# Sensory Properties of *Baijiu*

# 7

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## 7.1 Introduction

*Baijiu*, as a traditional distilled spirit in China, is one of the six oldest distilled alcoholic beverages in the world. The annual production of *baijiu* was approximately 7.86 million kL in 2019 [1]. *Baijiu* is very popular in China, and it can be classified into 12 categories according to its aroma characteristics: strong-, sauce-, light-, rice-, mixed-, sesame-, herb-like-, *feng*-, *laobaigan*-, *chi*-, *te*-, and *fuyu*-aroma *baijiu* [2]. The production of strong-aroma *baijiu* is the highest, with the most brands. The famous Wuliangye, Jiannanchun, Yanghe, and Luzhoulaojiao brands are all strong-aroma *baijiu*. Moutai and Langjiu are sauce-aroma *baijiu*, and Fenjiu is light-aroma *baijiu*.

*Baijiu* is a distilled spirit made from sorghum or a mixture of sorghum, rice, glutinous rice, wheat, and corn, using “daqu”, “xiaoqu”, or “fuqu” as the starter for fermentation. Its production starts with raw material cooking, saccharification, solid- or semisolid-state fermentation, and distillation, and then it is aged for several years to develop a harmonious aroma. Finally, different batches and different grades of *baijiu* are blended to achieve the unique and consistent flavour characteristics and quality of the brand.

The content of water and ethanol in *baijiu* accounts for 97–98%, and the volatile substances that contribute to the aroma constitute only approximately 2–3%. The important compounds to the aroma and flavour of *Baijiu* include fatty acid esters,

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alcohols, carboxy acids, ketones, aldehydes, aromatics, phenolics, pyrazines, furans, acetals, terpenes, and sulphur-containing compounds. Different aroma compounds contribute to the distinct aroma and flavour profiles of *baijiu*. This chapter aims to discuss the importance of aroma and taste compounds to *baijiu*.

## 7.2 Aroma and Taste of Chinese *Baijiu*

### 7.2.1 Aroma Compounds in *Baijiu*

Since the aroma and flavour attributes define the style of *baijiu*, it is very important to understand the chemical nature of these attributes. Research on *baijiu* aroma and flavour compounds began in three pilot projects from the Luzhou, Moutai and Fenjiu *baijiu* distilleries, and paper chromatography was attempted to study the trace compounds of *baijiu* [3]. In 1967, gas chromatography (GC) was first used to identify and quantify volatile acids, esters, and some high-boiling compounds in *baijiu* [4]. Since then, GC has been frequently used in *baijiu* analysis and is now widely used.

The gas chromatography-olfactometry (GC-O) technique, which combines GC with the human nose to detect aroma-active compounds, was invented in 1964 [5]. However, only since 1990 have food flavour researchers advanced the technique to understand the aroma-active compounds in complex food systems. In 2005, Qian's team at Oregon State University first applied the GC-O and odour activity value (OAV) approach to systematically investigate the aroma compounds in several famous Chinese famous *baijiu* [6–9] including Wuliangye, Yanghe, Jiannanchun, Moutai, and Langjiu. Since then, research on the aroma components of *baijiu* has gradually increased.

The main approach to studying aroma compounds of *baijiu* is similar to that for other foods [10], but special points should be addressed due to the high content of ethanol. The following main steps are typically employed:

1. Isolation of the aroma compounds.
2. Fractionation of the aroma extract into acidic, basic, and alcohol fractions.
3. Identification of the active aroma compounds by GC-O analysis, such as aroma extract dilution analysis (AEDA), aroma intensity (Osme).
4. Quantification of the aroma compounds and calculation of their OAVs.
5. Recombination and omission test to confirm the compounds.

To date, the aroma compounds of several aroma types of *baijiu* have been identified by GC-O and OAV, and aroma recombination experiments have confirmed the aroma-contributing compounds in some *baijiu*.

