

Sensory-Guided Characterization of Key Aroma Compounds in Five Five-Grain Strong-Flavor Baijiu Samples

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Abstract

Five-grain strong-flavor Baijiu is characterized by its intense pit aroma and mellow, sweet, and clean taste, and it plays a pivotal role in the Chinese Baijiu market. Its production is based on key processes including solid-state fermentation in mud pits, continuous fermented grain supplementation, mixed steaming and distillation, and the use of medium- to high-temperature Daqu. In terms of aroma composition, ethyl hexanoate is the predominant compound and, together with ethyl lactate, ethyl acetate, ethyl butyrate, and other esters, forms a well-balanced and complex flavor system. In this study, the five-grain strong-flavor Baijiu samples were produced using sorghum as the primary raw material, supplemented with rice, glutinous rice, wheat, and corn through multigrain co-fermentation. Different sorghum varieties can influence microbial metabolism and flavor formation due to variations in physicochemical properties such as starch, protein, and tannin content. Therefore, a sensomics-based approach was employed in this study. Under the guidance of national-level Baijiu experts, an olfactory panel was selected and systematically trained. By integrating quantitative descriptive analysis (QDA), gas chromatography–olfactometry–mass spectrometry (GC-O-MS), and aroma extract dilution analysis (AEDA), the aroma profiles and key aroma compounds of five-grain strong-flavor Baijiu produced from five different sorghum varieties were comprehensively characterized.

Keywords

Five-grain strong-flavor Baijiu; Sorghum varieties; Sensory evaluation; Aroma profile; Key aroma compounds.

1. MATERIALS

1.1. Samples

A total of 15 Baijiu samples were provided by the Sichuan Engineering Research Center for Brewing Specialty Grains. All samples were produced using the same five-grain formulation (36% sorghum, 22% rice, 18% glutinous rice, 16% wheat, and 8% corn) and the traditional solid-state fermentation process in mud pits for strong-flavor Baijiu. The only variable among the samples was the sorghum variety[1].

Five sorghum varieties were used, namely Yinuohong No. 4, Shanxi sorghum, Jinuohong No. 2, Chuanlianghong No. 9, and Australian sorghum. The corresponding sample codes and details are presented in Table 1. Each sorghum variety was represented by three parallel samples[2], resulting in a total of 15 samples. The representativeness of the samples was confirmed by five national-level Baijiu judges.

Table 1. Alcohol content and pH of five Strong aroma type Baijiux

Sample	Alcohol content (% v/v)	pH
Yinuohong No. 4	68.0±0.7%	4.0±0.4
Shanxi sorghum	70.0±0.5%	4.1±0.2
Jinuohong No. 2	68.0±0.4%	4.5±0.2
Chuanlianghong No. 9	70.0±0.5%	4.3±0.5
Australian sorghum	69.0±0.3%	4.3±0.3

1.2. Experimental Reagents

Table 2. Key reagents

Reagent	Specification	Manufacturer
Chinese Baijiu sniffing bottle	Professional version	Beijing Weibiao Biaowu Technology Co., Ltd.
β -Phenylethanol	AR	Shanghai Aladdin Reagent Co., Ltd.
Glacial acetic acid	AR	Shanghai Aladdin Reagent Co., Ltd.
C7–C40 n-alkanes	Analytical standard	Tanmo Testing Technology Co., Ltd.
Dichloromethane	GC grade	Shanghai Aladdin Reagent Co., Ltd.
Absolute ethanol	AR	Shanghai Aladdin Reagent Co., Ltd.
Anhydrous sodium sulfate	AR	Shanghai Aladdin Reagent Co., Ltd.
Hydrochloric acid	AR	Shanghai Aladdin Reagent Co., Ltd.
3-Nonanone	50 μ g/mL	Shanghai Aladdin Reagent Co., Ltd.
Ethyl hexanoate	99.5%	Shanghai Macklin Biochemical Co., Ltd.
Ethyl butyrate	99.5%	Shanghai Macklin Biochemical Co., Ltd.
Ethyl valerate	99.5%	Shanghai Macklin Biochemical Co., Ltd.
Ethyl octanoate	98.0%	TCI Development Co., Ltd.
Aged pit mud	–	Yibin, Sichuan, China
Medium- and high-temperature Daqu	–	Luzhou, Sichuan, China

