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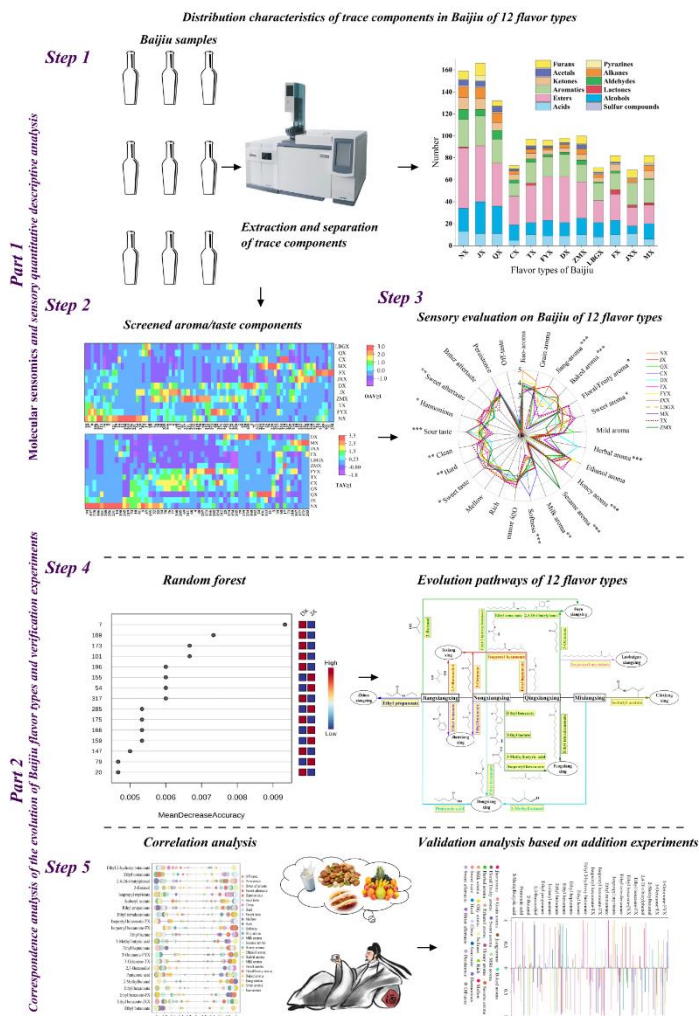
Article

Molecular Sensomics Combined with Random Forest Model to Reveal the Evolution on Flavor Type of Baijiu Based on Differential Markers

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Graphical Abstract



Abstract: Baijiu is popular with its long history and balanced flavor, and flavor type was the most widely used classification mode for Baijiu. However, the evolution relationship of Baijiu flavor types and the differential

markers between flavor types are still unclear, significantly impacting the development of the Baijiu industry. In this study, a total of 319 trace components were identified using gas chromatography-olfactometry-mass spectrometry and gas chromatography-mass spectrometry. Among them, 91 trace components with high odor active values or taste active values were recognized as flavor components. Then random forests were conducted to screen differential markers between derived and basic flavor types, while principal component analysis assessed their effectiveness in distinguishing the flavor types of Baijiu. Finally, 19 differential markers (including 3-methylbutyric acid, pentanoic acid, 2-butanol, 2,3-butanediol, ethyl pro-panoate, isobutyl acetate, ethyl butanoate, ethyl hexanoate, ethyl heptanoate, ethyl lactate, ethyl 2-hydroxy butanoate, isopentyl hexanoate, ethyl nonanoate, isopropyl myristate, ethyl tetradecanoate, ethyl benzoate, 2,4-di-t-butylphenol, 2-methylbutanal and 3-octanone) were screened and proved to effectively reveal the evolution Baijiu flavor types, and were further verified as key differential markers by addition test and correlation analysis.

Keywords: Baijiu; flavor type; molecular sensomics; differential marker; correlation analysis; random forest

1. Introduction

Baijiu is the most popular alcoholic beverage in China and has a historical and cultural accumulation of more than 2000 years [1]. It has almost penetrated into every aspect of social life, and become a medium for human beings to express their feelings and communicate with each other. According to industry statistics from the China Liquor Industry Association, in 2023, the annual output of Baijiu was 6.29 billion liters, and fell 5.1% year on year. However, the annual profit was 326.15 billion USD, accompanied by growth of 7.5%. In general, the production capacity was gradually decreased but the annual profit notably promoted, which indicated that the output of medium to high-end Baijiu was increasing. In the future, high-quality development will become the direction of Baijiu industry.

As known for complex brewing techniques and unique flavor, Baijiu was collectively known as the six world-renowned distilled liquors with whiskey, brandy, vodka, gin and rum [1]. Baijiu was mainly composed of water, ethanol and about 2% of trace components. Different from other distilled liquors, Baijiu was fermented with single sorghum or mixed grains (sorghum, glutinous rice, corn, etc.) and co-fermented with multiple microorganisms (*Bacillus*, *Microbacterium*, *Pseudomonas*, and *Corynebacterium*, etc.) [2], which provided a rich material basis for the generation of trace components in Baijiu. According to the statistics of our team, it was reported that 3443 kinds of trace components have been detected in Baijiu, including 792 esters, 419 alcohols, 293 acids, 37 lactones, 384 aldehydes and ketones, 65 acetals, 217 sulfur components, 304 nitrogen components, 127 furans, 92 pyrazines, 74 heterocycles, 241 aromatics (containing benzene), 179 hydrocarbons, 136 terpenes, and 83 others. These numerous and rich kinds of trace components affected the formation on various flavor characteristics of Baijiu and it was unscientific to use a unified standard to evaluate all types of Baijiu, which was one of the factors effecting the standardization management of the Baijiu industry. Thus, the concept of flavor type was proposed.

At first, the concept of flavor type had not yet formed. Until 1952, in the First China Famous Baijiu Appraisal Meeting, the judges ranked Baijiu according to their own preferences and the standards in the local region. This event led to the birth of revolutionary technical memorabilia of Baijiu: 'Maotai Pilot' and 'Fenjiu Pilot'. Through the pilots, it was found that although they were all famous Baijiu with well quality, their sensory and trace components were extremely different. Therefore, the question of whether Baijiu should be classified first by flavor type and then graded was raised. The earliest definite decision on Baijiu flavor type should be from the Third China Famous Baijiu Appraisal Meeting in 1979, when the concept of 'Xiangxing (i.e., flavor type)' was put forward. At that time, there were only 4 basic flavor types: qingxiangxing Baijiu, nongxiangxing Baijiu, jiangxiangxing Baijiu and mixiangxing Baijiu. Due to the unclear classification standards for flavor type of Baijiu, many products were not selected as famous Baijiu. After more than 30 years of development, integration and summary, 8 flavor types, containing chixiangxing Baijiu, texiangxing

Baijiu, fuyuxiangxing Baijiu, dongxiangxing Baijiu, zhimaxiangxing Baijiu, laobaiganxiangxing Baijiu, fengxiangxing Baijiu and jianxiangxing Baijiu, have been gradually derived, forming the 12 flavor type systems of Baijiu [3].

In the early stage of development, a few representative enterprises solidified the production technologies of Baijiu, and then their production technologies were promoted to other regions. During the process, many enterprises have optimized and improved the traditional production technology to adapt to the local culture, ecological environment, and eating habits. Of note, the production of Baijiu was extremely affected by water, raw materials, ecological environment, etc. Even if the same production technology was applied to different regions, the flavor of Baijiu was also quite different. Hence, the correlation and difference between the flavors for different types of Baijiu have been paid more and more attention. Currently, the traditional sensory evaluation of Baijiu flavor mostly relies on manual work, that is, through human senses (i.e., smell, taste) to comprehensively evaluate the appearance, aroma, taste and typicality of Baijiu, which was full of subjectivity. Although the current national standard document has standardized and described the terms related to the classification of Baijiu and the evaluation of Baijiu, it was still vague and general. The material basis that really caused the difference between Baijiu flavor types was still unclear. Therefore, it would help to support the clarification of the relationship between Baijiu flavor types that revealing the differential markers of different flavor types at the molecular level and analyzing the corresponding relationship between the differential markers and sensory quality.

According to research, the flavor quality of Baijiu mainly depended on the distribution characteristic of trace components. Thus, the current research mainly focused on the mining and evaluation of trace components and flavor components in Baijiu by the application of multiple pretreatment techniques combined with detection techniques. Of note, the vacuum-assisted sorbent extraction (VASE) has the characteristics of simple operation, high degree of automation, large adsorption phase volume, high extraction efficiency, and high sensitivity, it is suitable for identifying and analyzing trace components in complex liquid matrices (as shown in **Figure A.1**) [4]. However, there are few reports on its application on the analysis of trace components in Baijiu. Furthermore, the data set of trace components in Baijiu is quite large, but not all trace components have direct contribution to the sensory attributions of Baijiu. Therefore, it is necessary to use machine learning and molecular sensomics to reduce the dimension of the data set and further screen and verify the key flavor components in Baijiu. Researchers [5] used the random forest model, partial least squares discriminant analysis and spearman correlation analysis to screen the different components in Baijiu of different years from 98 kinds of volatile compounds. The results showed that ethyl oleate was found to be the best single age-marker. In previous studies [6], random forest [7] and molecular sensory science have been comprehensively used to screen the differential markers of jiangxiangxing Baijiu from different production regions. As a result, 6 key flavor components (containing ethyl octanoate, ethyl 2-methylpropanoate, propyl acetate, ethyl heptanoate, 2-nonanone and butyl hexanoate) could effectively trace back to the production region of jiangxiangxing Baijiu. Besides, recent research mostly focused on aroma expression [5,8–10] of trace components, and there was relatively little research about their impact on taste and sensation. Therefore, VASE and multi-dimensional sensory evaluation system (i.e., perspective of aroma, taste and sensation) combined with random forest model were performed in this study to clarify the differential markers between flavor types and further reveal the evolution relationship of Baijiu flavor types.

In this study, the objectives were (1) to identify and analyze the trace components in 12 flavor types of Baijiu by different pretreatment combined with multiple instruments; (2) to screen differential markers between 12 flavor types of Baijiu by molecular sensomics and random forest model; (3) to clarify the relationship between differential markers and sensory attributes by addition tests and further verify the chemical origin of their sensory characteristics.

2. Material and Methods

2.1. Sample Collection

In this study, Baijiu produced by enterprises with representative and large scale recognized in the industry was selected and a total of 22 representative samples were selected (**Table 1**). Due to the numerous representative brands of nongxiangxing Baijiu, jiangxiangxing Baijiu, and qingxiangxing Baijiu, multiple samples were selected. For other flavor types, Baijiu from the most representative manufacturer was selected. These samples were all purchased in the market and stored at 4 °C until further analysis.

Table 1. Information on Baijiu Samples.