#### 7.2.1.1 Strong-Aroma *Baijiu*

Strong-aroma *baijiu* is the most produced *baijiu* of China, with the largest variety of products. The distinct flavour profile of the strong-aroma *baijiu* was caused by the differences in the raw materials, production process, geographic environment, and microbes enriched in the air. Because the aroma profile is linked to geography, strong-aroma *baijiu* can be further divided into the Sichuan branch (produced in the Sichuan provinces of China, mainly Wuliangye, including Luzhoulaojiao, Jiannanchun, etc.) and the Jianghuai branch (produced in the Jiangsu, and Anhui, Shandong, and Henan provinces of China, mainly Yanghe daqu, including Gujing gongjiu) [11, 12]. Research on the aroma compounds of strong-aroma *baijiu* mainly includes the following several aspects:

### Quality-Based Volatile Compounds

Ethyl hexanoate was found to be the most important aroma compound in strong-aroma *baijiu* in 1964 [13]. Since then, extensive studies have been conducted to select other main compounds that could potentially "quantify" the quality. The Chinese national standard GB/T 10781.1 < Strong flavour Chinese spirits> [14] defines the concentration of ethyl hexanoate, total esters, total acids, and solid substances as grade indicators, although the quality of strong-aroma *baijiu* is mainly assessed based on overall sensory characteristics. The research on aroma in strong-aroma *baijiu* before 2005 mainly studied skeletal compounds [15, 16], including ethyl hexanoate, ethyl lactate, ethyl acetate, ethyl butanoate, isoamyl alcohol, 1-propanol, and 1-butanol. However, the detailed odour-contributing compounds are not well defined or understood.

### Aroma-Active Compounds in Strong-Aroma *Baijiu* Studied with GC-O Technology

To comprehensively understand the key and important aroma compounds in strong-aroma *baijiu*, Fan and Qian [7] first used GC-O technology to analyse the aroma-active compounds in Wuliangye and Jiannanchun in 2005. A total of 132 odourants were detected with GC-O, and 126 aromas were further identified by GC-MS. Esters were identified as the most important class in strong-aroma *baijiu*, especially ethyl esters. For single compound, ethyl hexanoate (fruity, floral, sweet, FD = 4096–8192), ethyl butanoate (pineapple, FD = 2048), 1,1-diethoxy-3-methylbutane (fruity, FD = 1024–4096), ethyl pentanoate (apple, FD = 512–2048), butyl hexanoate (pineapple, fruity, FD = 1024–2048), ethyl octanoate (fruity, FD = 512–1024), ethyl 3-methylbutanoate (apple, FD = 512–1024), and hexanoic acid (sweaty, cheesy, FD = 512–1024) had the highest FD factors. In addition, several pyrazines, which contributed nutty, baked, and roasted aromas, were important odourants for the overall aroma to Wuliangye and Jiannanchun baijiu, such as 2,5-dimethyl-3-ethylpyrazine, 2-ethyl-6-methylpyrazine, 2,6-dimethylpyrazine, 2,3,5-trimethylpyrazine, and 3,5-dimethyl-2-pentylpyrazine. Since then, the GC-O analysis of *baijiu* had begun, and this technology has been applied to study the aroma compounds in many different brands of strong-aroma *baijiu*, including Yanghe [9], Gujinggong jiu [17], Luzhoulaojiao [18], and a few others (see Table 7.1).

This approach was further used to compare the aroma compositions of different strong-aroma *baijius*, such as: (1) different ages of *baijius*, the aroma compounds of