1.3. Experimental Instruments

Table 3. Essential equipment

Instrument	Model/Specification	Manufacturer
Gas chromatography– olfactometry–mass spectrometry system	TRACE 1300-ISQ	Thermo Fisher Scientific, USA
Olfactometer	PAL RSI	Gerstel, Germany
Capillary GC column	DB-5MS 50/30 μ m	Agilent Technologies, USA
Solid-phase microextraction fiber	DVB/CAR/PDMS	Supelco, USA
Ultrapure water system	Milli-Q	Millipore, USA
Electronic analytical balance	ME204	Mettler Toledo, Switzerland
Constant-temperature magnetic stirrer	RCT basic	IKA, Germany
pH meter	FE28	Mettler Toledo, Switzerland
Grinder	TQ-300	Yongkang Tianqi Shengshi Industry and Trade Co., Ltd., China
Electric blast drying oven	DS-HXT9	Shanghai Hengke Scientific Instruments Co., Ltd., China

2. MATERIALS AND METHODS

2.1. Selection and Training of the Olfactory Panel

Twenty volunteers with extensive experience in sensory evaluation were recruited from the College of Food and Brewing Engineering, Sichuan University of Science and Engineering. The panel consisted of 10 males and 10 females, aged between 20 and 24 years[3]. Panelist selection was conducted in accordance with GB/T 16291.1-2012 (*Sensory analysis—General guidelines for the selection, training, and monitoring of assessors*).

Basic olfactory test: Panelists were required to correctly identify five standard compounds related to strong-flavor Baijiu, including ethyl hexanoate, ethyl butyrate, β -phenylethanol, acetic acid, and pit mud extract, with a required accuracy of 100%.

Aroma matching test: Panelists were asked to match randomly coded aroma standards with their corresponding descriptors, with a minimum accuracy of 83%.

Ranking test: Panelists ranked a series of ethyl hexanoate standard solutions with different dilution levels (1:2:4:8) according to aroma intensity, with a required accuracy of at least 80%.

Descriptive ability test: Panelists were required to freely describe typical Baijiu samples, with a minimum accuracy of 67%.

Candidates who passed the preliminary screening formed a candidate olfactory panel and underwent systematic training for 8 weeks (30 min per day). The training covered the fundamentals of five-grain strong-flavor Baijiu production[4], recognition of typical aroma attributes, and the use of intensity scales. Training materials included strong-flavor Baijiu samples of different ages, pit mud samples, aromas of steamed five-grain mixtures, and medium- to high-temperature Daqu[5].

After training, the candidate panelists evaluated five test samples using randomized three-digit codes, with each sample evaluated in triplicate. A consensus aroma descriptor lexicon was established through group discussion[6], and aroma intensities were scored using a 9-point

scale. The discrimination ability, consistency, and repeatability of panelists were evaluated based on F-values, mean square error (MSE), and sensory profile analysis. Finally, seven panelists with superior performance were selected to form Group A. In addition, five national-level Baijiu judges formed Group B, and both groups jointly participated in subsequent sensory evaluations[7]. Detailed information is provided in Table 4.

Table 4. Test sample

Sample code	Sorghum variety	Source
562	Yinuohong No. 4	Sichuan Engineering Research Center for Brewing Specialty Grains
842	Shanxi sorghum	Sichuan Engineering Research Center for Brewing Specialty Grains
595	Jinuohong No. 2	Sichuan Engineering Research Center for Brewing Specialty Grains
348	Chuanlianghong No. 9	Sichuan Engineering Research Center for Brewing Specialty Grains
165	Australian sorghum	Sichuan Engineering Research Center for Brewing Specialty Grains

2.2. Construction of Aroma Profiles of Five-Grain Strong-Flavor Baijiu Based on Quantitative Descriptive Analysis

Aroma descriptors were screened in accordance with GB/T 16861-1997 (*Sensory analysis—Identification and selection of descriptors for establishing a sensory profile using multivariate methods*). Initially, relevant aroma terms were generated through panel brainstorming. Subsequently, terms related to hedonic perception, quantitative expressions[8], and those unrelated to sample characteristics were excluded. The remaining descriptors were evaluated for intensity using a 9-point scale and ranked based on the geometric mean value (M), as shown in Equation (1), to determine the final descriptors used for aroma profile construction.

$$M = \sqrt{F \times I} \quad (1)$$

where F represents the frequency of mention of a given descriptor relative to the total possible mentions, and I represents the average intensity of the descriptor relative to the maximum possible intensity.

After the sensory descriptors were determined, reference samples were established and calibrated using a 9-point scale to ensure a unified scoring standard. Specifically, pit aroma, grain aroma, fermented grain aroma[9], Daqu aroma, fruity aroma, sweet aroma, and floral aroma were represented by pit mud combined with ethyl hexanoate, steamed five-grain mixture, freshly fermented grains, medium- to high-temperature Daqu, fresh pineapple combined with ethyl butyrate, honey aqueous solution, and β -phenylethanol, respectively.

During evaluation, 20 mL of each sample was placed in a glass container, and the temperature was controlled at 20 °C. Each sample was evaluated in triplicate per session, with each session completed within 1 h. Samples were coded with randomized three-digit numbers and presented in a randomized order. All sensory evaluations were conducted in a temperature-controlled sensory laboratory maintained at 20 ± 1 °C. Detailed experimental procedures are provided in Table 5.

