

Aroma Substances Generation and Variation of Broth in Pork Braised Processing based on Multi-Instrumental and Multiplex Analysis

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Abstract: The aim was to investigate and reveal the patterns of production and changes of major aroma substances in broth during quantitative repeated cycles of cooking and the effects of meat and spices on the formation of unique aroma in broth. Aroma substances were systematically identified and quantified for three groups (MS, broth cooked with meat and spices; M, broth cooked with meat; and S, broth cooked with spices) by using GC-MS, E-nose and tri-step infrared spectroscopy. The PCA model of M group E-nose showed that the total content of aroma substances reached the maximum value in the broth samples cooked for the third time. Meanwhile, the GC-MS results showed that benzaldehyde in the spices completely disappeared in the 4th brining, esters such as linalyl propionate and isopropyl myristate disappeared after the 5th and 6th brining, ketones basically disappeared in the 6th brining, and the relative content of alcohols in M group was highest in the 4th brining. Successful validation of the generation and variation of aroma substances by E-nose and GC-MS through tri-step infrared spectroscopy technique with increasing resolution. Therefore, the quality of braised meat products can be improved by replenishing the meat and spices after the 3th brining.

Keywords: Broth; Infrared Spectrum; Aroma Substances; Generation; Variation.

1. Introduction

Braised meat products are traditional cuisines with a long history in Asian countries, have abundant outputs and are widely popular among consumers owing to their bright color, unique flavor and excellent texture (Da, Nian, Shi, Li, Zhao, Zhang, et al., 2021). Braised meat is obtained by adding pre-processed raw meat to a broth added with spices or condiments and cooking for a long period of time. The broth will gradually evolve into a more stable and complex system after repeated cooking, which is often referred to as aged broth (Yao, Liu, Lin, Lu, Gan, Liu, et al., 2021). The generation of aroma substances in broth is a complex reaction process, including thermal degradation of muscle components after heating of raw meat and water, oxidation and degradation of lipid components, Maillard reactions and volatilization of various components in spices (Zhu, Yang, Song, Qiang, Han, & Zhang, 2023), all of which contribute to the rich flavor of braised meat products and affect the overall quality of the meat and broth. With the increasing number of braising cycles of broth and the constantly replenishment of raw materials, the flavor substances in the meat and spices were dissolved in the broth gradually (Kasaiyan, Caro, Ramos, Salvá, Carhuallanqui, Dehnavi, et al., 2023). Quantitative repeat braising cycles (QRBC) process is defined as a method where the parameters of braising raw materials such as meat, diversity spices, braising time, and temperature are

determined (Yao, Xu, Liu, Lu, Gan, Liu, et al., 2022). By utilizing the QRBC process, it is feasible to investigate how the flavor compounds quantitatively impact flavor attributes of the braised meat broth. Hence, it will provide valuable information to support the standard production of braised meat products.

It is well known that aroma is an important indicator that affects people's sensory evaluation of meat products (X.-H. Huang, Luo, Zhu, Ayed, Fu, Dong, et al., 2022). Gas chromatography-mass spectrometry (GC-MS) technique can be applied to analyze volatile substances in meat products, such as 109 volatile substances in roasted meat were detected by GC-MS technique (Song, Fan, Xu, Xu, Jia, & Feng, 2019). Electronic nose (E-nose) system is a potential method to analyze and anticipate changes in volatile substances in meat products during the entire cooking process (Chen, Gu, Zhang, Mao, & Tian, 2019). E-nose system combined with GC-MS technology could analyze the variations of volatile flavor compounds in duck meat during the cooking process (C. Li, Al-Dalali, Wang, Xu, & Zhou, 2022). Tri-step infrared spectroscopy (Tri-step IR), a comprehensive technique integrating Fourier transform infrared spectroscopy (FT-IR), second derivative infrared spectroscopy (SD-IR) and two-dimensional correlation infrared spectroscopy (2DCOS-IR), has been demonstrated as an effective approach for revealing the main constituents in complicated mixtures and distinguishing the varieties and contents of chemical constituents in highly similar matrices (Gu, Zou, Guo, Yu, Lin,

Hu, et al., 2017; S. J. Zhang, Xu, Chen, Zhou, & Sun, 2011). Therefore, Tri-step IR is feasible to analyze changes in odorants during cooking of meat.

The aroma of meat broth is one of the most important attributes for consumer acceptance or rejection. But until now, reports on the generation and variation of volatile compounds occurred in meat broth after reusage were still lacking. This work aimed to elucidate the generation and variation of overall aroma-relevant compounds and unveil the functions of meat and spices on the aroma formation of pork broth during the cycle cooking process. The content and change pattern of aroma-relevant compounds in QRBC broth samples (MS group) and two control groups (M and S groups) were analyzed by HS-SPME/GC-MS, E-nose, Soft Independent Modeling of Class Analogy (SIMCA) and Tri-step IR. The results of this work may provide more useful information for the optimization of QRBC processing methods and control the quality of braised meat products.

2. Materials and Methods

2.1. Materials and Reagents

Fresh pork loin (*Longissimus dorsi*) was purchased from Shanghai Aisen Meat Food Co., Ltd (Shanghai, China). The spice bag bought from the local market contained hawthorn (11 g), fennel (3 g), cinnamon (1.7 g), star anise (1.3 g), ginger (1 g), chili (1 g) and licorice (1 g).

2, 4, 6 -trimethylpyridine (TMP, purity $\geq 99\%$) was purchased from Shanghai Ampoule Experimental Technology Co. Deionized water was purified using the Milli-Q system (Millipore Corp., Billerica, Massachusetts, USA).