**Table 7.1** FD factors (≥100) of important aroma compounds in different strong-aroma *baijius*

| Compound | Sichuan brand | | Jianghuai brand | | |
|---|---|---|---|---|---|
| | Wuliangye [7] | Jiannanchun [7] | Yanghedaqu [6] | | Gujinggong [17] |
| | | | Aged | Young | |
| *Acetals* | | | | | |
| 1,1-diethoxyethane | 256 | 256 | 2048 | 256 | |
| 1,1-diethoxy-3-methylbutane | 4096 | 1024 | 2048 | 128 | |
| *Acids* | | | | | |
| Butanoic acid | 512 | 512 | | | 2187 |
| 3-methylbutanoic acid | 256 | 128 | | | 6561 |
| Pentanoic acid | | 128 | | | 2187 |
| Hexanoic acid | 512 | 1024 | | | 19,683 |
| Acetic acid | | | | | 243 |
| Octanoic acid | | | | | 243 |
| *Alcohols* | | | | | |
| 1-butanol | | 128 | | | |
| 3-methylbutanol | 256 | 128 | 256 | | 243 |
| 1-pentanol | 128 | 128 | | | |
| 2-pentanol | | | 256 | | |
| 2-methyl-1-butanol | | | | | 243 |
| *Aldehydes* | | | | | |
| Acetaldehyde | | | 256 | | |
| *Aromatics* | | | | | |
| 2-phenylethanol | 128 | 128 | | | 243 |
| Phenylacetaldehyde | 256 | | | | |
| *Esters* | | | | | |
| Ethyl acetate | 256 | 256 | 2048 | 256 | 243 |
| Ethyl 2-methylpropanoate | 512 | | | | |
| 2-methylpropyl acetate | 256 | | | | |
| Ethyl butanoate | 2048 | 2048 | >8192 | >8192 | 729 |
| Ethyl 3-methylbutanoate | 512 | 1024 | 128 | 256 | |
| Ethyl pentanoate | 2048 | 512 | >8192 | >8192 | 243 |
| Methyl hexanoate | 128 | | 256 | 128 | |
| Ethyl hexanoate | 8192 | 4096 | >8192 | >8192 | 59,049 |
| Propyl hexanoate | | 128 | | | |
| Ethyl heptanoate | | 256 | 256 | 128 | |
| Butyl hexanoate | 1024 | 2048 | 1024 | 128 | |
| Ethyl cyclohexanecarboxylate | 256 | 256 | | | |
| Ethyl octanoate | 512 | 1024 | 128 | | |
| Hexyl hexanoate | 256 | 128 | | | |
| Ethyl phenylacetate | | 128 | 128 | 128 | 243 |

(continued)

**Table 7.1** (continued)

| Compound | Sichuan brand | | Jianghuai brand | | |
|---|---|---|---|---|---|
| | Wuliangye [7] | Jiannanchun [7] | Yanghedaqu [6] | | Gujinggong [17] |
| | | | Aged | Young | |
| Ethyl 3-phenylpropanoate | 128 | | | | 19,683 |
| Ethyl 2-methylbutanoate | | | 256 | 128 | |
| Ethyl 4-methylpentanoate | | | 128 | 256 | |
| 3-methylbutyl butanoate | | | 128 | | |
| Ethyl benzoate | | | | 256 | |
| Ethyl propanoate | | | | | 243 |
| *Furans* | | | | | |
| 2-furancarboxaldehyde | 128 | | | | |
| *Lactones* | | | | | |
| γ-Nonalactone | | | | | 2187 |
| *Phenolics* | | | | | |
| Phenol | 128 | | | | |
| 4-methylphenol | | | | | 729 |
| Vanillin | | | | | 729 |
| *Pyrazines* | | | | | |
| 2-ethyl-6-methylpyrazine | 128 | | | | |
| 2,5-dimethyl-3-ethylpyrazine | 256 | 128 | | | |
| *Sulphurs* | | | | | |
| Dimethyl trisulphide | | | 128 | | |