No.	Abbreviation	Flavor types	Ethanol concentration/ %v/v
1	NX	nongxiangxing	52
2	NX	nongxiangxing	39
3	NX	nongxiangxing	52
4	NX	nongxiangxing	52
5	NX	nongxiangxing	42
6	JX	jiangxiangxing	53
7	JX	jiangxiangxing	53
8	JX	jiangxiangxing	53
9	JX	jiangxiangxing	53
10	JX	jiangxiangxing	46
11	QX	qingxiangxing	53
12	QX	qingxiangxing	53
13	QX	qingxiangxing	52
14	CX	chixiangxing	53
15	TX	texiangxing	52
16	FYX	fuyuxiangxing	54
17	DX	dongxiangxing	54
18	ZMX	zhimaxiangxing	53
19	LBGX	laobaiganxiangxing	67
20	FX	fengxiangxing	52
21	JXX	jianxiangxing	42
22	MX	mixiangxing	52

2.2. Analytical Reagents

Ethanol (chromatographically pure, 99.8%) was from Beijing InnoChem Science & Technology Co. Ltd (Beijing, China). A C₃–C₃₀ n-alkane mixture (Sigma–Aldrich, Shanghai, China) was used for determination of linear retention indices [11]. Sodium chloride (analytically pure, 99.5%, NaCl) was from Chengdu Colon Chemical Co. Ltd (Sichuan, China). The internal standard substances (2-ethylbutyric acid, IS1; 4-octanol, IS2; pentyl acetate, IS3) and the analytical standards employed for the identification and quantitative analysis of the trace components and were all purchased from J&K Scientific Company (Beijing, China).

2.3. Extraction, Quantification, and Identification of Trace Components

2.3.1. Extraction of Trace Components by VASE [4]

A diluted sample (2.0 mL), with a final ethanol concentration of 15.0% *v/v* was placed into a headspace bottle (20.0 mL), with a silicone rubber septum and saturated with sodium chloride (0.4 g). Added 40.0 μL of mixed internal standards solution (2-ethylbutyric acid, IS1; 4-octanol, IS2; pentyl acetate, IS3; with a mass concentration of 1000 mg/L). Inserted the sorbent pen into the headspace bottle and formed a seal with the bottle cap liner. Used a vacuum pump to vacuum the bottle to <0.01 atm through the sorbent pen. The vacuum sealing between the lid pad and the sorbent

pen allowed the sample to remain in a vacuum state after 30 seconds, thereby increasing the static diffusion rate and collecting much more headspace components on the adsorbent than at atmospheric pressure. The headspace bottle was equilibrated in extraction system (5600 SPES; Entech Instrument, Simi Valley, CA) for 20 min at a temperature of 50 °C and a speed of 240 r/min. After extracting, placed the sorbent pen on a cold tray for 20 min of water management, and then placed it in an isolation sleeve for gas chromatography-mass spectrometry (GC-MS) analysis.

2.3.2. Analytical Conditions for GC-MS

Gas chromatography-mass spectrometry (GC-MS) with a polar chromatographic column DB-FFAP (60 m×0.25 mm×0.25 µm; Agilent Technologies, Santa Clara, CA) was used to identify trace components. Each sample was analyzed in three replicates. Every sample (1.0 µL) treated through VASE was injected in a spitless mode and analyzed. Helium (99.999%) was used as a carrier gas at a constant flow rate of 1.0 mL/min, and the inlet temperature was 250 °C. Oven temperature was held at 40 °C at first, then raised to 50 °C at a rate of 10 °C/min and held for 10 min, then raised at 3 °C/min up to 80 °C and held for 10 min, finally raised at 5 °C/min up to 230 °C and held for 10 min. The total run time for each GC-MS analysis was about 73 min. The mass spectrometry (MS) was operated in an electron ionization (EI) mode at 70 eV. The temperature of the interface and the ion source were set at 150 and 230 °C, respectively. The identification of trace components was conducted in a full scan mode. The temperature of the transfer line was 245 °C. The mass range was set from 50 to 450 amu.

2.3.3. Isolation of Trace Components by Liquid-Liquid Extraction (LLE)

The 30 mL sample was diluted to 15% ethanol (v/v) with saturated salt water, and extracted three times with dichloromethane (50 mL each time). The combined organic phase (about 150 mL) was extracted three times by the Na₂CO₃ solution (50 mL each time; 0.50 mol/L; pH 10.0) and then washed by 50 mL of the saturated NaCl solution. The combined aqueous phase (about 200 mL) was acidified to pH 2.0 with HCl (4.0 mol/L), and extracted three times by the freshly distilled dichloromethane (70 mL each time). Next, being dried over anhydrous Na₂SO₄ for 12 hours at –20°C, both fractions were separated and concentrated to 1.5 mL, then blew to 500.0 µL using a nitrogen blowing instrument [12], and injected 1.0 µL separately for GC-O-MS analysis.

2.3.4. Screening of Trace Components by GC-O-MS

Screening of trace components was carried out through a gas chromatography-olfactometry-mass spectrometry (GC-O-MS) with a polar chromatographic column DB-WAX (60 m×0.25 mm×0.25 µm; Agilent Technologies, Santa Clara, CA). The temperature of the olfactory port was kept at 250 °C. The oven temperature was maintained at 40 °C initially, raised to 50 °C at a rate of 10 °C/min, then increased at a rate of 1 °C/min to 70 °C and held for 10 min, finally raised at 3 °C/min up to 250 °C and held for 15 min. The temperature of the transfer line was 250 °C and that of the MS ion source was set at 230 °C. MS fragmentation was detected in the electron impact mode (ionization energy of 70 eV) with an acquisition range from m/z 50 to 450 in full-scan mode [13].

2.3.5. Odor Specific Magnitude Estimation (Osme)

During the described GC run, the group members held their noses close to the sniffing port, responded to the aroma intensity of the stimulus, and recorded the aroma descriptor and intensity values and retention time. Aroma descriptors were determined through a previous evaluation of the flavor quality of the reference ingredient. Three panelists were familiar with aroma descriptors based on the aroma criteria provided. Strength was judged using a 5-point scale (0 (none), 1 (extremely weak), 2 (weak), 3 (moderate), 4 (strong), 5 (very strong)). The Osme value of aroma intensity was the average result of the group members.

2.3.6. Identification of Trace Components

The similarity between the mass spectrometry information of each chromatographic peak and the mass spectrometry libraries of the National Institute of Standards and Technology (NIST) and LIQUOR V1.0 (team self-built mass spectra library) was at least 80%. Combined with the results of standard components comparison and retention index comparison, it was considered as the preliminary identification of this component.

2.4. Quantification and Odor Active Values/Taste Active Values (OAVs/TAVs) Calculation of Trace Components

The quantification of target trace components was carried out using the internal standard method combined with the calibration curve method. The reserve solution was prepared in a 70% *v/v* solution and then diluted to a series of concentrations to obtain a working standard solution. Added IS 1-3 to the above working standard solution and all samples. Then, under the same conditions as above, 1.0 μ L Baijiu sample and working standard solution were injected into the GC without diversion. Drew a calibration curve by plotting the ratio of the response ratio between the target trace components and the corresponding IS to their concentrations.

The concentrations of the target trace components were calculated based on the calibration curves. The analytical limits of detection (LOD) of trace components were obtained from the lowest concentrations of the analyte standard solutions based on a signal-to-noise ratio of 3. All analyses were repeated in three replicates.

The odor thresholds for trace components were obtained from the previous papers [13–16], and taste thresholds for trace components were obtained from the previous papers [4,17–19]. According to the ratio of quantitative results to threshold values [20] (i.e., concentration/threshold), the OAVs/TAVs of trace components were obtained.

2.5. Sensory Quantitative Descriptive Analysis (SQDA)

According to the methods reported in related studies, the sensory evaluation team composed of 10 sensory evaluators (5 males and 5 females, aged from 21 to 28 years) with olfactory experience. The sensory quantitative descriptive analysis method was used to evaluate the sensory attributes of Baijiu samples. The descriptors with higher frequencies were screened out. All sensory evaluators were called together to discuss descriptors until an agreement was reached on sensory attributes. Sensory attributes were listed based on the description of aroma and taste for Baijiu. Sensory attributes refer to jiao-aroma, grain aroma, jiang-aroma, baked aroma, floral/fruity aroma, sweet aroma, mild aroma, herbal aroma, ethanol aroma, honey aroma, sesame aroma, milk aroma, oily aroma, softness, rich, mellow, sweet taste, hard, clean, sour taste, harmonious, sweet aftertaste, bitter aftertaste, persistence and off-taste. Finally, the evaluators were provided with Baijiu samples (10.0 mL) in glass bottles (25.0 mL) coded with 3-digit numbers and asked to score the sensory intensities using a 5-point scale mentioned above. The sensory evaluation was performed in a sensory panel room at 25 ± 1 °C with the humidity of 35% - 50%, and each sample was evaluated in triplicates [21].

2.6. Flavor Addition Experiments

The addition experiment was conducted to verify the contribution of the differential markers screened through the machine learning to the sensory attributes of Baijiu. According to the actual concentration in sample tested, each differential marker was added to the Baijiu sample with lower concentration in each group. Then, as described in section 2.5, the sensory attributes of the samples were evaluated by the same evaluators.

2.7. Statistical Analysis and Statistical Methods

Statistical analyses were performed using Excel. The random forest models were established through an online website (<https://www.metaboanalyst.ca>) to screen for differential markers. The correlation analysis was conducted with Pearson correlation coefficient. Graphics were drawn using an online website (<https://www.chiplot.online/>).

3. Results and Discussion

3.1. Analysis of Distribution Characteristics on Trace Components

For the purpose of clarifying the distribution of trace components in Baijiu of different flavor types. VASE-GC-MS was applied comprehensively. As shown (**Table B.1**), a total of 319 trace components were identified from Baijiu of 12 flavor types, including 83 esters, 47 alcohols, 18 acids, 5 lactones, 15 aldehydes, 26 ketones, 10 acetals, 7 sulfur components, 5 pyrazines, 57 aromatics (containing benzene), 25 alkanes, and 21 furans.

As presented in **Figure 1a~1b**, the kinds of trace components in NX, JX and QX was relatively abundant, with the number of 159, 166, and 132, respectively. There was a consistent phenomenon among the 12 flavor types of Baijiu, i.e esters, acids, alcohols and aromatics (containing benzene) accounted for the highest proportion. Esters represent the most abundant trace components in Baijiu, formed through three primary pathways: 1) microbial metabolism; 2) lipase-catalyzed esterification reactions; 3) chemical reactions occurring during the aging process of Baijiu [22]. Additionally, each flavor types of Baijiu possessed its own distinct trace components. Notably, 126 kinds of trace components were identified in only one flavor type of Baijiu (including 22 in NX, 22 in MX, 20 in JX, and 15 in QX, respectively), which collectively account for 39.50% of the total identified trace components. Specifically, 5 pyrazines were identified in JX, potentially contributing to its unique baking flavor. In contrast, 16 kinds of trace components were found across all flavor types, representing 5.02% of the total. Overall, the majority of trace components (60.50%) were commonly found across various flavor types of Baijiu, suggesting similarities in both trace component composition and sensory quality among the different flavor profiles.