2.2. Sample Preparation

Meat was stored at -32°C before further processing. In addition, the frozen pork loins were thawed overnight at 4°C before use. After removing the pork skin, bone, connective tissues, and visible fat, the meat was cut into small slices of about $10 \times 5 \times 1 \text{ cm}^3$. Three types of group samples labeled as MS, M, and S, were prepared for study and were stored at -80°C until use.

2.2.1. Broth Sample Preparation

The pork loin was pre-cooked at 100°C for 5 min in water to remove blood and gamy odor. The meat (500 g) was braised at 100°C for 1 h with spice bag (20 g), salt (20 g), and water (1,500 g), and was soaked for 40 min. After that, the broth sample (50 g) was collected for further analysis, and the cooked meat was taken out. The process was continued after new pre-cooked meat (500 g) was added in the pot and water was supplied to 1,500 g. The salt was replenished to original concentration by salinity meter and the spice bag was still reused. The braising process was repeated 10 cycles with four parallel. Ten broth samples were labeled from MS 1 to MS 10, respectively. The samples of M, containing only meat (500 g) and salt (20 g) in the braised broth (without spices) and the samples of S, containing only spice bag (20 g) and salt (20 g) in the braised soup, were prepared with the same process steps as MS with four parallel. Ten broth samples were labeled from M 1 to M 10 and S 1 to S 10, respectively.

2.2.2. Infrared Sample Preparation

Three broth sample groups, MS, M and S, were put into vacuum freeze dryer for 24 h to remove water and stored in a desiccator until use.

2.3. HS-SPME/GC-MS Assay

Pipette 5 mL broth sample containing TMP (internal standard, $20 \times 10^{-4} \mu\text{g/L}$) into a 20 mL headspace vial and seal. The headspace vial containing the samples was placed in a water bath at 60°C and (DVB/CAR/PDMS) SPME microextraction head (Supelco Inc., Bellefonte, USA) was selected and sorbed for 40 min. After sorption, the microextraction head was quickly inserted into the sample inlet and resolved for 5 min. An Agilent 7890B GC (Agilent) coupled with a 5977A inert XL series mass spectrometer (Agilent) and an HP-5 chromatographic column ($30 \text{ m} \times 0.25 \text{ mm} \times 0.25 \mu\text{m}$, Agilent Technologies, USA) was used for separation. The initial temperature of the column was 40°C maintained for 3 min and raised to 130°C at $5^{\circ}\text{C}/\text{min}$, then raised again to 250°C at $10^{\circ}\text{C}/\text{min}$ and kept for 3 min. Helium (purity 99.999 %) was used as the carrier gas at a constant flow rate of 1 mL/min and a shunt ratio of 3:1.

Using the NIST 11 and Wiley spectral libraries, the odorant substances were compared for qualitative analysis and screening to confirm the analytical identification results with both positive and negative matches greater than 800. The TMP was selected as the internal standard, and the internal standard method was used to quantify the odorants.

2.4. E-nose Measurement

The Heracles II E-Nose (Alpha MOS company, Toulouse, France) consists of two columns, (MXT-5) non-polar and (MXT-1701) weakly polar, with a column length of 10 m and a column diameter of $18 \mu\text{m}$. The detectors are two flame ionization detectors (FID), and the samples are injected and analyzed on both columns simultaneously. The chromatogram can show the separation data of both columns simultaneously. Four parallels were made for each broth sample and data were processed using Alphasoft V12.46.

2.5. Tri-step Infrared Spectrum Measurement

2.5.1. FT-IR

The FT-IR spectra were obtained at room temperature by PerkinElmer FT-IR spectrometer (PerkinElmer, Seer Green, UK) equipped with a single-point diamond attenuated total reflection (ATR) accessory, in the range of $4000\text{--}650 \text{ cm}^{-1}$ with a resolution of 4 cm^{-1} , and 32 scans were co-added for each spectrum. Background spectrum (recorded using ultrapure water) measurements were performed at intervals of 15 min.

2.5.2. SD-IR

The SD-IR spectra were obtained after Savitzky-Golay polynomial fitting (13-point smoothing) of the FT-IR spectrum. The pretreated spectra were exported from the PerkinElmer Spectrum software (Version 10.4.3).

2.5.3. 2DCOS-IR

The 2DCOS-IR spectra were obtained by processing the series of temperature-dependent dynamic spectra with 2DCOS-IR correlation analysis software programmed by Thermo Scientific (Nicolet iN10 SpectraCorr)

2.6. Statistical Analysis

SPSS 22.0 was used for statistical analysis

3. Results and Discussion

3.1. Volatile Compounds of Broth

The volatile compounds in three groups of broth samples

were analyzed by HS-SPME/GC-MS. A total of 78 volatile compounds were detected in the MS group, including 37 hydrocarbons, 11 alcohols, 9 aldehydes, 7 ketones, 13 esters and 1 other. Trans-cinnamaldehyde, anethole, p-methoxybenzene, and 4-allyl anisole were the main aroma contributors in the MS group. In M group, 41 volatile compounds were detected, including 14 hydrocarbons, 19 aldehydes, 4 alcohols, 4 esters. The aldehydes such as n-hexanal and nonanal were the main aroma contributors in the M group. There were 54 volatile compounds in S group, including 24 hydrocarbons, 6 alcohols, 12 aldehydes, 4 ketones, 7 esters and 1 other. Trans-cinnamaldehyde, p-methoxy benzaldehyde, L-anisole, and anethole were the main aroma contributors in S group. The overall aroma substances of the broth showed a gradual decrease and stabilization with the increase of the number of quantitative cyclic cooking, and the broth samples with different brining times had variability in their types and relative contents. The variations in the types and concentrations of volatile flavor compounds were analyzed by quantitative and qualitative detection of volatile compounds in three groups of samples. Venn diagrams were used to represent the interactions of the MS, M and S groups (Fig 1), indicating the presence of repetitive components among them.