different ages of Yanghe Daqu *baijiu* were analysed by head space-solid phase microextraction (HS-SPME) coupled with GC-O techology [6], the results revealed that the aroma profiles of two *baijius* were similar, and esters were also the most important class of compounds to the aroma of both of the two different ages of *baijiu*, on the other hand, some aroma compounds, especially acetals, had higher FD factors in the aged sample than that in the young sample. Niu et al. [19] also compared the aroma compounds in three Wuliangye of different ages by HS-SPME coupled with GC-O, and nine aroma compounds could be regarded as the key aroma compounds since they had higher FD factors ($\geq$ 256), and further quantitative analysis indicated that the total content of aroma compounds decreased with *baijiu* age. (2) different alcohol content of *baijius*, the flavour characteristics of low-alcohol Wuliangye and high-alcohol Wuliangye were compared by GC-O technology [20]. The results revealed that 3-methylbutanal (stinky bug, 5), 3-methylbutanoic acid (sour and rancid, 5), ethyl butanoate (fruity and balsamic, 4–5), ethyl hexanoate (fruity and winery, 4–5), butanoic acid (cheese and rancid, 4–5), phenylacetaldehyde (floral, 3.5–5), and hexanoic acid (sour and fatty, 3–5) were the most important aroma contributors according to their highest Osme values, in addition, ethyl hexanoate and ethyl butanoate presented similar odour intensities, in contrast, acids and aromatic compounds presented different odour intensities in different ages of Wuliangye samples.

In addition, the GC-O technique has been employed for comparative analysis of different aroma types of *baijiu*, such as strong- with sauce-aroma *baijiu* [21] or strong- with mixed-aroma *baijiu* [22].

Of all these aroma compounds, ethyl hexanoate has been reported as the most important aroma compound due to exhibiting the highest aroma intensity (5.0) or the highest FD factor (4096–59,049) under evaluation by GC-O. In addition, it presented a high concentration (up to g/L level [23]) in strong-aroma *baijiu*, and low odour threshold (55 μg/L), which means it can make a dominant contribution to the flavour of strong-aroma *baijiu*.

#### Selective Extraction and Fractionation for the Comprehensive Identification of Other Aroma-Active Compounds

Ethyl hexanoate and hexanoic acid are the dominant compounds in strong-aroma *baijiu*. The high concentrations of esters and the corresponding free fatty acids often overload the chromatographic column and interfere with the analysis of other aroma compounds. Thus, analysis of a specific class of compounds in strong-aroma *baijiu* is an active research area. (1) Phenolic compounds. Zhu et al. [24] developed a rapid method for determining free phenolic compounds in *baijiu* by direct immersion-SPME (DI-SPME) coupled with GC-MS. 4-Methylphenol, 4-ethylphenol, phenol, 4-methylguaiacol, 4-ethylguaiacol, 4-propylguaiacol, 4-vinylguaiacol, and 3,4-dimethylphenol were analysed. The results showed that compared to other aroma types of *baijiu*, the strong-aroma *baijiu* had a higher total content of phenolic compounds. Volatile phenolic compounds contribute to phenolic, horsy, medicinal, and smoky odours. (2) γ-Lactones. Nie et al. [25] employed liquid-liquid extraction (LLE) and solid phase extraction (SPE)-GC-MS identified and quantified eight γ-lactones in *baijiu*, including γ-butyrolactone, γ-valerolactone, γ-hexalactone, γ-heptalactone, γ-octalactone, γ-nonalactone, γ-decalactone, and γ-dodecalatone. They found that this method was rapid, selective and had a high correlation coefficient.

To better understand the aroma compounds of strong-aroma *baijiu*, some technology was used. (1) Stir bar sorptive extraction (SBSE)-GC-MS was also applied to the characterization of selected volatile compounds in *baijiu* [26], a lower limit of detection (LOD) and limit of quantitation (LOQ) were found in this method because of the high capacity of the magnetic stirring bar. (2) Volatile fractionation was also used to simplify the composition before GC-MS analysis. Fan and Qian [9] first used normal-phase chromatography fractionation followed by GC-O to identify the aroma compounds in Yanghe daqu, and the approach was proven to be very useful for separating complex aroma extracts before GC-O and GC-MS analysis. (3) More recently, comprehensive two-dimensional gas chromatography/time-of-flight mass spectrometry (GC × GC-TOF-MS) was a useful technology to identify aroma compounds, and now it was used in *baijiu* area [27].