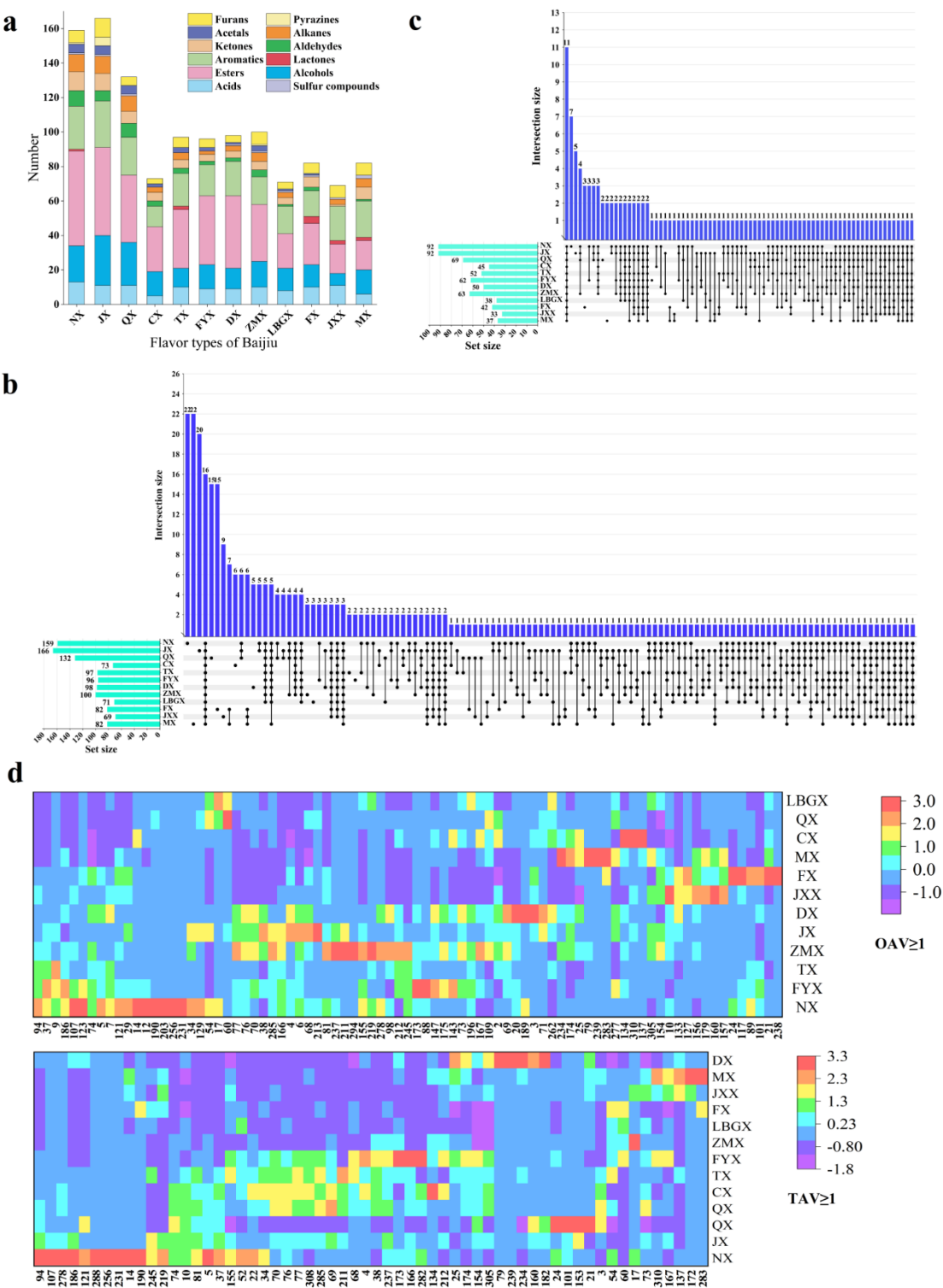


Figure 1. Molecular sensomics analysis of trace components in 12 flavor types of Baijiu. (a) Stacked bar chart of the distribution of trace component species. (b) Upset plot of the distribution of trace component species. (c) Upset plot of aroma expression evaluation of trace components. (d) Heat map of trace components distribution with TAVs ≥ 1 and OAVs ≥ 1.

3.2. Aroma Expression Evaluation of Trace Components

To investigate the aroma expression of trace components in Baijiu, LLE combined with GC-O-MS and the Osme evaluation method were conducted. The results (Table B.1) indicated that esters primarily impart fruity and sweet aromas, while acids contributed sour, fatty and cheesy aromas. Alcohols predominantly exhibit defective aromas, such as greasy, although some presented fruity

and floral characteristics. All pyrazines exhibited a nutty aroma. Moreover, the aroma intensities of trace components were recorded using the Osme evaluation method. In general, the aroma intensity of acids and esters was higher than that of other trace components, followed by aromatics (containing benzene) and alcohols. As presented in **Figure 1c**, only 11 kinds of trace components were identified across all flavor types of Baijiu. The aroma expression of other trace components varied among different flavor types Baijiu, lacking a consistent pattern. Consequently, further research is required to elucidate the specific aroma contribution of trace components to the flavor profile of Baijiu.

3.3. Quantification of Trace Components

In order to clarify the characteristics of trace components in 12 flavor types of Baijiu, according to the above results and trace components with strong flavor expression in previous reports, 119 kinds of trace components were selected and quantified. As shown in **Table B.2**, esters accounted for the highest proportion of all flavor types of Baijiu. Among them, the concentration of ethyl hexanoate was the highest in NX (5794.97 ± 168.35 mg/L), while the concentration of ethyl acetate (11771.56 ± 267.86 mg/L) and ethyl lactate (2488.03 ± 61.29 mg/L) were the highest in JX, and ethyl butanoate had the highest concentration in DX (1262.26 ± 39.85 mg/L). These four esters which may be the key factors affecting the quality and style of Baijiu were produced by microbial metabolism [23]. In addition, several trace components were only detected in one flavor of Baijiu. For example, 2,3,5-trimethylpyrazine and 2,3,5,6-tetramethylpyrazine, which usually existed in Baijiu fermented at high temperature [24], were detected in JX. On the whole, the concentrations of trace components in diverse flavor types of Baijiu were significantly different. The concentrations of higher alcohols in MX were higher, such as 2-methyl-1-propanol and (165.22 ± 17.96 mg/L) and 3-methyl-1-butanol (784.24 ± 13.83 mg/L), which was consistent with existing report [25] and related to the hydrolysis of raw rice to produce a large number of amino acids in brewing [26]. The concentrations of aldehydes and ketones detected in JX samples were significantly higher than that in other samples, which was determined by its unique geographical location and special brewing materials and processes. Most of JX Baijiu is produced in the Chishui River basin. The sorghum grown there is less glutinous and has high amylopectin, which can withstand multiple rounds of baking and cooking, and will form a unique grain flavor in production [27]. The high concentration of pyrazine compounds (such as 2,6-dimethylpyrazine, 2,3,5,6-tetramethylpyrazine, and 2,3,5-trimethylpyrazine) in JX and ZMX was related to the use of high-temperature Daqu (a saccharification and fermentation agent) in their production [28,29]. The concentration distribution characteristics of trace components classified by category were basically the same, such as more esters and acids and less furans, which indicated that different flavor types Baijiu had great similarity in flavor. However, due to the matrix effect, it was not sufficient to evaluate the contribution of trace components to baijiu flavor just by their concentrations.

3.4. OAVs and TAVs of Trace Components

As mentioned above, the contribution of trace components in Baijiu depended not only on their concentration, but also on the interaction between them as well as matrix effects [30], and GC-O-MS analysis was a method for identifying aroma without considering matrix effects. Hence, in order to reveal the flavor contributions of the trace components in Baijiu, the odor thresholds [13–16] and taste thresholds [4,17–19] of trace components from the literature were conducted to estimate their OAVs and TAVs. OAVs or TAVs ≥ 1 means that the trace components have a direct flavor contribution to Baijiu, and the larger the OAV/TAV is, the more significant the contribution to the overall flavor quality is. The overall distribution characteristics for trace components were shown in **Figure 1d**. As shown, trace components with OAVs ≥ 1 were mainly concentrated in NX, JX, FYX, TX, DX and ZMX, and these flavor types of Baijiu were more abundant in aroma quality, while trace components with TAVs ≥ 1 were mainly concentrated in NX, QX, JX, FYX, TX and CX which were richer in taste quality.

As shown in **Table B.2**, a total of 83 kinds of trace components (including 27 esters, 10 alcohols, 11 acids, 4 aldehydes, 6 ketones, 1 acetal, 3 sulfur components, 1 pyrazines, 16 aromatics (containing benzene), 2 alkanes, 2 furans) with OAVs ≥ 1 were screened as aroma components. Among these, 6

components were detected in all flavor types of Baijiu: ethyl acetate, ethyl hexanoate, ethyl octanoate, butanoic acid, octanoic acid and furfural. Esters imparted pleasant fruity and sweet aromas to Baijiu, while acids not only enhanced its flavor but also served as precursors to esters. Given their higher OAVs and corresponding aroma intensities, esters and acids were considered the two most important classes of aroma components in Baijiu. Currently, most studies focus on the aroma contribution of trace components, while relatively little research has been conducted on their contributions to taste.

Considering the significance of taste quality in Baijiu and the fact that individuals predominantly choose Baijiu based on their taste preferences, it was imperative to further investigate the taste contribution of trace components in baijiu. As exhibited in **Table B.3**, a total of 60 kinds of trace components (including 15 esters, 10 alcohols, 6 acids, 1 lactone, 3 aldehydes, 5 ketones, 2 acetals, 3 sulfur components, 11 aromatics (containing benzene), 1 alkane, and 3 furans) were screened as taste components with TAVs ≥ 1 . Notably, ethyl acetate, ethyl hexanoate, ethyl octanoate, butanoic acid, 2-methyl-1-propanol, 1-butanol, benzaldehyde, phenethyl alcohol, were screened as taste components in all types of Baijiu. Among these, all except phenethyl alcohol were also frequently screened as aroma components.

In conclusion, a total of 91 aroma and taste components were screened, which was speculated to contribute directly to Baijiu and may serve as significant markers for distinguishing between flavor types. Notably, some components with lower concentrations, such as 3-methylbutyric acid, 1-octanol, ethyl laurate, 4-methyl phenol, dimethyl trisulfide, furfuryl alcohol, obtained high final OAVs or TAVs by reason of their lower thresholds. Nevertheless, further research is needed to verify whether these aroma and taste components contribute to the overall flavor profile of Baijiu and to explore their interactions.

3.5. SQDA on 12 Flavor Types of Baijiu

Based on SQDA, the sensory attributes of 12 flavor types of Baijiu were evaluated and shown as sensory radar maps (**Figure 2**). Overall, there were great diversities in the sensory profile between 12 flavor types of Baijiu, with varying intensities of each sensory attribute across different flavor types. The off-taste in all flavor types was relatively weak, likely due to the representative nature of the Baijiu samples tested. Specifically, JX exhibited characteristics of jiang-aroma and sour taste, while NX featured jiao-aroma and sweet taste. QX was noted for its distinct grain aroma, and the ethanol aroma was most prominent in MX. In addition, the sensory attributes of other derived flavor types had new features. For instance, DX was characterized by herbal aroma and sour taste, attributed to the incorporation of traditional Chinese medicine during the brewing process. CX showed a pronounced oily aroma for the steeping process with chen rou (i.e., fatty pork). It was worth noting that ZMX expressed a prominent sesame aroma, closely linked to its complex technology and ecological environment. However, the relationship between Baijiu flavor types had not been understood at the molecular level. Based on this point, machine learning could be employed to further analyze the correlation and difference between Baijiu flavor type.