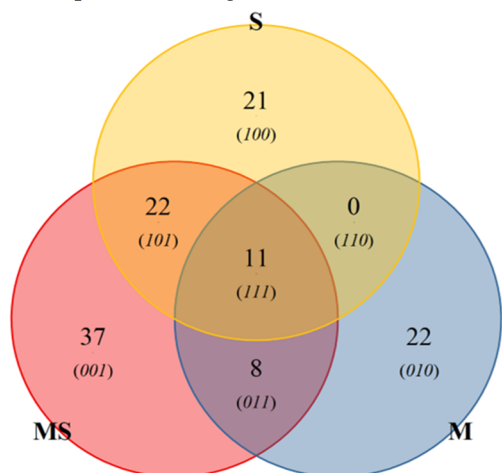


Fig 1. The interactions of MS, M and S groups are represented by Venn diagrams showing the presence of overlapping components. 001 (MS), 010 (M), 011 (MS&M), 100 (S), 101 (MS&S), 110 (M&S), 111 (MS&M&S).

3.1.1. Hydrocarbons

Unsaturated hydrocarbons were detected more frequently in the hydrocarbon volatiles detected by MS, mainly originating from the addition of spice packets. [1]. The highest relative content was anethole, mainly from star anise. Meanwhile, the relative content of anethole decreased gradually with the increase of cooking times. The total hydrocarbon volatile substances showed a trend of rising and then falling, indicating that as the cooking time increased, the unsaturated hydrocarbons in the spices gradually dissolved in water. However, due to its poor volatility, it accumulates in the broth and forms an integral part of the characteristic flavor of the broth [2]. As the hydrocarbons in the spices continue to leach into the broth, the content of hydrocarbon volatile components in the broth gradually increases. However, when the leaching rate is less than the absorption rate of hydrocarbon components by meat and its own volatilization rate, the content of hydrocarbon volatile components in the broth begins to decline. [3].

3.1.2. Alcohols

Alcohols in M were relatively few in number and were all fatty alcohols, and their total content showed an increasing and then decreasing trend. The highest relative content was found at the 4th cooking. Hence, it could be added raw materials on the fourth cooking cycle of the broth. Most of the precursors of the alcoholic volatile components in MS originated from spices, and their total content gradually decreased.

3.1.3. Aldehydes

Aldehydes are important aroma compounds in meat products, generated by the oxidation of unsaturated fatty acids, and have a fatty aroma [4]. The total content of aldehydes in the MS group gradually decreased. The content of aldehydes was the largest in the M group and tended to increase and then decrease, indicating that the main source of meat aroma substances were aldehydes [5]. Meat and broth were exposed to air for a long time. After heating, lipids undergo oxidative degradation reaction to generate fatty aldehydes mainly as hexanal, heptanal, nonanal, decanal, n-octanal and hexadecanal, and aromatic aldehydes mainly as cinnamic aldehyde, benzaldehyde, trans-cinnamic aldehyde, phenylacetaldehyde, 2-methoxybenzaldehyde, phenylpropanal, p-methoxybenzaldehyde, and 2-methoxycinnamic aldehyde. Fatty aldehydes had good water solubility, and their relative content would gradually increase with the increase in the number of cycles. However, with the increase of the number of broth cooking, a series of cinnamaldehyde-based aroma substances were absorbed by the meat, and their relative content gradually decreased [6]. The aldehydes content in the S group gradually decreased, indicating that the aldehydes in the spices were gradually volatilized with the increase in the number of cooking times. Benzaldehyde was mainly derived from spices, which were highly oxidized and unstable. With the increase in the number of cooking, its content was a decreasing trend. The fourth completely disappeared of brine cooking. The main reason was that, on the one hand, part of the benzaldehyde was absorbed by the cooked pork, on the other hand, under high temperature conditions, benzaldehyde oxidized to generate other volatile compounds with more stable properties [7].

3.1.4. Ketones

Ketones were produced by the oxidation of alcohols, by the Maillard reaction, or by the oxidation of fats, and enhance the flavor of broth [8]. The total content of ketones in the MS group showed a gradual decrease. The ketones disappeared from the samples of group S after 6 cycles of cooking. No ketones were detected in the broth of the M group, indicating that the ketones in the broth of the MS group mainly originated from spices. The ketone with the largest relative content in the MS and S group samples was anisone, mainly from anise oil, the main component of anise in the spice pack. Since it can sublimate at room temperature and has a low boiling point, its content gradually decreased with the increase of brining time. [9].

3.1.5. Esters

The MS group had the largest variety of esters, and the highest relative content of detected esters was ethyl acetate, which tended to increase significantly with increasing cooking time. The MS group had the largest variety of esters, and the highest relative content of detected esters was ethyl acetate, which tended to increase significantly with increasing halogenation time. The most abundant ester in the M group

was methyl butyrate, which was probably derived from the degradation of fatty acids in meat. [10]. The larger amounts of esters in the S group indicated the presence of large amounts of volatile ester components in the spices. For example, linalyl propionate and isopropyl myristate disappeared after the 5th and 6th cooking times, indicating that the esters in the spices were volatilized or adsorbed into the meat with the increase of cooking time, adding aroma to the meat.