Table 5. Quantitative Descriptive Analysis Experiment Form

Aroma descriptor	Reference intensity value	Sample score				
		562	842	595	348	165
Pit aroma						
Grain aroma						
Fermented grain aroma						
Daqu aroma						
Fruity aroma						
Sweet aroma						
Floral aroma						

2.3. Sample Preparation

Approximately 5 g of each Baijiu sample, along with its diluted solutions (4-, 16-, 64-, 256-, and 1024-fold), were accurately weighed into 20 mL headspace vials. Subsequently, 20 μ L of 3-nonanone (50 μ g/mL) was added to each vial as an internal standard.

Solid-phase microextraction (SPME) was employed for sample preparation. The samples were incubated at 40 °C for 5 min with agitation at 450 r/min, followed by extraction using a 50/30 μ m DVB/CAR/PDMS fiber at 40 °C for 30 min. The analytes were then thermally desorbed for 300 s prior to GC-MS analysis[10].

2.4. GC-O-MS Analysis Conditions

Chromatographic analysis was performed using a DB-5MS capillary column (30 m \times 0.25 mm \times 0.25 μ m), with the injector temperature set at 250 °C. The oven temperature program was as follows: initial temperature of 40 °C held for 2 min, increased to 180 °C at a rate of 4 °C/min and held for 1 min, then increased to 250 °C at 15 °C/min and held for 10 min. High-purity helium was used as the carrier gas at a constant flow rate of 1.666 mL/min[11].

The mass spectrometer was operated in electron ionization (EI) mode at 70 eV. The ion source and transfer line temperatures were both maintained at 280 °C. Data were acquired in full scan mode over a mass range of 50–600 m/z, with a solvent delay of 2 min[12].

For olfactometric analysis, the effluent at the end of the capillary column was split at a ratio of 1:1 between the mass spectrometer detector and the olfactometer. The sniffing port was supplied with humidified air. Aroma compounds were identified by a trained olfactory panel[13].

2.5. Aroma Extract Dilution Analysis (AEDA)

In the AEDA procedure, Baijiu samples were serially diluted with ultrapure water at dilution factors of 4, 16, 64, 256, and 1024, and pretreated according to the method described in Section 2.3. The diluted samples were sequentially analyzed by GC-O until no aroma signal could be detected. The highest dilution at which an odor could still be perceived was defined as the flavor dilution (FD) factor.

To minimize experimental error, only those odor-active compounds detected simultaneously by at least two panelists were recorded[14].

2.6. Qualitative Analysis of Key Aroma Compounds

Qualitative identification of volatile compounds was performed using the NIST mass spectral library integrated in Xcalibur software[15], combined with mass spectral fragmentation patterns. Only compounds with both similarity index (SI) and reverse similarity index (RSI) values greater than 800 were considered for further analysis[16].

Further confirmation was achieved by comparison with reference standards, retention indices (RI), and GC-O aroma descriptions. The RI values were calculated based on the retention times of a homologous series of n-alkanes (C₇–C₄₀) analyzed under identical conditions.

2.7. Data Processing and Statistical Analysis

Sensory evaluation data from candidate panelists were analyzed using PanelCheck 1.4.0 software. All other experimental data were processed and calculated using Microsoft Excel 2021. Aroma profile radar plots were generated and visualized using Origin 2023 software[17].

3. RESULTS AND DISCUSSION

3.1. Selection and Training of Panelists

According to the selection criteria specified in GB/T 16291.1-2012, a systematic evaluation of olfactory ability was conducted on 20 candidates. The results showed that 12 panelists (Nos. 1, 2, 5, 6, 7, 9, 10, 14, 15, 18, 19, and 20) met all the assessment criteria and were selected as candidate panelists (Table 6).

Table 6. Candidate sniffer screening results

No.	Accuracy				Qualified
	Basic olfactory test (100% required)	Aroma matching test (≥83% required)	Ranking ability test (≥80% required)	Descriptive ability test (≥67% required)	
1	100	100%	100%	83%	√
2	100%	100%	100%	100%	√
3	87.50%	83%	100%	100%	×
4	100%	100%	80%	67%	×
5	100%	100%	100%	100%	√
6	100%	100%	100%	100%	√
7	100%	67%	100%	100%	√
8	100%	100%	60%	100%	×
9	100%	100%	100%	67%	√
10	100%	100%	100%	83%	√
11	100%	100%	60%	83%	×
12	87.50%	100%	100%	67%	×
13	100%	67%	100%	100%	×
14	100%	100%	80%	100%	√
15	100%	83%	80%	100%	√
16	100%	100%	100%	67%	×
17	100%	100%	60%	67%	×
18	100%	100%	100%	100%	√
19	100%	100%	100%	83%	√
20	100%	100%	100%	100%	√