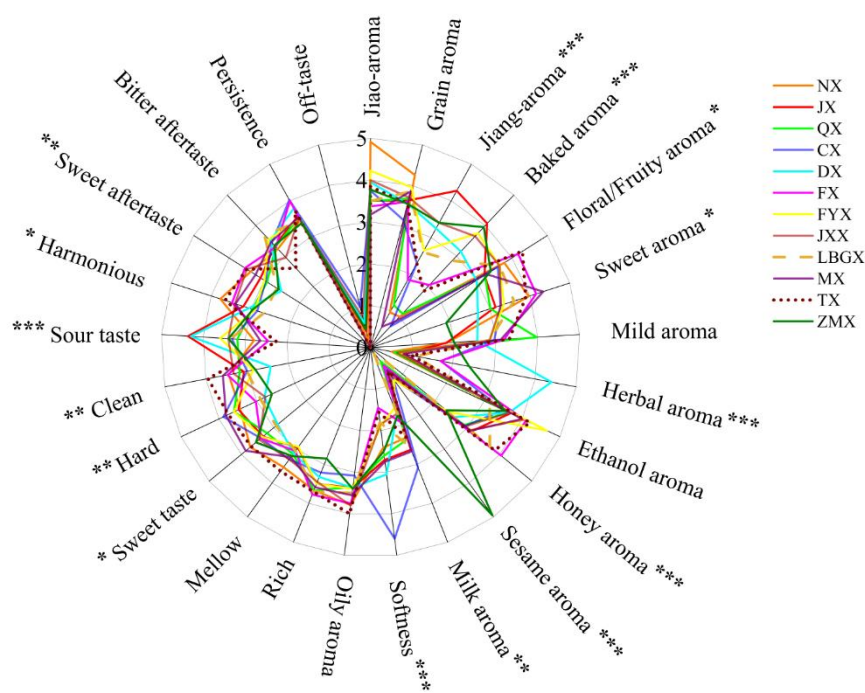


Figure 2. Sensory radar maps on Baijiu of 12 flavor types.

3.6. Correspondence Analysis on the Evolution of Baijiu Flavor Types

3.6.1. Analysis of Similarities (ANOSIM) on Baijiu of 12 Flavor Types

Baijiu was a complex mixture. Even if it was classified according to flavor type, factors such as production region would also cause differences in trace components from the same flavor type of Baijiu in actual production. In order to minimize the misleading of other characteristics and further screen the differential markers between different flavor type of Baijiu, analysis of similarities (ANOSIM) was conducted based on the distribution characteristics of trace components. ANOSIM was a non-parametric test used to determine whether the differences between groups (two or more groups) were significantly greater than the differences within groups, and thus whether the grouping was meaningful [7]. Specifically, considered the data set of samples with the same flavor type as intra group samples, and grouped the samples according to flavor type to form inter group samples. The R-value was used to indicate whether there was a difference between groups, and the P-value was used to indicate whether there was a significant difference. The results were shown in **Figure 3a**, where an R-value of 0.985 indicated that the inter group difference was greater than the intra group difference, that was, the difference between flavor types was significantly greater than the difference on Baijiu with the same flavor type, and a P-value of 0.001 indicated that the inter group difference was significant. These results could fully demonstrate that although there were differences among Baijiu of the same flavor type due to multiple factors such as region and technology, the diversities between different flavor types were more significant. Therefore, it was feasible to use reasonable methods to differentiate the flavor types of Baijiu.

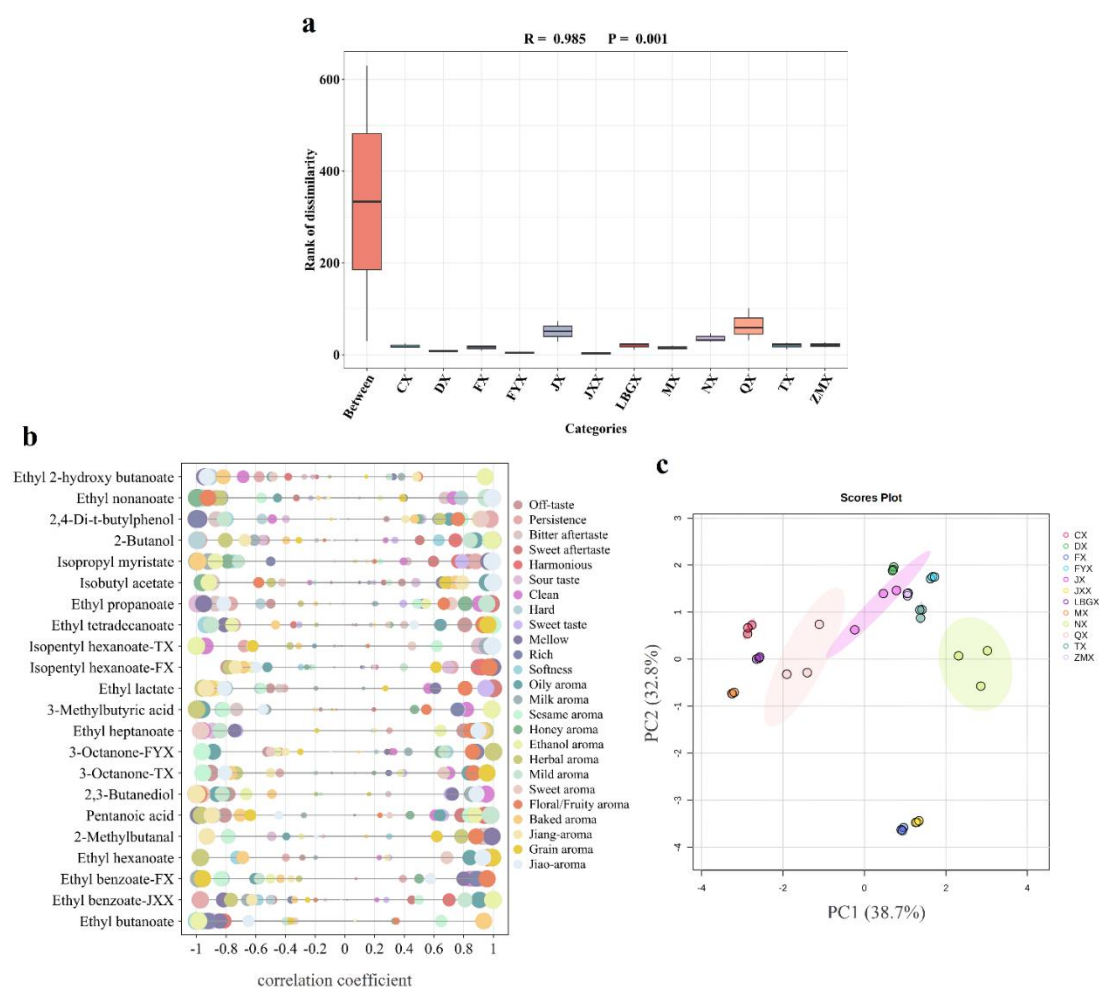


Figure 3. Correspondence analysis of the evolution of Baijiu flavor types. (a) ANOSIM between all samples tested and flavor types. (b) The relationship between differential markers and sensory attributes based on SQDA. (c) The PCA score plot of Baijiu with 12 flavor types by differential markers.

3.6.2. Differential Analysis on the Evolution of Baijiu Flavor Types through Machine Learning

The dataset of trace components in Baijiu was extensive and the flavor perception of Baijiu was notably complex [31]. Traditional identification methods, which primarily utilize principal component analysis (PCA), cluster analysis, and similar methods, were often limited in their effectiveness when analyzing small datasets. These methods typically struggle with non-linear relationships and larger datasets. In contrast, machine learning approached, such as random forests [7] and support vector machines (SVM), possessed the advantage of uncovering potential unknown connections within extensive datasets [32]. Recently, machine learning has been employed to establish identification methods for food based on various treatment techniques [33]. In this study, random forest analysis (**Figure A.2**) was performed, focusing on the distribution characteristics of trace components. Within 500 decision trees, the trace components were ranked according to their feature importance, ultimately identifying the differential markers between derived and basic flavor types with high accuracy [34]. Based on, the Pearson correlation coefficient was calculated to analyze the relationship between the concentrations of differential markers and the scores of SQDA for Baijiu, as illustrated in **Figure 3b**. In this figure, 3-octanone-TX and 3-octanone-FYX indicated that this component was screened in both the TX and FYX groups, a trend that applied to other components as well.

Jianxiangxing (JXX) Baijiu was identified as a flavor type in 1983. Its production technique was borrowed JX in the early stage and NX in the late stage, which formed a sensory feature that combined

both JX and NX styles [35,36]. As shown in **Figure A.2**, ethyl benzoate and ethyl butanoate made an important contribution to identifying JXX and its basic flavor types. Among them, in previous study [37], ethyl benzoate was also identified as a flavor differential marker to distinguish JXX and its basic flavor types. Correlation analysis (**Figure 3b**) indicated that ethyl butanoate was negatively correlated with ethanol aroma, softness and persistence, while positively correlated with the baked aroma. Meanwhile, ethyl benzoate was positively correlated with oily aroma and ethanol aroma but positively correlated with bitter aftertaste.

Dongxiangxing (DX) Baijiu was considered as a flavor type in 1986. The production technique combined Daqu and Xiaoqu (two saccharification fermenters with different production technology) [38], and the flavor contained the characteristics of three flavor types, namely, JX, NX and MX. Adding traditional Chinese medicine was a feature of DX, which provided a comfortable herbal aroma while promoting or inhibiting microorganisms. In terms of flavor, DX possessed unique style, with a composite aroma composed of herbal aroma, ester aroma and ethanol aroma. As shown in **Figure A.2**, pentanoic acid (positively correlated with mild aroma and sour taste while negatively correlated with mellow), 2-methylbutanal (positively correlated with mellow and bitter aftertaste while negatively correlated with jiang-aroma), and ethyl hexanoate (negatively correlated with grain aroma while positively correlated with herbal aroma and harmonious) played an important role in distinguishing DX from its basic flavor types.

Texiangxing (TX) Baijiu, with whole grain rice as the brewing material, had independently been a new flavor type since 1988. The unique ratio of flour, wheat bran, and distilled grains used in the production of Daqu was one of the importance factors that contributed to the formation of TX style [39,40]. TX simultaneously possessed the characteristics of three basic flavor types (referring to JX, NX, QX). The results (**Figure 3b**) showed that 3-octanone, isopentyl hexanoate, ethyl heptanoate with the highest contribution were all negatively correlated with bitter aftertaste.

Fengxiangxing (FX) Baijiu had a long history, but its flavor type was not officially determined until 1992. The raw material for its Daqu was consistent with QX, while the production technology was similar to NX so that FX possessed the sensory characteristic of combining both QX and NX [41]. **Figure A.2** showed that 3-methylbutyric acid (positively correlated with ethanol aroma while negatively correlated with oily aroma), ethyl lactate (positively correlated with sweet taste and sweet aftertaste), isopentyl hexanoate (positively correlated with floral/fruity aroma, mellow, harmonious and sweet aftertaste), ethyl tetradecanoate (positively correlated with floral/fruity aroma and grain aroma while negatively correlated with softness) and ethyl benzoate (positively correlated with floral/fruity aroma while negatively correlated with milk aroma and grain aroma) were identified to make major contributions to the classification of FX and its basic aroma types. In particular, the low concentration of ethyl lactate in FX was related to its short fermentation cycle [42], which may have a positive impact on the sweetness of Baijiu.