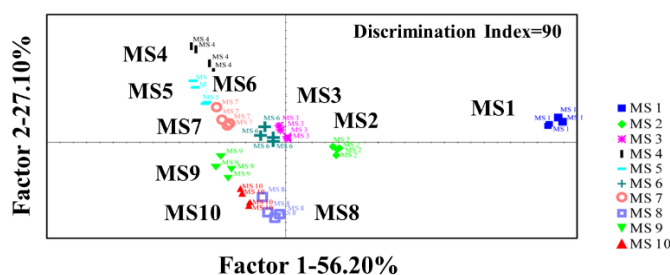
3.2. E-nose Analysis

3.2.1. Principal Component Analysis (PCA)

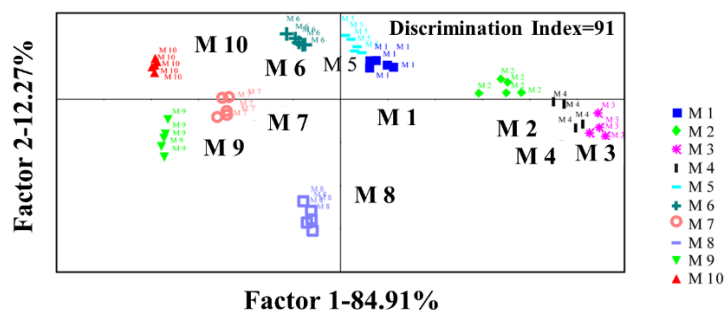
E-nose showed excellent ability to discriminate the changes trends in the aroma of the broth during the quantitative cycle of cooking, especially for meat products [2]. In the present study, the aroma rule of generation and variation in broth could be obtained by PCA of E-nose data. Furthermore, it could be also learned that QRBC process and the existence of spices had effects on the overall aroma of broth. Those different contents of volatile compounds, resulted in the different E-nose responses among the QRBC process of broth samples, were analyzed by PCA (Fig 2). The result indicated good discrimination among the broth samples of MS, M and S as the contributions of PC1 and PC2 explained more than 82% of the total variance between broth

samples braised with different cycles. The PCA model of MS showed that the broth samples gradually shifted leftward and downward to the PC1 end and became closer and closer to each other as the number of cooking times increased (Fig 2a), indicating that the content of aroma gradually decreased. Meanwhile, their compositions were somewhat similar as the number of cooking times increased. This result was verified with the GC-MS results. The PCA model of M showed that the broth samples first shifted to the right of the PC1 end and then to the left of the PC1 end as the number of cooking times increased (Fig 2b), indicating that the total content of aroma increased and then decreased as the number of cooking times increased. The total content of aroma reached the maximum value in the third cooking, which was consistent with the GC-MS results. The PCA model of S showed that the broth samples first moved to the left of PC1, and then moved upward as the number of cooking times increased, and the distance between S 1 and other broth samples on PC1 was larger (Fig 2c), indicating that all the aroma substances had been dissolved in water after the spices were cooked once. At this time, the spices contributed the most to the aroma of the broth. After that, the aroma substances were volatilized with the increase of cooking times. This result was verified with the GC-MS results. Hence, E-nose based on PCA analysis could be applied to discriminate broth with QRBC process.

a



b



c

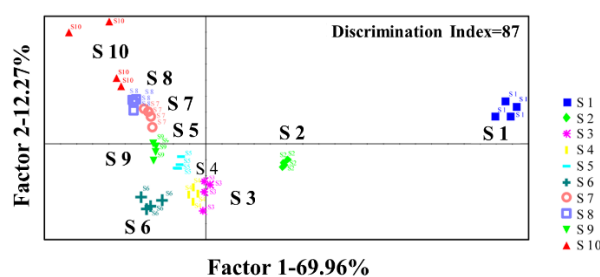


Fig 2. PCA results of broth from three groups of broth based on E-nose (MS group (a), M group (b), S group (c)).

3.2.2. Soft Independent Modeling of Class Analogy (SIMCA)

SIMCA is a supervised classification technique based on PCA [11]. The principle is to project the new measurements into the space of each component describing a specific class and to evaluate the Euclidean number of objects to the model using an F-test. By comparing the F-distribution with a 99% confidence interval, unknown broth samples can be identified as specific groups. Using this analysis method, 30 chemical classes were modeled with odorant substance analysis, and 12 plots with good model validation were left, including 3 for the MS group, 8 for the M group and 1 for S group (Tab. 1). Among the models developed with the MS group, the SIMCA model validation scores for MS 1, MS 2 and MS 9 were 100, 94 and 94, respectively, indicating a significant difference in the aroma of the cooked first and second cycle. Among the models developed with M group, only M 3 and M 4 had low SIMCA model validation scores, while all the others had validation scores greater than 92, indicating that the broth samples obtained with different cooking times have different aroma characteristics. Among the models established with S group, only S 1 had a reliable model effect with a SIMCA model validation score of 100. It was found that the aroma substances in the spices were basically dissolved in the broth after one cooking, after which the aroma substances in the broth gradually evaporated. Since the content and composition of aroma substances in the samples obtained after nine rounds of cooking did not change much and their aroma characteristics were somewhat similar, the model effect of the other samples was not satisfactory. This result verified the results of PCA analysis.

Table 1. SIMCA results of broth from MS 1, MS 2, MS 9, M 1, M 2, M 5, M 6, M 7, M 8, M 9, M 10 and S 1 groups based on E-nose.