The statistical analysis of the training results is shown in Fig. 1. The F-value, defined as the ratio of between-sample variance to within-sample variance, directly reflects the sensitivity of panelists to differences among samples. Specifically, a higher F-value indicates a stronger ability of the panelist to discriminate a given sensory attribute. As shown in Fig. 1a, the F-values of panelists No. 1, 3, 4, 6, 7, 8, 9, 10, and 11 were all not lower than the critical value at the 1% significance level, indicating satisfactory discriminative ability. In contrast, panelists No. 2, 5, and 12 showed relatively low F-values, suggesting weaker discrimination performance.

The MSE value reflects the consistency of repeated evaluations, with lower values indicating better repeatability. Based on the combined analysis of MSE values, F-values, and profile plots, panelists No. 2, 3, 5, 7, and 12 showed relatively weaker performance. Therefore, the remaining seven panelists were retained to form Group A for subsequent sensory evaluation.

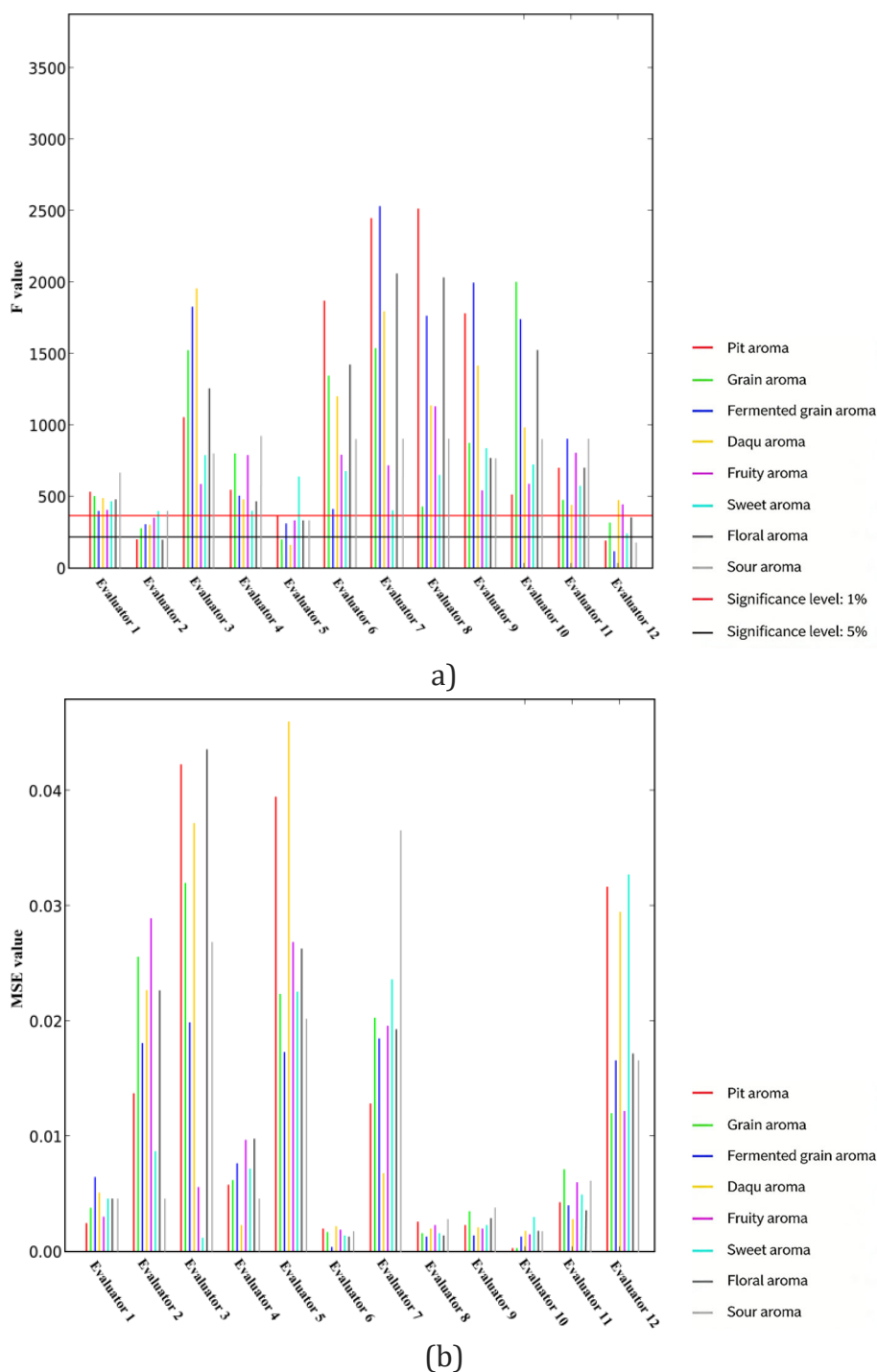


Figure 1. F-values and MSE-values for the 12 candidate sniffers

Note: (a) F-values; (b) MSE values.