Zhimaxiangxing (ZMX) Baijiu was officially determined as an independent flavor type in 1995. In fact, its technology was carried out according to JX, due to the less humid and hot climate in the north compared to the south, the microorganisms produced during the accumulation process were not abundant enough [43], resulting in the Baijiu had presenting a prominent sesame aroma. As shown in **Figure A.2**, ethyl propanoate (negatively correlated with jiang-aroma and mellow) made the greatest contribution in distinguishing between ZMX and JX.

Chixiangxing (CX) Baijiu was determined in 1996 and derived from MX with the process feature of saccharification and fermentation simultaneously. Specifically, its soaking process of chen rou (i.e., fatty pork) [44] was the biggest difference from MX and the Chixiang referred to the unique aroma that combined the basic aroma of the Baijiu (such as ester aroma, floral aroma, etc.) with the mature aroma of chen rou [45]. The results (**Figure A.2**) showed that isobutyl acetate (positively correlated with jiao-aroma and oily aroma while negatively correlated with honey aroma and ethanol aroma) played an important role in distinguishing between CX and MX.

Laobaiganxiangxing (LBGX) Baijiu, whose acid/ester ratio was basically the same as QX, and the concentration of ethyl acetate was also higher, was once considered to belong to QX. After long-term practice, it had been found that there were significant differences in the distribution characteristics of

trace components between LBGX and QX [46]. It was not until 2005 that LBGX was officially recognized as a separate flavor type. The classification and feature selection of QX and LBGX were performed by random forests, and the results (**Figure A.2**) showed that isopropyl myristate (positively correlated with jiao-aroma and mellow while negatively correlated with oily aroma and baked aroma) made an important contribution to classification accuracy.

Fuyuxiangxing (FYX) Baijiu was derived from NX, JX, and QX, and formed a style of pre-NX flavor, mid-QX flavor, and post-JX flavor [47]. It was officially identified as an independent flavor type in 2005. The main characteristic of its technology was that unbroken grains were chosen as raw material, and were saccharified by using Xiaoqu to cultivate microorganism, while Daqu was added for fermenting in the cellar [48]. There were 5 kinds of differential markers selected by random forests (**Figure A.2**), namely 2-butanol (positively correlated with ethanol aroma and rich), ethyl 2-hydroxy butanoate (negatively correlated with jiao-aroma, mellow, sweet taste and hard), 3-octone (positively correlated with herbal aroma while negatively correlated with sesame aroma), ethyl nonanoate (positively correlated with jiao-aroma while negatively correlated with softness), and 2,4-di-tert-butylphenol (positively correlated with sweet aroma and persistence while negatively correlated with harmonious and rich).

In summary, random forest model was used to classify and select features for derived and basic flavor types. The 19 differential markers with the highest contribution to classification were selected based on the accuracy ranking of each group, containing 11 esters, 2 alcohols, 2 acids, 1 aldehyde, 1 ketone, and 2 aromatics (containing benzene). Based on, PCA analysis was carried out on different flavor types with 19 selected differential markers to evaluate whether they can distinguish the flavor types of Baijiu. The results (**Figure 3c**) showed that the total variance was 71.5% (PC1 was 38.7%, PC2 was 32.8%), which indicated that the 19 differential markers screened could effectively distinguish Baijiu of different flavor types. However, the influence of these differential markers in corresponding flavor type of Baijiu on sensory attributes still needed to be further verified by flavor addition test.

3.7. Correlation Analysis Based on Flavor Addition Experiments

On the basis of the research discussed above, each differential marker was added to the corresponding Baijiu with lower concentration in each group and scored the sensory attributes based on SQDA. Then visualized the relationship between sensory attributes and differential marker by Pearson correlation analysis. As shown in **Figure 4a**, acids were negatively correlated with mellow and persistence, and positively correlated with ethanol aroma and bitter aftertaste. In detail, pentanoic acid had a strong positive correlation with sour taste which was the prominent sensory attribute of DX according to its sensory radar map, and 3-methylbutyric acid had a strong negatively correlation with mellow and ethanol aroma. The contribution of alcohols to sensory attributes was distinctive greatly in different Baijiu matrices. Specifically, 2-butanol, a differential marker between FYX and JX, had a strong positively correlated with ethanol aroma whose sensory intensity in FYX was much higher than in JX. While 2,3-butanediol was positively correlated with jiao-aroma, which was consistent with the previous research [13].

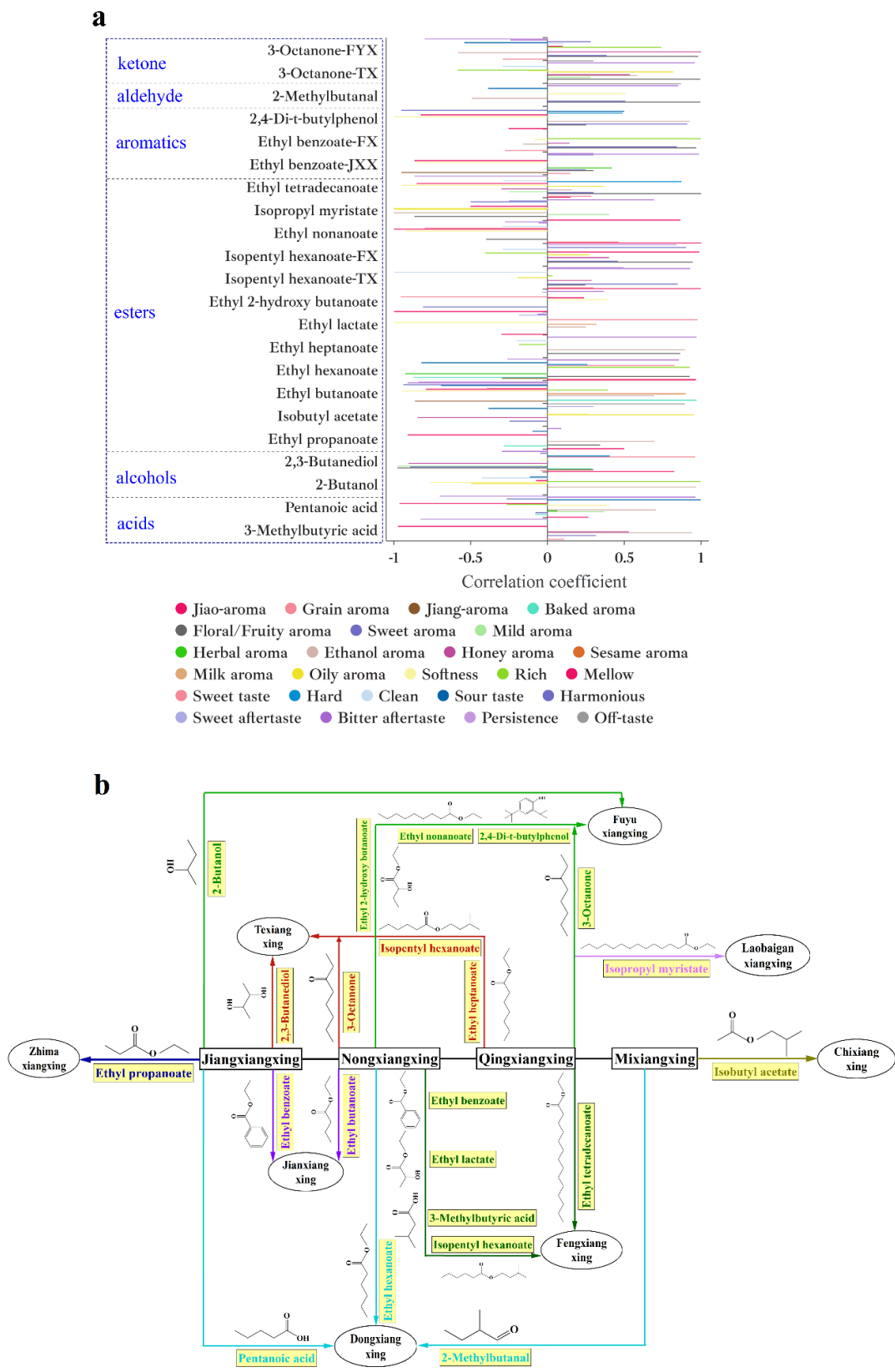


Figure 4. Differential markers of 12 flavor types. **(a)** The relationship between differential markers and sensory attributes based on flavor addition experiments. **(b)** The evolution pathways of Baijiu flavor types based on differential markers.

As the most abundant class of components, most esters had a positive correlation with floral/fruity aroma and were negatively correlated with softness. Wherein, ethyl butanoate, ethyl lactate, ethyl nonanoate, isopropyl myristate, and ethyl tetradecanoate were observed to have a strong negative correlation with softness. Meanwhile, some esters had a strong positive correlation with jiao-aroma, such as ethyl hexanoate, isopentyl hexanoate, ethyl nonanoate, and isopropyl myristate. In addition, ethyl propanoate, as a differential marker between JX and ZMX, showed a certain promoting effect on sesame aroma. It was speculated that many components jointly affect the sesame aroma on Baijiu. Propionic acid acts as a precursor for ethyl propionate, directly influencing its synthesis. The production of ethyl propionate is positively correlated with the acid production capacity of propionic acid-producing bacteria, such as *Propionibacterium jensenii*, during the brewing process [49]. Therefore, effectively monitoring and managing the levels of these bacteria is crucial for optimizing the flavor profile of Baijiu. In the above research conclusions, isobutyl acetate was a differential marker for distinguishing CX and MX, and the result of addition experiment showed a strong positive correlation between isobutyl acetate with oil aroma, which may be determined by the difference in the technology of CX and MX. Significantly, isopentyl hexanoate had various sensory contributions in different flavor types of Baijiu, such as opposite contributions to jiao-aroma. It was preliminarily supposed that isopentyl hexanoate had synergistic or inhibitory effects in different Baijiu matrices. Similarly, ethyl 2-hydroxybutyrate was not considered to have a direct contribution to the senses according to OAV/TAV analysis, but the result of addition experiment showed a strong negative correlation with jiao-aroma, sweet aroma, and sweet taste, of which may also exist synergistic or inhibitory effects.

For aromatics (containing benzene), positive correlations with differential markers were found on the floral/fruity aroma, and sweet aroma attributes, which was consistent with previous research [50]. Of note, ethyl benzoate was found to have the highest score for floral/fruity aroma followed by the sweet aroma attribute. According to the above conclusions, ethyl benzoate was considered as a differential marker both in JXX and FX groups, and its sensory contribution in these two flavor types was unequal. Specifically, it was positively correlated with floral/fruity aroma in the FX group and negatively correlated with jiang aroma in the JXX group. Although ethyl benzoate was only considered to have a direct contribution to aroma but not to taste according to OAV/TAV analysis, it was found that ethyl benzoate was correlated with softness, rich, mellow, and bitter aftertaste. Additionally, 2,4-di-*t*-butylphenol had a strong positive correlation with sweet and ethanol aroma, which was the prominent sensory attribute of FYX. The research found that the unique brewing environment of the FYX Baijiu producing area fosters a distinct microbial community. The weak acid mud cellar serves as the optimal growth environment for caproic acid and butyric acid bacteria, which play a key role in aroma production. The interactions between the enzyme production and metabolic activities of these microorganisms contribute to the sweet and ethanol aroma of Baijiu, enhancing its overall flavor profile [51].