Group	Validation Score
MS 1	100
MS 2	94
MS 9	94
M 1	100
M 2	92
M 5	100
M 6	100
M 7	100
M 8	100
M 9	98
M 10	100
S 1	100

3.3. Tri-step Infrared Spectroscopy Analysis

3.3.1. FT-IR

Comparison of IR raw spectra of infrared samples cooked in different cycles (Fig 3), it was found that the infrared samples of MS and M had distinctive peaks at 2973, 2926, 2583, 1745, 1395, 977, 930 and 852 cm^{-1} . The infrared samples of S showed distinct peaks at 1719, 1607, 1517, 1408, 1242, 1144, 1076, 1051, 1028, 926, 820 cm^{-1} .

The MS and M have $-\text{CH}_3$ and $-\text{CH}_2$ antisymmetric stretching vibrations at 2973 and 2926 cm^{-1} [12], $-\text{CH}_2$ symmetric stretching vibrations at 2583 cm^{-1} [13], and $\text{C}=\text{O}$ symmetric stretching vibrations at 1745 cm^{-1} [12], with the main contributor being the fat component from the meat. At 1395 cm^{-1} there are CH_3 symmetric bending vibrations and

COO^- symmetric stretching vibrations with acids as the main contributors. The C-H out-of-planar bending vibrations and C-O bending vibrations at 977, 930 cm^{-1} [12], and pyran ring skeleton vibrations at 852 cm^{-1} [14], were generated by the contribution of sugars in the broth. However, the infrared spectra of S differed significantly from the other two groups, with characteristic peaks mainly coming from different volatile components. For example, the O-H stretching vibration in the 2940-2901 cm^{-1} region was mainly caused by alcohols and phenols [15]. The $\text{C}=\text{O}$ symmetric stretching vibration was caused by aldehydes, ketones, and esters near 1719 cm^{-1} . The main contributors to the $\text{C}=\text{C}$ stretching vibration at 1610-1617 cm^{-1} were aromatic compounds and phenolic substances. The COO^- stretching vibrations in the range of 1419-1390 cm^{-1} belonged to carboxylic acids and esters [16]. The C-O stretching vibrations in the ranges of 1253-1240 and 1145-1028 cm^{-1} were mainly attributed to phenols, ethers, and alcohols. The C-H planar bending vibrations in the range of 928-819 cm^{-1} are mostly due to the presence of olefins and phenyl derivatives [17]. It indicated that the aroma components of MS and M have some similarity. The types and contents of aroma substances of S were more different, especially the components of volatile substances such as hydrocarbons, aldehydes, ketones, alcohols and esters have significant differences. This result was consistent with the results of E-nose PCA analysis.

3.3.2. SD-IR

SD-IR were performed on the basis of FT-IR to enhance the spectral resolution. Thus, the hidden information in the sample was obtained. SD-IR spectra were constructed in the selected wave number band of 3000-800 cm^{-1} (Fig 4). The number and morphology of the characteristic peaks in the SD-IR spectra of the MS and M were the same, and the trends of the flavor were the same in both groups. The peak areas increased with the increase of the number of cycles, and the contents of various substances showed an increasing trend in combination with FT-IR. The number and intensity of the SD-IR characteristic peaks of the S group were smaller than those of the other two groups. It indicated the total contents of volatile substances in this group decreased and gradually stabilized with the increase of the number of cycles. This result was consistent with the results of GC-MS.

3.3.3. 2DCOS-IR

2DCOS-IR illustrated the sensitivity, correlations, and response order for each IR band group when the system under study is subjected to a given perturbation [18]. Automatic peaks on the diagonal of the simultaneous spectra show the autocorrelation and sensitivity of specific absorption bands in the broth sample spectra. With positive correlations (red/green regions) indicating simultaneous changes (increases or decreases) in a group of absorption bands, the opposite is true for negative correlations (blue regions) [12]. The FT-IR spectra of infrared samples for each group were used as a series of dynamic spectra for 2DCOS-IR spectral information acquisition to further improve the spectral resolution. Both MS and M groups selected wave number bands 2950-2840 cm^{-1} , 1780-1600 cm^{-1} , 1600-1000 cm^{-1} , and 900-800 cm^{-1} (Fig 5 and Fig 6) to plot 2DCOS-IR of broth. The wave number bands 2950-2840 cm^{-1} , 1780-1600 cm^{-1} , 1120-1000 cm^{-1} , and 900-800 cm^{-1} (Fig 7) were selected in S to plot the 2DCOS-IR figures. The automatic peaks with relative intensities above 50% were also recorded as strong automatic peaks (Tab. 2). By comparing 2DCOS-IR

fingerprints, there were significant changes at the characteristic peaks of fat (2921,1745 cm^{-1}), amino acids (1587-1541 cm^{-1}), nucleotides (1080 cm^{-1}), and sugars (850 cm^{-1}) in the MS, indicating an increasing trend with the increase of cycle times. This result was consistent with our previous findings [3]. The number of automatic peaks in S

was less than those in MS and M. The results indicated that the main component of flavour in broth comes from raw meat. The strong absorption peaks at 2901, 1612, 1645, 1060 and 879 cm^{-1} were probably caused by the decreasing volatile content of the brine broth and the telescopic vibrations of aldehydes (C=C), ketones (C=O) and alcohols (-OH) [19].