Up to now, more than 1000 volatile compounds have been identified in strong-aroma *baijiu* [6, 7, 9, 17, 19, 27–30]. Approximately 50 of them are considered important aroma compounds, and most of them are esters, followed by fatty acids and alcohols, although some acetals, aldehydes, aromatics, furans, lactones, phenolics, pyrazines, and volatile sulphur compounds have also been identified in strong-aroma *baijiu* (Table 7.1).

#### 7.2.1.2 Light-Aroma *Baijiu*

Light-aroma *baijiu* is mainly produced in northern China, with pleasant fruity and floral aroma, is another major Chinese baijiu category which was welcomed by consumers. [31]. Representatives brands of light-aroma baijiu include Fenjiu, Qingke, Baofeng, and Erguotou.

Fan and Xu [32, 33] isolated the volatile compounds of Fenjiu by LLE, and achieved fractionation by normal-phase liquid chromatography, then a total of 451 volatile compounds were identified by GC-MS. This was the first comprehensive analysis of volatile compounds in light-aroma *baijiu*. However, this work did not identify which compounds contributed to the aroma, and there were no quantitative data on these volatile compounds.

Aroma-active compounds in three light-aroma *baijiu*, Fenjiu, Qingke, and Baofeng, were further identified by Gao et al. [34]. A total of 66 aroma compounds were analysed by GC-O technology, 27 of them were further suggested as important ($\geq$1, see Table 7.2) based on the OAVs. Omission experiments further confirmed the important contribution of $\beta$-damascenone and ethyl acetate to the aroma profile, and the study revealed the significance of esters. For single compound, ethyl lactate, geosmin, acetic acid, and 2-methylpropanoic acid were important to the overall aroma of Fenjiu.

A total of 80 odourants was identified in five different light-aroma *baijiu* (Guoseqingxiang, Hongxing, Xinghuacun, Fenjiu, and Jinmen) by Niu et al. [35], and 27 of them, mainly include esters, were further suggested as important odourants because of their high OAVs.

Qian et al. [36] further researched two types of Qingke (high and low elevation, respectively) by AEDA, Osme, OAVs, and aroma recombination and omission test. A total of 67 aroma-active compounds were identified by GC-O analysis. According to the OAVs, 7 esters (including ethyl butanoate (OAV = 104, 369), ethyl octanoate (OAV = 25, 247), ethyl hexanoate (OAV = 47, 109), ethyl 3-methyl butanoate (OAV = 21, 34), ethyl pentanoate (OAV = 22, 27), ethyl 2-methyl propanoate (OAV = 18, 27), ethyl acetate (OAV = 7, 11)), 3 aldehydes and ketones (including 3-methylbutanal (OAV = 79, 122), 2,3-butanedion (OAV = 47, 59), acetoin (OAV = 60, 92)), 2 alcohols (3-methyl-1-butanol (OAV = 44, 68), 1-octen-3-ol (OAV = 27, 44)), 1 terpenoid ($\beta$-damascenone (OAV = 54, 120)), and 1 phenol compound (2-methoxyphenol (OAV = 3, 4)) were considered as important contributors to Qingke. It was also noticed that for most aroma compounds, the OAVs were higher in the high elevation Qingke than low elevation Qingke. It was not clear if the difference was caused by the use of grains grown at different elevations or differences in alcohol content (the high elevation Qingke had 52%

