	0.006	Spices	11.595	0	0	0	7.801
(Z)-Ocimene	5989-27-5	4.8	Spices	0.188	0.054	0.114	0.194	0.584
Moslene	3338-55-4	0.034	Spices	1.052	0.283	0	0	1.537
nofimertp	99-85-4	1	Spices	0.097	0.033	0.062	0.106	0.166
(-)-Caryophyllene	586-62-9	0.2	Spices	0.762	0	0	0	0.761
α -Humulene	87-44-5	0.064	Spices	0.754	0.145	0	0.666	0.889
alpha-Pinene	6753-98-6	0.16	Spices	0.159	0	0	0.312	0.436
(E)-Ocimene	80-56-8	0.041	Spices	0	0.35	0	0	2.452
Sabinen	3779-61-1	0.0187	Spices	0	0	1.353	0	0
m-Cymol	104-46-1	0.05	Spices	5.118	1.629	0	6.253	5.987
APIOL	535-77-3	0.036	Spices	0	0	0	2.236	0
a-Phellandrene	99-83-2	0.36	Spices	0	0	0	0	0.11
Toluene	108-88-3	0.33	Spices	0	0.062	0	4.956	0
Methyl palmitate	112-39-0	2.85	Meaty	0	0	0	0.013	0
cinnamic acid ethyl ester	4192-77-2	0.15	Spices	0.118	0	0	0	0

Note: "—" indicates that the volatile substance was not detected.

According to the method of Zhang Zeyu et al [23]. with slight modifications, four attribute terms describing the aroma of marinated duck were determined, namely spicy, roasted, meaty, and fruity. Based on the cumulative contribution of ROAV values of aroma compounds (see Appendix D), radar maps of aroma characteristics for the five marinated duck parts were obtained (Figure 11). The results

showed that among the aroma attributes of the five marinated duck parts, meaty aroma was much higher than the other three attributes, with intensities in the following order: MDN > MDC > MDH > MDW > MDG. No significant differences were observed in the fruity aroma dimension (MDW = 16.776; MDN = 5.775; MDH = 7.384; MDG = 13.841; MDC = 11.189). However, the MDN sample exhibited a more prominent meaty aroma; the MDC sample displayed a more prominent spicy aroma attribute; the MDH sample showed a more significant roasted aroma; and the MDW sample demonstrated a relatively prominent fruity aroma.

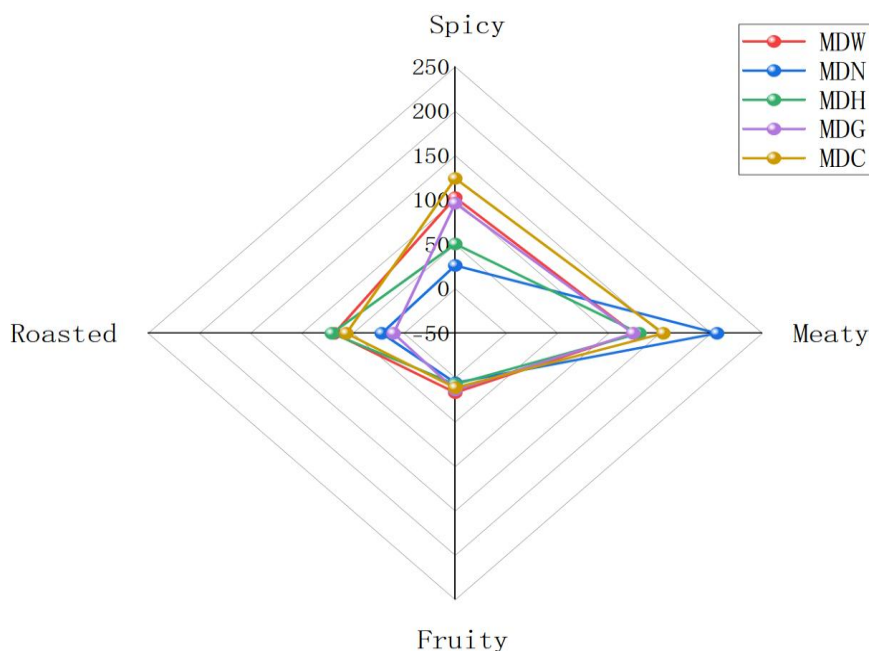


Figure 11. Radar Chart of aroma characteristics of five parts Marinated duck

MDH: Marinated duck head; MDN: Marinated duck neck; MDC: Marinated duck clavicle; MDW: Marinated duck wing; MDG: Marinated duck gizzard