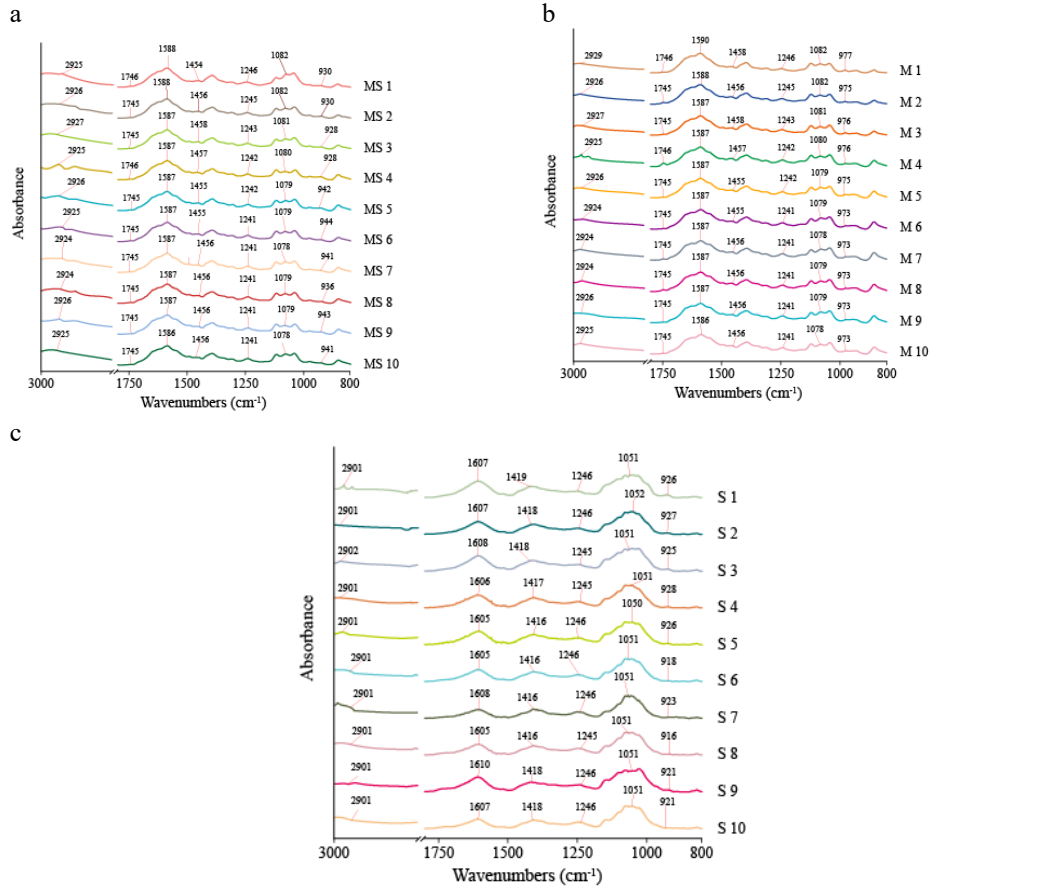


Fig 3. FT-IR spectroscopy of ten QRBC broth of MS group (a), M group (b) and S group (c) in the range of 3000-800 cm^{-1} .

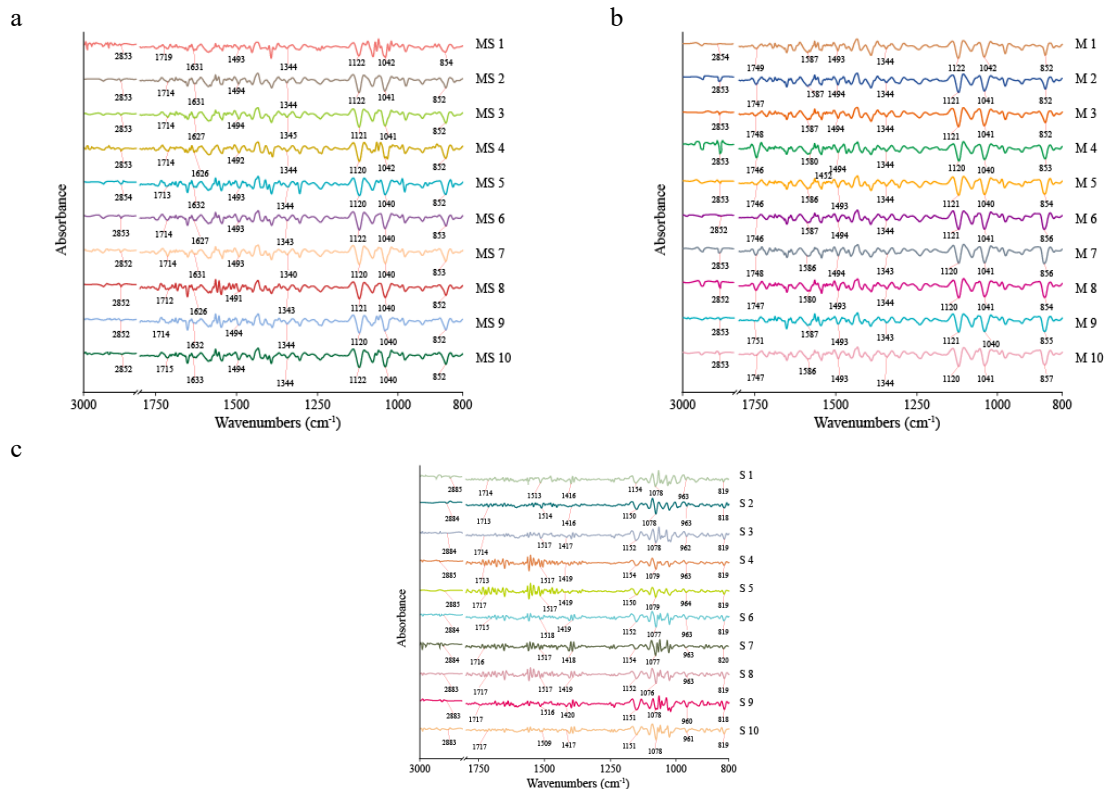


Fig 4. SD-IR spectroscopy of ten QRBC broth of MS group (a), M group (b) and S group (c) in the range of 3000-800 cm^{-1} .