3.2. Aroma Profiles of Five-Grain Strong-Flavor Baijiu

Based on the brainstorming results of all panel members, aroma descriptors were screened and ranked according to their geometric mean values (M). A total of eight descriptors with M values greater than 0.7 were selected to construct the aroma profiles of five-grain strong-flavor Baijiu, including pit aroma, grain aroma, fermented grain aroma, Daqu aroma, fruity aroma, sweet aroma, floral aroma, and sour aroma, as shown in Table 7.

The reference samples and their corresponding intensity levels used for each descriptor are presented in Table 8.

Table 7. Geometric mean of Strong aroma type Baijiu aroma descriptors

Aroma descriptor	F	I	M	Aroma descriptor	F	I	M
Pit aroma	0.92	0.88	0.90	Caramel aroma	0.54	0.69	0.61
Grain aroma	0.90	0.82	0.86	Fermented grain aroma	0.76	0.80	0.78
Daqu aroma	0.84	0.78	0.81	Green aroma	0.52	0.61	0.56
Fruity aroma	0.86	0.82	0.84	Woody aroma	0.32	0.64	0.45
Sweet aroma	0.88	0.80	0.84	Smoky aroma	0.34	0.49	0.41
Floral aroma	0.82	0.81	0.81	Roasted aroma	0.48	0.46	0.47
Sour aroma	0.72	0.79	0.75	Alcohol aroma	0.68	0.76	0.72

Table 8. Strong aroma type Baijiu sensory descriptors for sensory description and comparison of reference samples and intensity

Sensory descriptor	Sensory description	Reference sample	Intensity
Pit aroma	Composite aroma resembling aged pit mud and fermentation pit	20 mL of 10% ethanol solution containing 1 mg/L ethyl hexanoate + 5 g aged pit mud	7
Grain aroma	Aroma resembling steamed five grains (sorghum, rice, glutinous rice, wheat, and corn)	10 g steamed five-grain mixture	7
Fermented grain aroma	Fermented aroma resembling freshly distilled fermented grains	10 g freshly distilled fermented grains	5
Daqu aroma	Roasted and beany aroma resembling medium- to high-temperature Daqu	5 g medium- to high-temperature Daqu powder dissolved in 20 mL of 10% ethanol	5
Fruity aroma	Aroma characteristic of tropical fruits such as pineapple and banana	5 g fresh pineapple + 20 mL of 10% ethanol solution containing 1 mg/L ethyl butyrate	7
Sweet aroma	Aroma resembling honey and granulated sugar	20 mL of 10% ethanol solution containing 200 g/L honey	7
Floral aroma	Aroma resembling fresh flowers such as rose and Chinese rose	20 mL of 10% ethanol solution containing 1 mg/L β -phenylethanol	7

The aroma profiles of the five five-grain strong-flavor Baijiu samples are presented in Fig. 2. Overall, significant differences were observed among the five samples across all aroma attributes. Specifically, the Yinuohong No. 4 sample exhibited the highest intensities of pit aroma, grain aroma, fermented grain aroma, and sour aroma, with moderate fruity and sweet aromas, while floral and Daqu aromas were relatively weak. The Shanxi sorghum sample showed the strongest pit aroma, with prominent fruity and sweet aromas, moderate grain and fermented grain aromas, and relatively well-balanced Daqu and sour aromas. The Jinuohong No. 2 sample was characterized by relatively high intensities of pit and grain aromas, moderate fruity and sweet aromas, and balanced fermented grain and Daqu aromas. The Chuanlianghong No. 9 sample exhibited a generally balanced aroma profile, with relatively strong pit, grain, and fruity aromas. In contrast, the Australian sorghum sample showed the highest intensities of fruity and sweet aromas, along with a pronounced floral aroma, but relatively weaker pit and grain aromas. To further investigate the material basis underlying these differences in aroma characteristics, aroma extract dilution analysis (AEDA) was subsequently applied to comprehensively analyze the volatile components of the five samples.