**Table 7.2** OAVs of 27 odourants in light-aroma Fenjiu, Qingke, and Baofeng (≥1) (Reprinted with permission from [34])

| Compound | Fenjiu | | Baofeng | | Qingke | |
|---|---|---|---|---|---|---|
| | Con.[a] | OAV | Con. [a] | OAV | Conc. [a] | OAV |
| Ethyl octanoate [b] | 5.04 | 391 | 6.39 | 495 | 19.3 | 1500 |
| 1,1-diethoxyethane [b] | 419 | 200 | 214 | 102 | 558 | 267 |
| β-Damascenone | 19.1 | 159 | 28.6 | 238 | 11.5 | 96 |
| Ethyl acetate [c] | 2.12 | 65 | 2.76 | 85 | 3.23 | 99 |
| 3-methylbutyl acetate [b] | 5.87 | 63 | 13.7 | 146 | 14.1 | 150 |
| Ethyl hexanoate [b] | 3.09 | 56 | 5.39 | 97 | 7.68 | 139 |
| Ethyl lactate [c] | 4.91 | 38 | 1.06 | 8 | 1.02 | 8 |
| Ethyl butanoate [b] | 1.82 | 22 | 3.81 | 47 | 42.8 | 525 |
| Hexanal | 484 | 19 | 208 | 8 | 813 | 32 |
| Ethyl 3-methylbutanoate [b] | 0.119 | 17 | 0.0498 | 7 | 2.87 | 417 |
| Decanal | 798 | 11 | 253 | 4 | 587 | 8 |
| Ethyl 2-methylpropanoate [b] | 0.642 | 11 | 2.10 | 37 | 8.58 | 149 |
| Geosmin | 1.1 | 10 | 1.22 | 11 | 1.17 | 11 |
| Ethyl pentanoate [b] | 0.256 | 10 | 0.498 | 19 | 8.62 | 322 |
| 1-octen-3-ol | 48.2 | 8 | 23.3 | 4 | 52.4 | 9 |
| 2-methylpropanol [b] | 194 | 7 | 392 | 14 | 291 | 10 |
| Phenylacetaldehyde [b] | 1.78 | 7 | 0.535 | 2 | 0.784 | 3 |
| Ethyl decanoate [b] | 6.57 | 6 | 7.34 | 7 | 6.82 | 6 |
| 2-methylpropanoic acid [b] | 7.84 | 5 | 2.03 | 1 | 2.12 | 1 |
| γ-Nonalactone | 275 | 3 | 169 | 2 | 324 | 4 |
| 3-methylbutanol [b] | 514 | 3 | 886 | 5 | 454 | 3 |
| Acetic acid [b] | 397 | 2 | 415 | 3 | 770 | 5 |
| 2-methylpropyl acetate [b] | 2.14 | 2 | 3.50 | 4 | 1.01 | 1 |
| 1-butanol [b] | 6.16 | 2 | 5.52 | 2 | 10.1 | 4 |
| Ethyl 3-phenylpropanoate [b] | 0.145 | 1 | 0.201 | 2 | 2.78 | 22 |
| Nonanal | 117 | 1 | 160 | 1 | 287 | 2 |
| 1-hexanol [b] | 6.30 | 1 | 7.29 | 1 | 6.71 | 1 |

[a]The concentration of aroma compounds in μg/L
[b]The concentration in mg/L
[c]The concentration in g/L

alcohol, v/v, whereas the low elevation samples had 42% alcohol, v/v). Furthermore, the important aroma contributors in Qingke were confirmed by aroma recombination, and 3-methylbutanal was further suggested as the key aroma compound for both types of Qingke according to the aroma omission test.

#### 7.2.1.3 Sauce-Aroma *Baijiu*

Sauce-aroma *baijiu* is one of three main famous *baijiu* types in China. Famous brands include Moutai, Langjiu, and Xijiu. The distinct flavour of sauce-aroma *baijiu* is determined by its specific geographical environment, production process, and raw materials.