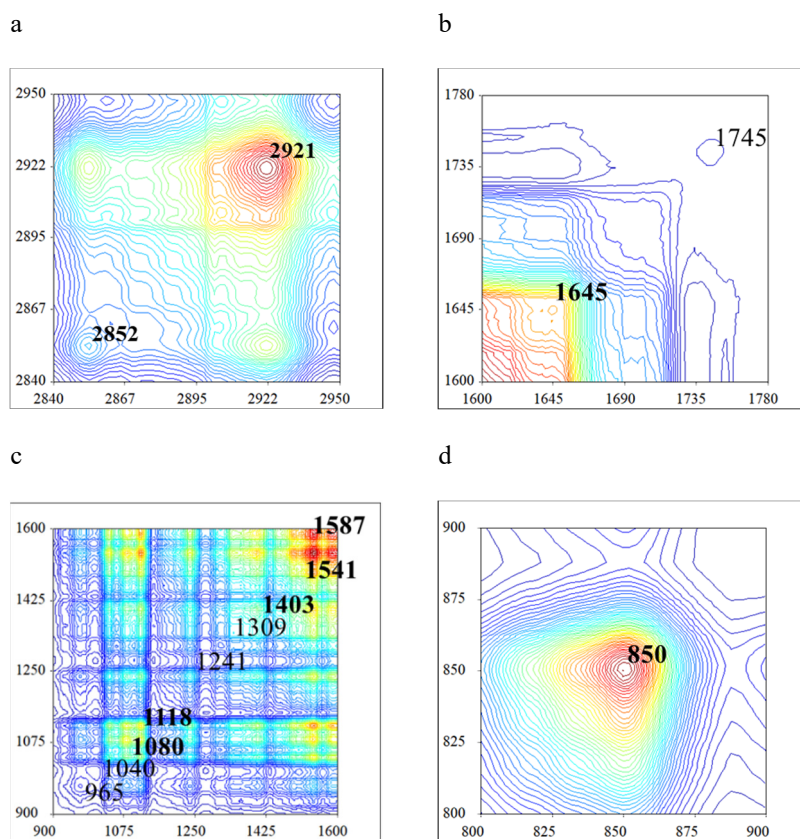


Fig 5. DCOS-IR synchronous spectroscopy of ten QRBC broth of MS group (2950~2840 cm^{-1} (a) 1780~1600 cm^{-1} (b), 1600~1000 cm^{-1} (c), 900~800 cm^{-1} (d)).

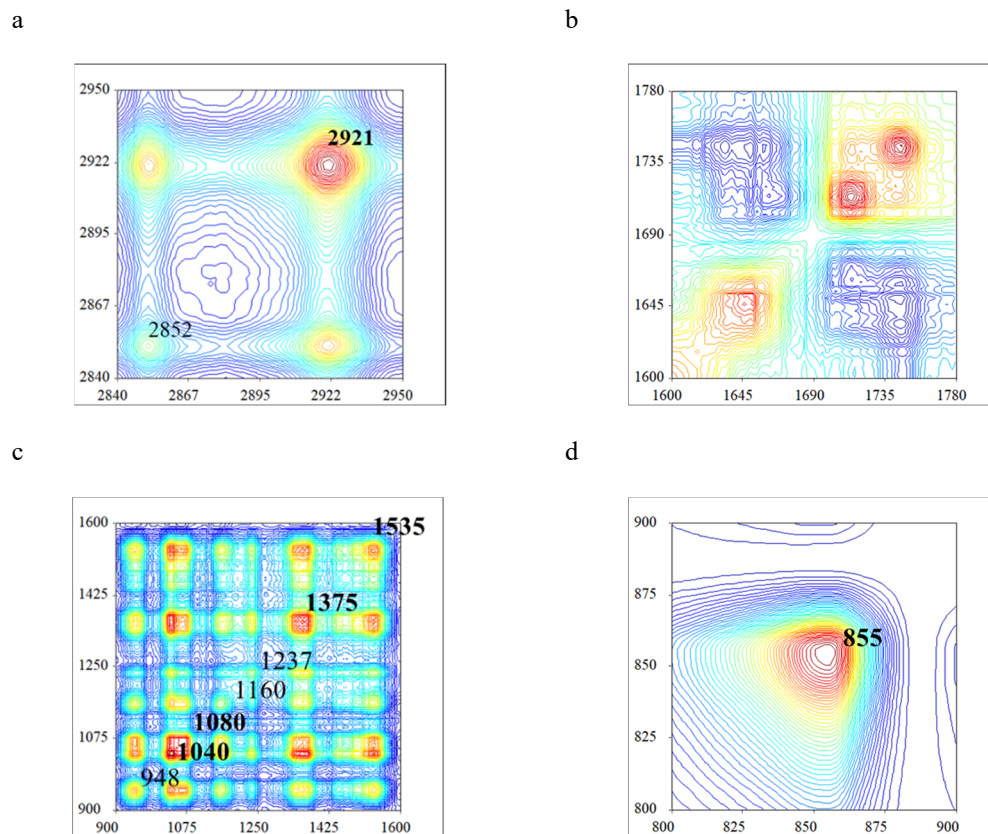


Fig 6. 2DCOS-IR synchronous spectroscopy of ten QRBC broth of M group (2950~2840 cm^{-1} (a) 1780~1600 cm^{-1} (b), 1600~1000 cm^{-1} (c), 900~800 cm^{-1} (d)).