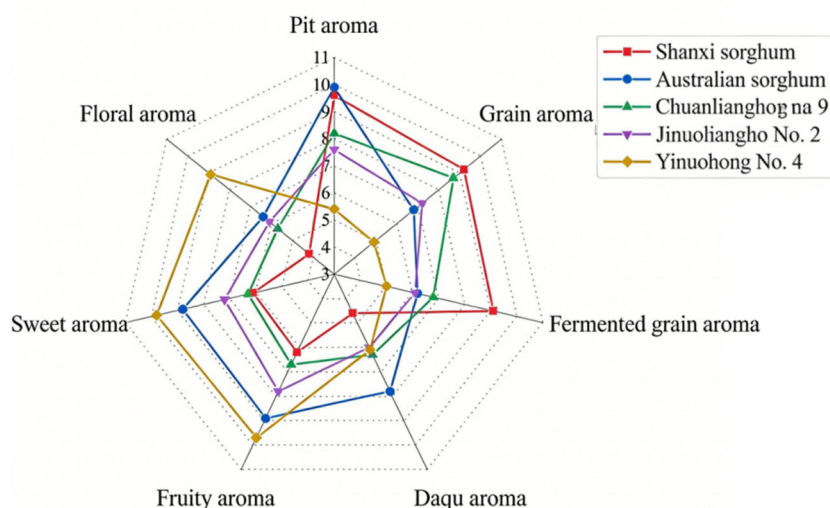


Figure 2. Aroma profile of 5 Strong aroma type Baijiu

3.3. Qualitative GC-MS and AEDA Analyses

A total of 92 volatile compounds were identified in the five five-grain strong-flavor Baijiu samples, namely Yinuohong No. 4, Shanxi sorghum, Jinuohong No. 2, Chuanlianghong No. 9, and Australian sorghum. These compounds included 39 esters, 19 alcohols, 8 aldehydes, 4 ketones, 6 acids, 4 phenols, 7 olefins, and 5 other compounds. In terms of the number of odor-active compounds with FD values ≥ 4 , the Shanxi sorghum sample ranked first with 47 compounds, followed by the Australian sorghum sample (46), Jinuohong No. 2 (45), Yinuohong No. 4 (44), and Chuanlianghong No. 9 (42), indicating that the Shanxi sorghum sample possessed the richest variety of aroma-active compounds.

From the perspective of compound class distribution, esters, alcohols, and aldehydes constituted the main aroma skeleton in all five samples, although clear differences were observed among them. The Shanxi sorghum sample contained the highest number of esters (31) and alcohols (9) with FD values ≥ 4 , showing the most pronounced ester dominance. In contrast, the Yinuohong No. 4 sample contained the highest number of aldehydes (8) and phenols (3). The Australian sorghum sample was characterized by a relatively high abundance of acids (3), while also maintaining comparatively high numbers of esters (29) and alcohols (8). Jinuohong

No. 2 and Chuanlianghong No. 9 exhibited relatively balanced distributions across compound classes. These differences in compound distribution suggest that the Shanxi sorghum sample may present a more intense fruity character, whereas Yinuohong No. 4 may show greater contributions from green and fatty notes associated with aldehydes. The relatively abundant acid compounds in the Australian sorghum sample may further enhance aroma complexity and coordination[18].

At the level of characteristic backbone aroma compounds, all five samples shared several high-FD compounds ($FD \geq 256$), including ethyl acetate, ethyl butyrate, ethyl valerate, ethyl heptanoate, ethyl nonanoate, and γ -elemene, which together formed the common fruity, sweet, and woody aroma foundation of five-grain strong-flavor Baijiu. However, clear sample-specific differences were still evident. In the Shanxi sorghum sample, a series of key esters, including ethyl butyrate, ethyl valerate, ethyl hexanoate, ethyl heptanoate, ethyl octanoate, ethyl nonanoate, ethyl decanoate, butyl hexanoate, and isoamyl hexanoate, all reached the maximum FD value of 1024. In addition, 1-hexanol with an FD value of 1024 was uniquely detected in this sample, indicating a markedly stronger fruity and fresh aroma intensity than in the other samples. By contrast, the Yinuohong No. 4 sample showed a relatively low FD value for ethyl hexanoate (64), and neither ethyl octanoate nor ethyl decanoate was detected, suggesting a relatively weaker fruity profile. Nevertheless, the high FD values of ethyl phenylacetate (256) and nonanal (256) contributed more pronounced honey-like, rose-like, green, and fatty notes. The Australian sorghum sample contained both ethyl decanoate (256) and 1-pentanol (256), imparting coconut-like and creamy characteristics. Although butyl hexanoate and isoamyl hexanoate were not detected in Jinuohong No. 2, the FD value of 1-pentanol reached 256, indicating a distinct creamy note.