Aldehydes and ketones exhibited similar contributions to the sensory attributes of Baijiu, representing a strong positive correlation with floral/fruity aroma, sweet aroma and bitter aftertaste. For 3-octanone, a differential marker identified both in TX and FYX groups, its contribution to floral/fruity aroma was consistent. Compared to NX, TX had a more prominent floral/fruity aroma according to above sensory radar maps, indeed, the addition of 3-octanone greatly enhanced the intensity of its floral/fruity aroma. Moreover, 3-octanone also showed a strong positive correlation with honey aroma in the FYX group.

To sum up, the results of this study were illustrated in **Figure 4b**, demonstrating the evolution pathways of these differential markers and their corresponding flavor types. The sensory characteristics of Baijiu across different flavor types were formed through the combined action of various trace components, mainly consisting of esters, acids, alcohols, aromatics (containing benzene), aldehydes, and ketones. For example, esters, aromatics (containing benzene), aldehydes, and ketones had a positive impact on floral/fruity aroma and sweet aroma, while the ethanol aroma was predominantly affected by alcohols. The sour taste was primarily affected by acids, and mellow was mainly affected by acids and certain esters. Additionally, differential markers with lower OAVs and

TAVs may still exert an indirect impact on the sensory attributes of Baijiu, with their sensory contributions varying across different Baijiu matrices, probably due to synergistic or inhibitory effects. Based on these findings, the differential markers between various flavor types of Baijiu effectively explained their sensory differences. Eventually, the addition experiments proved that the contribution of the 19 differential markers (including 3-methylbutyric acid, pentanoic acid, 2-butanol, 2,3-butanediol, ethyl propanoate, isobutyl acetate, ethyl butanoate, ethyl hexanoate, ethyl heptanoate, ethyl lactate, ethyl 2-hydroxy butanoate, isopentyl hexanoate, ethyl nonanoate, isopropyl myristate, ethyl tetradecanoate, ethyl benzoate, 2,4-di-t-butylphenol, 2-methylbutanal and 3-octanone) to the overall sensory attributes of Baijiu varied significantly, which were not only verified as key differential markers but also effectively elucidated the evolution pathways of Baijiu flavor types. In previous studies, most of these differential markers were identified as key flavor active components in various flavor types of Baijiu. For instance, ethyl lactate, ethyl butanoate, ethyl hexanoate, and 3-methylbutyric acid were highlighted in FYX [52], while ethyl hexanoate, ethyl lactate, and ethyl butanoate were prominent in JXX [37]. Additionally, ethyl tetradecanoate, ethyl butanoate, isopentyl hexanoate, ethyl lactate, and ethyl hexanoate were noted in MX [53]. These findings confirmed that the differential markers were critical components of the characteristic flavor for Baijiu. Furthermore, this study bridged the gap in understanding the relationship between these key components and the differences in Baijiu flavor types.

4. Conclusion

In total, 319 trace components were identified in Baijiu across 12 flavor types using GC-O-MS and GC-MS. Among them, 91 trace components were further recognized as aroma and taste components owing to their relatively high OAVs and TAVs in all samples. Ultimately, 19 differential markers (including 3-methylbutyric acid, pentanoic acid, 2-butanol, 2,3-butanediol, ethyl propanoate, isobutyl acetate, ethyl butanoate, ethyl hexanoate, ethyl heptanoate, ethyl lactate, ethyl 2-hydroxy butanoate, isopentyl hexanoate, ethyl nonanoate, isopropyl myristate, ethyl tetradecanoate, ethyl benzoate, 2,4-di-t-butylphenol, 2-methylbutanal and 3-octanone) were screened and validated between derived and basic flavor types of Baijiu using random forests combined with PCA, which could effectively reveal the evolution pathways of Baijiu flavor types. The key differential markers exhibited varying degrees of influence on the sensory characteristics of Baijiu across different flavor types. Of note, differential markers with lower OAVs and TAVs may still exert an indirect impact on the sensory attributes of Baijiu, and their sensory contributions could vary across different matrices, probably due to synergistic and inhibitory effects. This study provided a theoretical foundation for the scientific and standardized expression of Baijiu flavor quality and supported the digital and intelligent development of traditional brewing industry.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author Contributions: **He Huang:** Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Yiyuan Chen:** Investigation, Methodology, Project administration. **Yaxin Hou:** Investigation, Methodology, Writing – review & editing. **Jiaxin Hong:** Investigation, Methodology, Writing – review & editing. **Hao Chen:** Investigation, Writing-review & editing. **Dongrui Zhao:** Investigation, Methodology, Writing – review & editing, Resources. **Jihong Wu:** Resources. **Jinchen Li:** Writing – review & editing. **Jinyuan Sun:** Resources. **Xiaotao Sun:** Resources, Methodology. **Mingquan Huang:** Investigation, Writing – review & editing. **Baoguo Sun:** Resources.

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Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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.

Abbreviation

QX: qingxiangxing; NX, nongxiangxing; JX, jiangxiangxing;MX, mixiangxing;CX, chixiangxing; TX, texiangxing; FYX, fuyuxiangxing; DX, dongxiangxing; ZMX, zhimaxiangxing; LBGX, laobaiganxiangxing; FX, fengxiangxing; JXX, jianxiangxing.

VASE: vacuum-assisted sorbent extraction; RF, random forest; GC-MS, gas chromatography-mass spectrometry; LLE, liquid–liquid extraction; GC-O-MS, gas chromatography-olfactometry-mass spectrometry; Osme, odor specific magnitude estimation; OAV, odor active value; TAV, taste active value; SQDA, sensory quantitative descriptive analysis; ANOSIM, analysis of similarities.

References

1. Zheng, X. W. and B. Z. Han. "Baijiu (白酒), chinese liquor: History, classification and manufacture." *Journal of Ethnic Foods* 3 (2016): 19-25. <https://doi.org/10.1016/j.jef.2016.03.001>. <https://www.sciencedirect.com/science/article/pii/S2352618116300087>.

2. Zou, F., L. Ye, L. Feng, X. W. Zheng, B. Huang, B. Xia, W. J. Zhang, X. Y. Chen, Z. G. Fang and Y. T. Sun. "Research progress on microbial diversity, evaluation and maintenance of baijiu pit mud." *Food Science* 45 (2024): 320-28. <https://kns.cnki.net/kcms2/article/abstract?v=MBTPQIn9ZKFNrtSxfJvtvZ91bJIfikyTA-sMaWGky85VNwENCAApCjEPXqDPsczsc4R4WyUTh2P301GaDfA5k0GV3CcnIOxF8r9XOZV7Fw9A5YS2N9q-UADGoalSH18AV9jpLd-tWbniNV94oQ7SMPWnPIsdoUA2yiU-x9jh39vjuZomU3OgfDvclg9KO0QN&uniplatform=NZKPT&language=CHS>.

3. Hou, X. B., X. X. Lu and H. Huang. "Five sessions of baijiu appraisal fuelled chinese baijiu flavor type with continuous growth." *Liquor Making* 50 (2023): 152-53. https://kns.cnki.net/kcms2/article/abstract?v=7P8mTOHD94Fq9cxE4vSrNZYZyaylnAx8ydufyh7lavH0-ZgPevr_rLrd6THdOEOML4o2EAZiBxsW4feoQVBZZ3MgJ92LcCeKMllh17G4bD3usiSTJR60RhKX7TpBqyWJiaLcfaEEQ3LIPq1yN7TOFg==&uniplatform=NZKPT&language=CHS. https://kns.cnki.net/kcms2/article/abstract?v=7P8mTOHD94Fq9cxE4vSrNZYZyaylnAx8ydufyh7lavH0-ZgPevr_rLrd6THdOEOML4o2EAZiBxsW4feoQVBZZ3MgJ92LcCeKMllh17G4bD3usiSTJR60RhKX7TpBqyWJiaLcfaEEQ3LIPq1yN7TOFg==&uniplatform=NZKPT&language=CHS.

4. Hou, Y. X., Y. C. Ma, H. Huang, Y. S. Wu, H. Chen, D. R. Zhao, R. Ao, Z. G. Zhao, C. S. Zhang, J. Y. Sun, et al. "Anchoring for the quality difference factor of strong-flavor baijiu based on sensory quantitative descriptive analysis and sorbent pen-gas chromatography-mass spectrometry." *Food and Fermentation Industries* 49 (2023): 255-67. 10.13995/j.cnki.11-1802/ts.034549. <https://kns.cnki.net/kcms/detail/11.1802.ts.20230302.1435.004.html>.

5. Zhang, X. J., L. J. Meng, Z. M. Lu, L. J. Chai, S. T. Wang, J. S. Shi, C. H. Shen and Z. H. Xu. "Identification of age-markers based on profiling of baijiu volatiles over a two-year maturation period: Case study of lu-flavor baijiu." *Lwt-Food Science and Technology* 141 (2021): 10.1016/j.lwt.2021.110913. <Go to ISI>://WOS:000636138600057.

6. Huang, H., Y. S. Wu, H. Chen, Y. X. Hou, J. S. Wang, J. X. Hong, D. R. Zhao, J. Y. Sun, M. Q. Huang and B. G. Sun. "Identification of regional markers based on the flavor molecular matrix analysis of sauce-aroma style baijiu." *J Sci Food Agric* 103 (2023): 7434-44. 10.1002/jsfa.12823. <Go to ISI>://WOS:001034066100001.

7. Somerfield, P. J., K. R. Clarke and R. N. Gorley. "A generalised analysis of similarities (anosim) statistic for designs with ordered factors." *Austral Ecology* 46 (2021): 901-10. 10.1111/aec.13043. <Go to ISI>://WOS:000657172200001.

8. Niu, Y. W., Q. Zhu and Z. B. Xiao. "Characterization of perceptual interactions among ester aroma compounds found in chinese moutai baijiu by gas chromatography-olfactometry, odor intensity, olfactory threshold and odor activity value." *Food Research International* 131 (2020): 108986. <https://doi.org/10.1016/j.foodres.2020.108986>. <https://www.sciencedirect.com/science/article/pii/S0963996920300119>.

9. Niu, Y., Q. Zhu and Z. Xiao. "Characterization of perceptual interactions among ester aroma compounds found in chinese moutai baijiu by gas chromatography-olfactometry, odor intensity, olfactory threshold and odor activity value." *Food Research International* 131 (2020): 10.1016/j.foodres.2020.108986. <Go to ISI>://WOS:000528252800011.

10. He, Y., Z. Liu, M. Qian, X. Yu, Y. Xu and S. Chen. "Unraveling the chemosensory characteristics of strong-aroma type baijiu from different regions using comprehensive two-dimensional gas chromatography–time-of-flight mass spectrometry and descriptive sensory analysis." *Food Chemistry* 331 (2020): 127335.