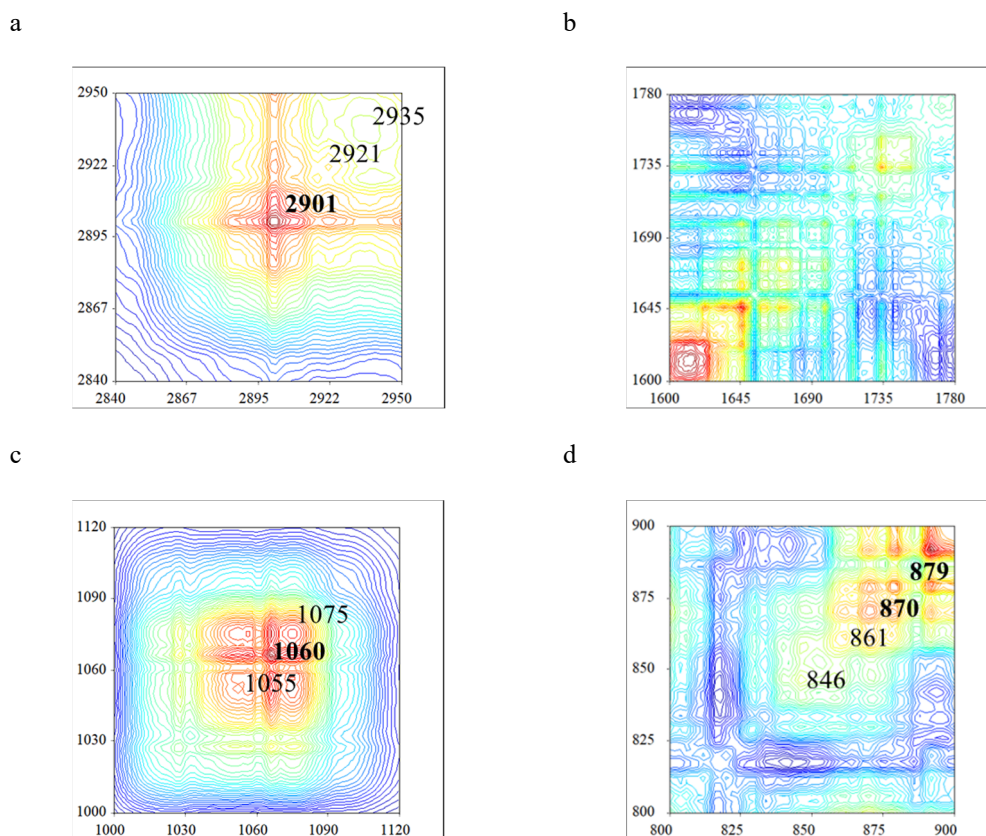


Fig 7. 2DCOS-IR synchronous spectroscopy of ten QRBC broth of S group (2950~2840 cm^{-1} (a), 1780~1600 cm^{-1} (b), 1600~1000 cm^{-1} (c), 900~800 cm^{-1} (d)).

Table 2. Auto-peaks in 2DCOS-IR synchronous spectra of three broth groups

Group	Auto peak/ cm^{-1} (threshold: 10% relative intensity)						
MS	2921	2852	1745	1645	1587	1541	1403
	1309	1241	1118	1080	1040	965	850
M	2921	2852	1745	1714	1645	1535	1375
	1237	1160	1080	1040	948	855	
S	2935	2921	2901	1735	1697	1672	1645
	1612	1075	1060	1055	879	870	861
	846						

Note: Numbers in bold in the table indicate strong auto-peaks (relative intensity $\geq 50\%$).

4. Conclusion

The information obtained from the study provided insight into the production and changes of aroma substances in the broth during braising and their contents showed a gradual decrease and stabilization with the increase of the braising cycle. The results showed that the main aroma substances in the broth were n-hexanal and n-octanal, trans-cinnamaldehyde, nonanal, anethole, fennel, fennel ketone and ethyl acetate. With the increase of the number of quantitative cycles of brining, the aroma substances content of all three groups of samples per round of brining changed significantly, indicating that the formation of aroma in the MS group was a result of the joint action of the brined meat and the spices. The PCA-based analysis of e-nose and SMICA showed excellent ability to distinguish the overall aroma quality changes of broth samples through the QRBC process, which can provide an effective monitoring tool for the quality assessment of braised meat products. The PCA model of M group E-nose showed that the total content of aroma substances reached the

maximum value in the broth samples cooked for the third time. Meanwhile, the GC-MS results showed that benzaldehyde in the spices completely disappeared in the 4th brining, esters such as linalyl propionate and isopropyl myristate disappeared after the 5th and 6th brining, ketones basically disappeared in the 6th brining, and the relative content of alcohols in M group was highest in the 4th brining. Therefore, the quality of braised meat products can be improved by replenishing the meat and spices after the 3th brining.

In conclusion, this study makes an important contribution to the aroma study of braised meat products and provides a scientific basis for their production and processing, aroma evaluation, quality control and industrial application.

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