Further analysis of differential and unique compounds with FD values ranging from 16 to 256 provided deeper insight into aroma differentiation among the samples. The Australian sorghum sample uniquely contained octyl acetate (floral note, $FD = 256$) and ethyl undecanoate (fruity and coconut-like note, $FD = 256$). In addition, ethyl hexanoate (256), isobutyl butyrate (64), and isoamyl octanoate (256) all reached relatively high levels, endowing this sample with the richest composite floral, coconut-like, and fruity aroma characteristics. The Jinuohong No. 2 sample contained styrene (floral note, $FD = 16$) and 2-pentylfuran (creamy note, $FD = 16$), while also showing relatively high FD values for isoamyl acetate (64) and isobutyl butyrate (64), resulting in pronounced floral-fruity and creamy characteristics. The Yinuohong No. 4 sample was characterized by nonanal (256), ethyl isocaproate (256), and decanal (64), indicating a combination of green and fruity notes; in addition, its unique detection of butyl acetate (fruity note, $FD = 64$) further enriched its fruity aroma complexity. Besides its dominance in backbone esters, the Shanxi sorghum sample also contained several specific compounds, such as limonene (fruity note, $FD = 16$), 2-methylbutyl hexanoate (fruity note, $FD = 64$), and trans-2-octenal (green note, $FD = 1$), which further broadened its fruity aroma spectrum. In contrast, the Chuanlianghong No. 9 sample uniquely contained 2,4-di-tert-butylphenol (disinfectant/ink-like note, $FD = 64$), which contributed a distinctive phenolic character. Most of the other differential compounds in this sample showed relatively low FD values, suggesting a comparatively weaker fruity profile overall[19].

In summary, the five five-grain strong-flavor Baijiu samples showed systematic differences in both the diversity and intensity of aroma-active compounds. The Shanxi sorghum sample was characterized by an intense fruity profile dominated by high-intensity esters. Yinuohong No. 4 exhibited a combination of green notes contributed by aldehydes and floral-fruity notes derived from esters. The Australian sorghum sample was notable for its composite floral and coconut-like aroma characteristics. Jinuohong No. 2 was distinguished by a balanced combination of floral-fruity and creamy notes, whereas Chuanlianghong No. 9 was marked by its unique

phenolic character. Together, these differences constitute the material basis for the diversified aroma styles of five-grain strong-flavor Baijiu[20].

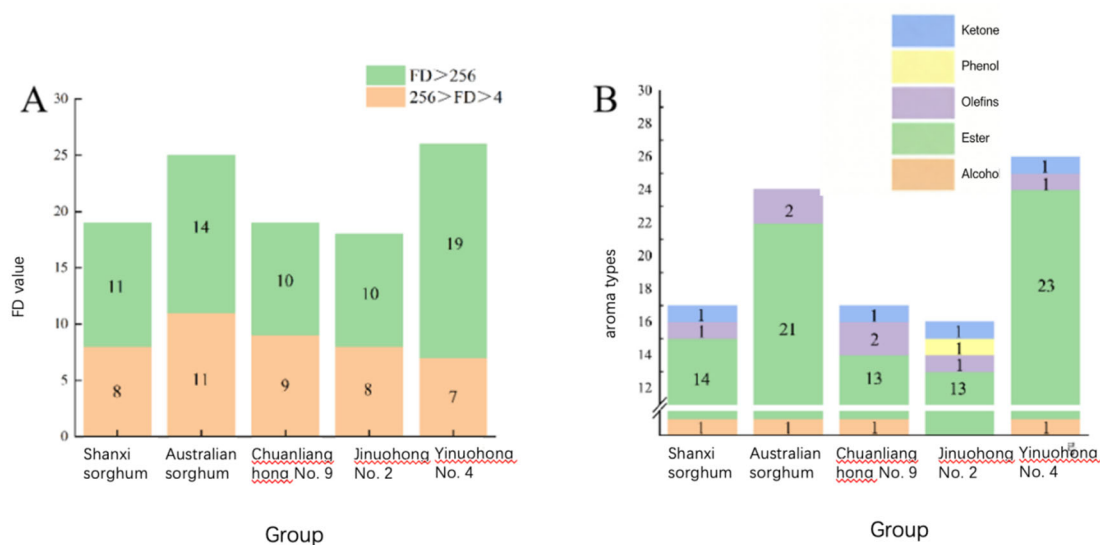


Figure 3. Five Strong aroma type Baijiu FD values of important aroma compounds

4. CONCLUSION

In this study, a sensory evaluation and instrumental analysis system suitable for investigating the aroma characteristics of five-grain strong-flavor Baijiu was systematically established. For panelist selection, 12 qualified olfactory assessors were screened from 20 candidates according to the GB/T 16291.1-2012 standard through multiple tests, including the basic olfactory test (100% accuracy required), aroma matching test (>83% accuracy), ranking test (>80% accuracy), and descriptive ability test (>67% accuracy). After 8 weeks of systematic training, seven panelists with superior performance were ultimately selected to form Group A based on a comprehensive evaluation of F-values, MSE values, and profile plots. Together with five national-level Baijiu judges in Group B, they jointly participated in the subsequent quantitative descriptive analysis. For the determination of sensory descriptors, the geometric mean value ($M = F \times I$) was used for screening. Eight aroma descriptors with M values greater than 0.7, namely pit aroma, grain aroma, fermented grain aroma, Daqu aroma, fruity aroma, sweet aroma, floral aroma, and sour aroma, were finally selected to establish the aroma profile evaluation system. In addition, ethyl hexanoate, steamed five-grain mixture, fresh fermented grains, medium- to high-temperature Daqu, fresh pineapple combined with ethyl butyrate, honey solution, β -phenylethanol, and acetic acid were used as reference samples for the corresponding aroma attributes, thereby establishing a systematic intensity reference system.