- <https://doi.org/10.1016/j.foodchem.2020.127335>.
<https://www.sciencedirect.com/science/article/pii/S0308814620311973>.
11. Lytra, G., S. Tempere, S. Marchand, G. de Revel and J.-C. Barbe. "How do esters and dimethyl sulphide concentrations affect fruity aroma perception of red wine? Demonstration by dynamic sensory profile evaluation." *Food Chem* 194 (2016): 196-200. 10.1016/j.foodchem.2015.07.143. [10.1016/j.foodchem.2015.07.143](https://doi.org/10.1016/j.foodchem.2015.07.143). [Go to ISI://WOS:000364248900026](https://www.sciencedirect.com/science/article/pii/S0308814620311973).
 12. Liu, L., H. Yang, X. Jin, Y. Zhang, Z. Yan, Y. Qi and C. Xu. "Effect of different liquor storage containers on flavor substances of feng flavor baijiu." *Food Science* 43 (2022): 285-93. https://kns.cnki.net/kcms2/article/abstract?v=j14_WWxyq7LJQacnNVZ4zZJq4CVS1P8VpPdqzyYUFeLgDlDk_hZemUWHBF3LdKj-dVwaipmJed-LktRueuLcKbhs67838UyIxWYLS98CS3sYCBYAz7XcskK8N2kcQ9Ur&uniplatform=NZKPT&language=CHS.
 13. Hong, J. X., H. Huang, D. R. Zhao, J. Y. Sun, M. Q. Huang, X. T. Sun and B. G. Sun. "Investigation on the key factors associated with flavor quality in northern strong aroma type of baijiu by flavor matrix." *Food Chem* 426 (2023): 136576-86. 10.1016/j.foodchem.2023.136576. [Go to ISI://WOS:001020227000001](https://doi.org/10.1016/j.foodchem.2023.136576).
 14. Yan, Y., S. Chen, Y. Nie and Y. Xu. "Characterization of volatile sulfur compounds in soy sauce aroma type baijiu and changes during fermentation by gc × gc-tofms, organoleptic impact evaluation, and multivariate data analysis." *Food Res Int* 131 (2020): 109043. <https://doi.org/10.1016/j.foodres.2020.109043>. <https://www.sciencedirect.com/science/article/pii/S0963996920300685>.
 15. Wang, Z., Y. Wang, T. T. Zhu, J. Wang, M. Q. Huang, J. W. Wei, H. Ye, J. H. Wu, J. L. Zhang and N. Meng. "Characterization of the key odorants and their content variation in niulanshan baijiu with different storage years using flavor sensory omics analysis." *Food Chem* 376 (2022): 131851. <https://doi.org/10.1016/j.foodchem.2021.131851>. <https://www.sciencedirect.com/science/article/pii/S0308814621028570>.
 16. Wang, P. P., Q. X. Kan, L. X. Yang, W. T. Huang, L. F. Wen, J. Y. Fu, Z. Liu, Y. Q. Lan, Q. R. Huang, C.-T. Ho, et al. "Characterization of the key aroma compounds in soy sauce by gas chromatography-mass spectrometry-olfactometry, headspace-gas chromatography-ion mobility spectrometry, odor activity value, and aroma recombination and omission analysis." *Food Chem* 419 (2023): 135995. 10.1016/j.foodchem.2023.135995. [Go to ISI://WOS:000970030000001](https://doi.org/10.1016/j.foodchem.2023.135995).
 17. Wang, L. H., L. Zhu, F. P. Zheng, F. G. Zhang, C. H. Shen, X. J. Gao, B. G. Sun, M. Q. Huang, H. H. Li and F. Chen. "Determination and comparison of flavor (retronasal) threshold values of 19 flavor compounds in baijiu." *J Food Sci* 86 (2021): 2061-74. 10.1111/1750-3841.15718. [Go to ISI://WOS:000641954500001](https://doi.org/10.1111/1750-3841.15718).
 18. Huang, H., H. Chen, Y. S. Wu, J. X. Hong, Y. Y. Chen, S. Wang, Y. Sun and D. R. Zhao. "Non-targeted identification of age markers of north category strong flavor baijiu." *Journal of Food Safety & Quality* 14 (2023): 171-82. 10.19812/j.cnki.jfsq11-5956/ts.2023.20.028.
 19. Gemert, L. J. v. Compilation of compound flavour threshold values (second enlarged and revised edition). Science Press., 2015,
 20. Niu, Y. W., W. H. Li and Z. B. Xiao. "Research progress on analysis of flavor compounds in baijiu." *Journal of Food Science and Technology* 39 (2021): 23-31+90. https://kns.cnki.net/kcms2/article/abstract?v=6TwuVQQ8bf_UJMFzt5BcirQdlwhph5tKU90dJciXInj3JxrC4X3CxiOa_mhlatYSLsbeAHJms31lnMs1Z1EPCmfnN8QDX4l4AnN56BgBAJEstYMzFNQ12JfMDYGLf5oZ5_iqm8kVGUIOamjre66Necowh1F-DUj_fGQmwSXJeAdUILKMNacvIBCUGZ01U4IBPjIq02TEQrk=&uniplatform=NZKPT&language=CHS.
 21. Xiao, Z., D. Yu, Y. Niu, N. Ma, J. J. F. Zhu and F. Journal. "Characterization of different aroma-types of chinese liquors based on their aroma profile by gas chromatography-mass spectrometry and sensory evaluation." 31 (2016): 217-27. 10.1002/ffj.3304.
 22. Wang, Z., W. J. Hao, J. W. Wei, M. Q. Huang, X. A. Zeng, Y. Wang, J. H. Wu and B. R. Chen. "Unveiling innovation in aroma attribute evaluation of niulanshan baijiu: An advanced exploration of two different processing methods via food sensory omics and penalty analysis." *Food Chem* X 19 (2023): 100852. 10.1016/j.fochx.2023.100852. [Go to ISI://WOS:001106569900001](https://doi.org/10.1016/j.fochx.2023.100852).
 23. Ding, L. J., Y. Tang, Y. X. Zhao, D. Xun, T. Wang, L. Guo and R. Wang. "Research status of important esters in baijiu and their sources." *Liquor-Making Science & Technology* (2024): 91-100+07. 10.13746/j.njkj.2023104. <https://link.cnki.net/doi/10.13746/j.njkj.2023104>.
 24. Xu, Y., Q. Wu, W. L. Fan and B. F. Zhu. "The discovery & verification of the production pathway of tetramethylpyrazine(ttmp) in chiese liquor." *Liquor-Making Science & Technology* (2011): 37-40. 10.13746/j.njkj.2011.07.001. <https://kns.cnki.net/kcms/detail/52.1051.TS.20110611.0752.001.html>.
 25. Zhang, M., Z. Tian, J. P. Wei and T. L. Yue. "Analysis of volatile flavor compounds in 6 flavor types of baijiu based on gas chromatography-ion mobility spectrometry and solid phase microextraction-gas chromatography-mass spectrometry." *Journal of Food Safety & Quality* 14 (2023): 226-35. 10.19812/j.cnki.jfsq11-5956/ts.2023.05.045.

26. Yu, J. Y., G. L. Liu, W. D. Bai, Y. T. Fei, L. Z. Ai, J. S. Yu and L. C. Wang. "Research progress on rice-flavor baijiu." *China Brewing* 40 (2021): 29-32. https://kns.cnki.net/kcms2/article/abstract?v=MBTPQIn9ZKE6rjLmVTnx0wlwls9B1aXqTGZl79g0z-Dn73V7K7iZYojn_HtU1J2Hvh5c0ssyJm1TecwAWw_th01HnerT7TtK5r7SboJzleOYLNGKXFYZLAB1GrItVsZOHrMsewUICpt1vIlEzkGoo0Yrli6mTdtP7xsgSjQyAh4EuppdfJL1pcjQFSc5hCdrF1EaWyL_ZI=&uniplatform=NZKPT&language=CHS.
27. Tang, P., G. M. Shan Qi, L. Wang, F. Wang, C. W. Li and J. Lu. "A review of research methods in baijiu flavor chemistry and recent progress in the flavor chemistry of maotai-flavored baijiu." *Food Science* 41 (2020): 315-24. <https://link.cnki.net/urlid/11.2206.TS.20191115.1342.012>.
28. Miao, K. C., M. M. Zhang, Q. Z. Zhao, Z. Y. Lv, X. F. Lv and G. H. Ren. "Influence of mixed application of functional fuqu on the production of zhimaxiang baijiu." *Liquor-Making Science & Technology* (2024): 74-82. 10.13746/j.njkj.2024403. <https://link.cnki.net/doi/10.13746/j.njkj.2024403>.
29. Yang, S., Y. H. Luo, J. Zhang and R. Hou. "Simultaneous determination of 12 kinds of pyrazine compounds in different vintages of maotai-flavor baijiu by high performance liquid chromatography." *Journal of Food Safety & Quality* 15 (2024): 220-29. 10.19812/j.cnki.jfsq11-5956/ts.20240328003. <https://link.cnki.net/doi/10.19812/j.cnki.jfsq11-5956/ts.20240328003>.
30. Chen, H., Y. X. Hou, H. Huang, Y. Sun, Y. S. Wu, J. X. Hong, D. R. Zhao, J. Y. Sun, M. Q. Huang and B. G. Sun. "Anchoring of quality variance factors and uncovering its influence on the flavor quality of bcsbg during aging process of sun-exposure." *Int. J. Food Prop* 26 (2023): 3445-64. 10.1080/10942912.2023.2281885. <Go to ISI>://WOS:001128305600003.
31. Yu, Y., Y. Nie, S. Chen and Y. Xu. "Characterization of the dynamic retronasal aroma perception and oral aroma release of baijiu by progressive profiling and an intra-oral spme combined with gc * gc-tofms method." *Food Chemistry* 405 (2023): 134854-54. 10.1016/j.foodchem.2022.134854. <Go to ISI>://FSTA:2023-04-HI3406.
32. Wang, N. X. X., X. Li, Y. L. Huang, Y. L. Wang, H. M. Lai, M. L. Yang, C. W. Tang, L. H. Ge and N. Zhao. "Advances in the application of machine learning to microbial structure and quality control of traditional fermented foods." *Science and Technology of Food Industry* (2023): 1-13. 10.13386/j.issn1002-0306.2023070288. <https://kns.cnki.net/kcms/detail/11.1759.TS.20231110.1123.002.html>.
33. Wang, Y. T., H. B. Ren, W. Y. Liang, X. Jin, Q. Yuan, Z. R. Liu, D. M. Chen and Y. H. Zhang. "A novel approach to temperature-dependent thermal processing authentication for milk by infrared spectroscopy coupled with machine learning." *J Food Eng* 311 (2021): 1-9. 10.1016/j.jfoodeng.2021.110740. <Go to ISI>://WOS:000687724700015.
34. Guo, X. L., X. G. Gao, J. Jia and X. L. He. "Identification of coffee flavor by gc-ims." *Analytical Instrumentation* (2021): 16-21. https://kns.cnki.net/kcms2/article/abstract?v=b4E8SuETvILlk5-DlHq7r0i-5Irm-gJxwoGUvAZnyKc5MPROhJnYCBYxTeQHPEKRDv0H1xjP-npaB7GKLuIT6W04Gre4-I9lKhYf5zIK5oHxLFDy-rdZelARBYMjjbiKefPR_T4r3u4=&uniplatform=NZKPT&language=CHS.
35. Zhou, R., Q. Yuan, X. Y. Jin, Y. Zhang, M. B. Chen and S. L. Fang. "Analysis of aroma components of strong-sauce-flavor aged baijiu." *China Brewing* 39 (2020): 137-43. https://kns.cnki.net/kcms2/article/abstract?v=6TwuVQQ8bf-CO6oIU84NNrIIYbCFEemWMkboMHkFV-uf7Fu0c7fSKC7jLAYyN0agFkMOyYK-BHhMU5OH62qHuDP19OPTCO8xyMoSD4fcXw0fnGsD72MMvnGvvPb0grX0qqTPlYn6hOt4k5iuNNVCs6ITjqHcSgDtsO0wAmcly-JeZNj2bbmL24ClS0W0bvs5xjO_w2isqSvc=&uniplatform=NZKPT&language=CHS.
36. Zhou, R., Q. Yuan, Y. Xia, Y. L. Zheng and S. L. Fang. "Application of electronic nose technology in distinguishing the strong-sauce-flavor aged baijiu." *China Brewing* 39 (2020): 65-69. https://kns.cnki.net/kcms2/article/abstract?v=6TwuVQQ8bf8GlyqfG2nPJGspFDxoXw-zFNjw5mgvMYcBJder5jc0YYP0NiXoFSFSGtFB9kjlzgbGuHL_h2X4SCM3arxjZGiTJs0HWfXGXLeqYFfOE085gf13scor4BDYCsNNCi5Kc02Xtk1He_Wqo8lu5nbG8CgMY6RLBOM36u7omNQdVd8WlRtR6g75uQbeUU79sJpFyc=&uniplatform=NZKPT&language=CHS.
37. Li, T., J. Wang, B. Z. Xu, H. B. Sun, H. Q. Liu, D. Q. Wang, Y. Shen, J. H. Wu, J. L. Zhang, M. Q. Huang, et al. "Comparative analysis of the differences among langya flavor baijiu and strong and soy sauce flavor baijiu by targeted flavor analysis." *J Food Compos Anal* 122 (2023): 105479. <https://doi.org/10.1016/j.jfca.2023.105479>. <https://www.sciencedirect.com/science/article/pii/S0889157523003538>.
38. Li, Q. S. and H. Y. Fan. "Discussion on the origin of flavoring substances and healthcare substances in dongjiu." *Liquor-Making Science & Technology* (2020): 125-30. 10.13746/j.njkj.2020213.
39. Li, T. Y., W. P. Li, L. X. Tian, Z. J. Liu, Z. Guo and Q. C. Hou. "Quality difference of twelve flavor types baijiu of china based on bionics technology." *China Brewing* 41 (2022): 39-44. https://kns.cnki.net/kcms2/article/abstract?v=b4E8SuETvILYQHlFfOx0EpG11f1E-rzxNvQ_3ZGYZ315xmO57lr2_CefMp1v2OOTtxrZkAYHouJ6iUd6pefYyWeSy8r-Tu2APTbdOSFLceFNMZGw22WONGielHFJtMITXlpRGZdcYA=&uniplatform=NZKPT&language=CHS.