4. CONCLUSION

The products obtained from marinating different parts of Cherry Valley duck, namely duck neck, duck wing, duck head, duck gizzard, and duck keel (breast plate cartilage), were analyzed through sensory evaluation, SPME-GC-MS, and GC-IMS to investigate the flavor differences among different parts after marinating and to comprehensively determine which part is more suitable for the same marinade. Sensory evaluation revealed that marinated duck neck was the most popular among consumers. The synergistic use of SPME-GC-MS and GC-IMS was then applied to comprehensively analyze the types of volatile compounds and aroma attributes. A total of 54 volatile compounds were detected by SPME-GC-MS across the five marinated duck parts, while 22 volatile compounds were detected by GC-IMS. Through VIP values and ROAV values, a total of 12 key volatile compounds were screened out: beta-Pinene, 2-methoxy-3-methylpyrazine, benzaldehyde, propyl butyrate, 2-heptanone, 1-hexanol, 1,8-cineole, 7-methyl-, hexanal, 1-nonanal, linalool and Toluene. Further analysis revealed that 1-Nonanal were a specific volatile compound unique to marinated duck neck. The aroma profile analysis showed differences in aroma characteristics among the five marinated duck parts. Among the aroma attributes of the five marinated duck parts, the marinated duck neck sample exhibited a more prominent meaty aroma; the marinated duck keel sample displayed a more prominent spicy aroma attribute; the marinated duck head sample showed a more pronounced roasted aroma; and the marinated duck wing sample demonstrated a relatively prominent fruity aroma. In summary, this study reveals from a flavor chemistry perspective that marinated duck neck possesses a more prominent meaty aroma attribute due to its richness in aldehydes, which is an important reason

for its greater popularity among consumers in terms of flavor. The results also indicate that the marinade formula used is more suitable for the marinating process of duck neck, effectively enhancing the presentation of its characteristic flavor.

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REFERENCES

- [1] Liu, K., Wang, X., & Chen, J. (2025). Comparative Study on the Meat Quality of Cherry Valley Duck and Jinling White Duck. *China Animal Health*, 27(10), 208–210. <https://doi.org/10.3969/j.issn.1008-4754.2025.10.087>
- [2] Jiang, J., Wu, M., & Wang, H. (2025). Changes in Sodium, Potassium Content and Physicochemical Properties of Sodium-Reduced Marinated Duck Legs and Brine. *China Meat Research Center*, 39(8), 34–2025. <https://doi.org/10.7506/rlyj1001-8123-20241209-323>
- [3] Wang, X., Wang, F., & Zhong, H. (2008). Determination of Capsaicin and Dihydrocapsaicin in Food by High Performance Liquid Chromatography. *Food Science*, 29(7), 378–381. <https://doi.org/10.7506/spkx1002-6630-200807>
- [4] Lu, K., Wang, X., & Sun, X. (2018). Analysis of the Volatile Components of Fermented Hot Pepper from Different Varieties Grown in Guizhou by Electronic Nose Combined with SPME-GC-MS. *Food Science*, 39(4), 199–205. <https://doi.org/10.7506/spkx1002-6630-201804030>
- [5] He, X., Yi, L., & Zhong, R. (2023). Analysis of volatile components and key aroma substances in the fermentation process of traditional chopped pepper based on HS-SPME-GC-MS. *Food and Fermentation Industries*, 49(19), 296–303. <https://doi.org/10.13995/j.cnki.11-1802/ts.034875>
- [6] Yu, J., Zeng, Y., & Bai, Y. (2024). Analysis of key volatile flavour compounds in chilli oil by odor activity combined with gas chromatography-olfactometry. *Food and Fermentation Industries*, 50(1), 286–292. <https://doi.org/10.13995/j.cnki.11-1802/ts.034875>
- [7] Yao, W., Cai, Y., & Liu, D. (2021). Analysis of volatile flavor compounds in smoked chicken thighs by HS-GC-IMS and HS-SPME-GC-MS. *Food and Fermentation Industries*, 47(9), 253–262. <https://doi.org/10.13995/j.cnki.11-1802/ts.034875>
- [8] Zhao, Z., Zhang, Y., & Ying, Y. (2024). Determination of Volatile Flavor Compounds in Beef from Tongliao, Inner Mongolia by Solid Phase Microextraction Combined with Gas Chromatography-Mass Spectrometry. *Journal of Food Safety and Quality*, 15(14), 178–187. <https://doi.org/10.19812/j.cnki.jfsq11-5956/ts.20240422004>
- [9] Wang, L., Lei, Q., & Zhong, Z. (2023). Effects of Different Processing Methods on Volatile Flavor Components of *Zanthoxylum bungeanum* Extract and Braised Duck Neck. *Science and Technology of Food Industry*, 44(3), 67–75. <https://doi.org/10.13386/j.issn1002-0306.2022040171>
- [10] Zhang, Y. Q., Ma, L. Z., & Wang, L. (2012). Use of rich BHI medium instead of synthetic TMH medium for gene regulation study in *Yersinia pestis*. *Biomedical and Environmental Sciences*, 25(6), 639–644. <https://doi.org/10.3967/0895-3988.2012.06.005>
- [11] Chen, J., Li, J., & Zhao, J. (2025). Effects of Different Drying Methods on the Volatile Substances of *Dictyophora rubrovolvata* Based on HS-SPME-GC-MS and HS-GC-IMS. *Science and Technology of Food Industry*, 46(12), 284–295. <https://doi.org/10.13386/j.issn1002-0306.2024070074>