The aroma profile analysis of the five five-grain strong-flavor Baijiu samples revealed clear differences in sensory attributes among the samples. Specifically, the Yinuohong No. 4 sample exhibited the highest intensities of pit aroma, grain aroma, fermented grain aroma, and sour aroma, with moderate fruity and sweet aromas but relatively weak floral and Daqu aromas. The Shanxi sorghum sample showed the strongest pit aroma, along with prominent fruity and sweet aromas, moderate grain and fermented grain aromas, and relatively good Daqu and sour aroma characteristics. The Jinuohong No. 2 sample displayed relatively high intensities of pit and grain aromas, moderate fruity and sweet aromas, and balanced fermented grain and Daqu aromas. The Chuanlianghong No. 9 sample showed a relatively balanced overall aroma profile, with good performance in pit, grain, and fruity aromas. In contrast, the Australian sorghum sample

exhibited the highest intensities of fruity and sweet aromas and a pronounced floral aroma, whereas its pit and grain aromas were relatively weak.

To further elucidate the material basis underlying these aroma differences, headspace solid-phase microextraction (HS-SPME) combined with gas chromatography-mass spectrometry (GC-MS) was employed for qualitative analysis of volatile compounds, while aroma extract dilution analysis (AEDA) together with gas chromatography-olfactometry (GC-O) was used to systematically evaluate aroma intensity in terms of FD values. A total of 92 volatile compounds were identified in the five samples, among which esters were the most abundant (39 compounds), followed by alcohols (19), olefins (7), acids (6), aldehydes (8), ketones (4), phenols (4), and other compounds (5). Among the backbone aroma compounds with FD values of 256 or above, esters were dominant, including ethyl acetate, ethyl butyrate, ethyl valerate, ethyl heptanoate, ethyl nonanoate, and γ -elemene. These results indicate that esters play a central role in the overall flavor contribution of five-grain strong-flavor Baijiu and collectively shape the common fruity, sweet, and woody aroma attributes shared by the samples.

Regarding the distribution characteristics of key aroma compounds, the five samples exhibited systematic differences in both compound diversity and FD intensity, which was consistent with the sensory profile results. The Shanxi sorghum sample contained the highest numbers of ester compounds (31) and alcohol compounds (9) with FD values not lower than 4. Moreover, key esters such as ethyl butyrate, ethyl valerate, ethyl hexanoate, ethyl heptanoate, ethyl octanoate, ethyl nonanoate, ethyl decanoate, butyl hexanoate, and isoamyl hexanoate all reached the maximum FD value of 1024, and 1-hexanol (FD = 1024) was uniquely detected in this sample. These findings are highly consistent with its most prominent fruity and sweet sensory characteristics. In contrast, the Yinuohong No. 4 sample contained the highest numbers of aldehydes (8) and phenols (3), with a relatively low FD value for ethyl hexanoate (64), whereas ethyl phenylacetate and nonanal both showed high FD values (256), corresponding well to its strong pit, grain, and sour aroma intensities but relatively weaker fruity aroma. The Australian sorghum sample was characterized by a relatively high number of acid compounds (3) and uniquely contained octyl acetate (FD = 256) and ethyl undecanoate (FD = 256), which contributed distinctive floral and coconut-like notes and corresponded to its highest fruity, sweet, and floral aroma intensities in sensory evaluation. The Jinuohong No. 2 sample contained styrene and 2-pentylfuran, resulting in a well-coordinated floral-fruity and creamy aroma profile. The Chuanlianghong No. 9 sample uniquely contained 2,4-di-tert-butylphenol (FD = 64), which imparted a distinctive phenolic character and corresponded to its relatively balanced overall aroma intensity.

It should be noted that AEDA can only evaluate the aroma intensity of individual flavor compounds separately and does not take into account the influence of non-volatile components in the Baijiu matrix or the possible synergistic and antagonistic interactions among volatile compounds. Therefore, future studies should combine aroma recombination experiments with accurate quantitative analysis of flavor compounds to further clarify the specific contribution mechanisms of individual compounds to the overall liquor style, thereby providing a more comprehensive understanding of the material basis underlying the aroma characteristics of five-grain strong-flavor Baijiu.

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