40. Wu, S. W., P. Lin, Z. H. Ye, S. Cai and Q. H. Li. "Construction of flavor wheel of te-flavor baijiu and description of typical sensory characteristics." *China Brewing* 40 (2021): 148-53. https://kns.cnki.net/kcms2/article/abstract?v=b4E8SuETvIKbdz9rFIVTJYo3XSSo7KoU0njg5XbJFNL9mmpYMXn0MunA-1lWmIEozGBpuc3W9J2sma245t1RXIYK0x8UKcuQp3VqOUyMUM4mN9k_krp6kik-Ec1Oc7oSq1oY6z-StY=&uniplatform=NZKPT&language=CHS.

41. Hu, J. H., J. X. Hu, Y. Q. Chen, J. Xia, M. C. He, J. J. Zhang, Z. P. Xu and X. L. Han. "Summary of the development of feng-flavor baijiu." *Liquor Making* 50 (2023): 11-18. https://kns.cnki.net/kcms2/article/abstract?v=b4E8SuETvIKbdz9rFIVTJYo3XSSo7KoU0njg5XbJFNL9mmpYMXn0MunA-1lWmIEozGBpuc3W9J2sma245t1RXIYK0x8UKcuQp3VqOUyMUM4mN9k_krp6kik-Ec1Oc7oSq1oY6z-StY=&uniplatform=NZKPT&language=CHS.

42. Fu, G. C. "Studies on relationship between content of micro components and quality of feng-flavor liquou." *Liquor Making* (2008): 113-16. https://kns.cnki.net/kcms2/article/abstract?v=b4E8SuETvIKbdz9rFIVTJYo3XSSo7KoU0njg5XbJFNL9mmpYMXn0MunA-1lWmIEozGBpuc3W9J2sma245t1RXIYK0x8UKcuQp3VqOUyMUM4mN9k_krp6kik-Ec1Oc7oSq1oY6z-StY=&uniplatform=NZKPT&language=CHS.

43. Gao, C. Q. "Typical technological characteristics of sesame flavor baijiu: A review." *Liquor Making* 49 (2022): 3-15. https://kns.cnki.net/kcms2/article/abstract?v=6TwuVQQ8bf9hKLkdUlv4yRaDu69GGVAvlQSgdgKQYxufnoBv_4cwOVb-1yhEh0JDTMRE7bnk_-bFj8k7NT2rKkEeFmNG5BanQlWNJxW5nvRktOKuihTDmnpvraw518Ol614sjJoRi5vuBB5KjzX9C8v3bU42ubkwnZBgAQVP15r2Fo3VeydeZ7xrQyvds2kGs6jiSndIBw=&uniplatform=NZKPT&language=CHS.

44. Fan, H. Y., W. L. Fan and Y. Xu. "Characetrization of volatile aroma components in chinese chixiang aroma type liquor by gc-o and gc-ms." *Food and Fermentation Industries* 41 (2015): 147-52. 10.13995/j.cnki.11-1802/ts.201504028. <https://kns.cnki.net/kcms/detail/11.1802.ts.20150302.0301.011.html>.

45. Zeng, X. A., B. S. Zhang and S. J. Yu. "A study on the typical fragrane components of chi-xiang style rice wine." *Journal of South China University of Technology(Natural Science Edition)* (2001): 93-95. https://kns.cnki.net/kcms2/article/abstract?v=7P8mTOHD94HTABLRbQxNYNnGPGNKAbDjCyxuwVGOYiGdKjYakyH1Du7WSnuX9TA665e5yiLjk9Fix281zdYv-_mvruqn_QLL_SsH7MgTkt2RvTrpPK43oxEIMH2JSC&uniplatform=NZKPT&language=CHS.

46. Shen, Y. F. *Complete book of baijiu production technology*. China Light Industry Press Ltd., 1998,

47. Chang, Y. T., Y. J. Luo, C. J. Qian, Y. T. Yang and X. M. Shi. "Analysis of relationship between flavor and quality of fuyu flavor baijiu by two comprehensive dimensional gas chromatography-mass spectrometry." *Journal of Food Science and Technology, China* 37 (2019): 64-93. 10.3969/j.issn.2095-6002.2019.06.009. <Go to ISI>://FSTA:2020-06-HI4341.

48. Chen, Y. C., J. Mao, Z. L. Zhou, S. Q. Zhan and W. M. Wang. "Research progress on brewing technology and flavor of fuyu-flavor baijiu." *China Brewing* 43 (2024): 1-6. https://kns.cnki.net/kcms2/article/abstract?v=6TwuVQQ8bf-Iulk_iB_NE7dpb9nSzz8u877jrmMaxAqpcawPsnLJuOnOm6Ee0BJyK-GQqpYpssfNePHIUs9vNGf7Zo4j4qjiV0VtSWFveXasczq7471JBIIZAwxUNfb2xtuns7PJuMlKuJN8DBXIWjv00FmhN7Y5oYMTusFZwwX_ljevd2m7jXm3_Ag9Q_1J&uniplatform=NZKPT&language=CHS.

49. Zhang, W., F. Y. Mou, M. Chen, X. Y. Dong, X. Chang, S. L. Fang and M. B. Chen. "Research progress on propionic acid bacteria and application in baijiu brewing." *China Brewing* 43 (2024): 1-6. https://kns.cnki.net/kcms2/article/abstract?v=_dQyPpHggRtUJ3e0VHtMvDooVhcgeQa9deY5F2lAYkZWvy3fPMX6VRgWKxa9OV9p8_uE3KaZlc2UZnmFQdaRodf-ZwdxfjZn4yB48h1uAvsVN9P3ayw-A2PzZ2hN-dNkdTag4Ca6v4VrExfoh7HMy3ejPVn68tM99HUBASv1NbIhXPXQDR77M8pSlrN8hgYqawH4LiUWE64=&uniplatform=NZKPT&language=CHS.

50. Yu, H. Y., T. Xie, J. R. Xie, L. Z. Ai and H. X. Tian. "Characterization of key aroma compounds in chinese rice wine using gas chromatography-mass spectrometry and gas chromatography-olfactometry." *Food Chem* 293 (2019): 8-14. 10.1016/j.foodchem.2019.03.071. <Go to ISI>://WOS:000469331900002.

51. Ye, L., S. Q. Chen, H. Yin, Z. Y. Ding, X. W. Zheng, H. Zhao, B. Yu and X. Q. Jin. "Relationship between flavor and quality of fuyu flavor baijiu and its flavor source." *China Brewing* 42 (2023): 1-6. https://kns.cnki.net/kcms2/article/abstract?v=_dQyPpHggRtUJ3e0VHtMvDooVhcgeQa9deY5F2lAYkZWvy3fPMX6VRgWKxa9OV9p8_uE3KaZlc2UZnmFQdaRodf-ZwdxfjZn4yB48h1uAvsVN9P3ayw-A2PzZ2hN-dNkdTag4Ca6v4VrExfoh7HMy3ejPVn68tM99HUBASv1NbIhXPXQDR77M8pSlrN8hgYqawH4LiUWE64=&uniplatform=NZKPT&language=CHS.

52. Chen, P. P., Y. Liu, J. H. Wu, B. Yu, H. Zhao, M. Q. Huang and F. P. Zheng. "Sensory-directed decoding of key aroma compounds from jiugui-series baijiu, the representative of fuyu-flavor-type baijiu (fftb)." *J Food Compost Anal* 114 (2022): 104799. <https://doi.org/10.1016/j.jfca.2022.104799>. <https://www.sciencedirect.com/science/article/pii/S0889157522004173>.

53. Zhen., S. X., D. J. Wei., Z. Fan. and H. Pan. "Analysis of volatile aroma components of tianlongquan rice-flavor liquors by headspace solid phase microextraction-gas chromatography mass spectrometry." *Liquor Making* (2021): 48

https://kns.cnki.net/kcms2/article/abstract?v=WOGJpqC0z4aLmhkY_WOO2qxyDGaGJxrtO_r9GUDKc5RoPw6rfnBwDguzrrNSLB1xG7_7eZJsChC8A2A1sn6dRFTEhJEqUqKZH4VHJ6TTxNfYi12fkgGt2NlogzwaVrSaUlw_gsfTyqqQIpnjWL7Y1NKYJJ8Zaai&uniplatform=NZKPT&language=CHS.
https://kns.cnki.net/kcms2/article/abstract?v=WOGJpqC0z4aLmhkY_WOO2qxyDGaGJxrtO_r9GUDKc5RoPw6rfnBwDguzrrNSLB1xG7_7eZJsChC8A2A1sn6dRFTEhJEqUqKZH4VHJ6TTxNfYi12fkgGt2NlogzwaVrSaUlw_gsfTyqqQIpnjWL7Y1NKYJJ8Zaai&uniplatform=NZKPT&language=CHS.

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