- [12] Tan, Q. L. (2023). Study on Effect and Mechanism of Sous-vide Cooking Technology on Quality of Marinated Duck [Master's thesis]. <https://doi.org/10.27684/d.cnki.gxndx.2023.000718>
- [13] Standards Press of China. (2022). General Quality Standard for Soy Sauce and Pot-Roasted Meat Products (GB/T 23586-2022). Standards Press of China.
- [14] Gong, Y., Liu, H., & Luo, F. (2020). Effect of processing technology on the volatile flavor components of Zhijiang duck. *Food & Machinery*, 36(7), 194–200. <https://doi.org/10.3969/j.issn.1003-5788>
- [15] Wu, D., Lin, H., & Lu, D. (2025). Analysis of the Effects of Drying Methods on Volatile Components of Mexican Bay Scallop Based on Electronic Nose, GC-IMS and GC-MS. *Science and Technology of Food Industry*, <https://doi.org/10.13386/j.issn1002-0306.2025070209>
- [16] Sun, G., Luo, X., & Lin, D. (2024). Analysis of Impact of Different Parts of Beef on the Quality and Volatile Aroma Components of Boletus Beef Sauce Based on GC-MS. *Science and Technology of Food Industry*, 45(19), 216–227. <https://doi.org/10.13386/j.issn1002-0306.2023070053>
- [17] Meng, C., Li, J., & Wu, J. (2025). GC-IMS combined with HS-SPME-GC-MS and chemometrics were used to characterize and identify the characteristic flavor substances. *Science and Technology of Food Industry*. <https://doi.org/10.13386/j.issn1002-0306.2025080186>
- [18] Li, Y., Yuan, L., & Liu, H. (2022). Analysis of the changes of volatile flavor compounds in a traditional Chinese shrimp paste during fermentation based on electronic nose, SPME-GC-MS and HS-GC-IMS. *Food Science and Human Wellness*, 12(1), 173–182. <https://doi.org/10.1016/j.fshw.2022.07.035>
- [19] Liao, G., Shi, X., & Wang, J. (2025). Comparison of Aroma Components of Different Mulberry Leaf Teas Based on GC-MS and GC-IMS. *Modern Food Science and Technology*, 41(1), 262–272. <https://doi.org/10.13982/j.mfst.1673-9078.2025.1.1481>
- [20] Zhao, Z., Ding, Z., & Xu, P. (2018). Change of Flavor Compounds in Coix Seed Beverage during Storage Analyzed by SPME-GC-MS and Electronic Nose. *Food Science*, 39(14), 276–281. <https://doi.org/10.7506/spkx1002-6630-201814041>
- [21] Sun, Y., Miao, R., & Jiang, L. (2019). Analysis of Volatile Components of Potato Bread under Different Storage Conditions by Electronic Nose Combined with HS-SPME-GC-MS. *Food Science*, 40(2), 222–228. <https://doi.org/10.7506/spkx1002-6630-20180429388>
- [22] You, T., He, J., & Li, D. (2024). Regular Physicochemical and Microbiological Properties and Volatile Flavors of Sichuan Wu xiang-style Sausage. *Science and Technology of Food Industry*, 45(14), 224–233. <https://doi.org/10.13386/j.issn1002-0306.2023080055>
- [23] Zhang, Z., Wang, B., & Cao, Y. (2023). Effect of Spices on Aroma Quality of Beef Flavoring Produced by Thermal Reaction during Storage. *Food Science*, 44(12), 189–198. <https://doi.org/10.7506/spkx1002-6630-20220918166>