The flavour of sauce-aroma *baijiu* was first attempted to be quantified by Xiong and Hu at the first stage of the "Moutai test" in 1959. The total acids, total esters, total aldehydes, fusel oil, furfural, and methanol in Moutai were quantified by the wet chemistry method [37]. In the second stage of the "Moutai test" in 1964, 48 trace compounds in Moutai *baijiu* were identified by paper chromatography [37]. At this point, the door to flavour compound analysis of sauce-aroma *baijiu* was open [37]. In 2007, Zhu et al. [38] used GC $\times$ GC-TOF-MS technology on this type of *baijiu*, and a total of 528 compounds were identified. Among them, esters were the most important contributors to its flavour. Additionally, Fan et al. [39] further identified the aroma compounds of sauce-aroma *baijiu* (Moutai and Langjiu) by GC-O analysis after fractionation and normal-phase chromatography separation. A total of 186 aroma compounds were detected, and 184 of them were further identified, the result also revealed that esters were the most important aromas to the overall aroma of sauce-aroma *baijiu*, and aromatics, acids, pyrazines, and lactones were also important. Of them, ethyl hexanoate (fruity, floral, and sweet), hexanoic acid (sweaty, cheesy), 3-methylbutanoic acid (rancid, cheesy,), 3-methylbutanol (rancid, nail polish), 2,3,5,6-tetramethylpyrazine (roasted, baked), ethyl 2-phenylacetate (rosy, honey), 2-phenylethyl acetate (rosy, floral), ethyl 3-phenylpropanoate (fruity, floral, and rosy), 4-methylguaiacol (smoky), and γ-decalactone (sweety, coconut) had the highest aroma intensities in both *baijiu* (intensity $\geq$10). This was the first systematic study of aroma-active compounds in sauce-aroma *baijiu*.

Wang et al. [40] investigated the skeleton compounds in sauce-aroma *baijiu* by using GC/O-MS after liquid-liquid microextraction (LLME). A total of 48 aroma compounds were identified and quantified, 29 of them were considered as skeleton aromas according to their high concentrations. In order to confirm that these aroma compounds were important, recombination, omission, and addition experiments were undertaken, the result indicated that (1) recombination experiment: the overall aroma of recombination sample consisting of 52 aroma compounds (including 48 compounds identified by LLME and 4 compounds with high concentrations reported in references) was similar with the original sauce-aroma *baijiu*, with strong fruity and floral aromas, it was shown the background aroma of sauce-aroma *baijiu*, without the typical sauce aroma. (2) omission experiment: the samples in the absence of esters (similarity = 28%) and alcohols (similarity = 47%) were very similar to the original sample, which means these two classes of aromas were important for this *baijiu*. For single aroma compound, ethyl hexanoate (similarity = 31%), ethyl butanoate (similarity = 45%), 1-propanol (similarity = 45%), 2-phenylethanol (similarity = 48%), ethyl acetate (similarity = 49%), and 3-methylbutanol (similarity = 52%) were important to the overall aroma of this *baijiu*. (3) omission and addition experiments corroborated that trimethylpyrazine, furfural, 4-ethylguaiacol, and furaneol were unrelated to the typical aroma of sauce-aroma *baijiu*.

Although more than 1000 volatile compounds in sauce-aroma *baijiu* have been identified, and many have been quantified, it has been challenging to identify the key aroma compounds of this aroma type of *baijiu*. Numerous conjectures about its key aroma have been proposed: (1) High boiling point phenolic compounds such as 4-ethylguaiacol [41], proposed in the "Moutai test" in 1964. Nevertheless, repeated experiments using GC combined with sensory tasting have confirmed that 4-ethylguaiacol is not the key aroma of sauce-aroma *baijiu* [42, 43]. (2) Pyrazines [44]. Tetramethylpyrazine was also proposed because of its sauce-like aroma. Tetramethylpyrazine was produced at the high temperature qu-making process for sauce-aroma *baijiu*. However, sensory experiments on tetramethylpyrazine showed that the compounds smelled like soaked beans and sweet but not like the typical sauce aroma in the *baijiu* [43, 45]. (3) A mixture of high boiling point acids and low boiling point esters [46]. (4) Furans and furan derivatives [47]. All these hypotheses are now known to be incorrect, and the key aroma compounds of sauce-aroma *baijiu* are still unclear, so further research on the aroma and flavour analysis of sauce-aroma *baijiu* by molecular sensory science is needed.

Some studies have also investigated a specific class of compounds in sauce-aroma *baijiu*:

1. Pyrazines in different aroma types of *baijiu* were compared by Fan et al. [48]. A total of 27 pyrazines were found in 12 *baijiu* samples, the total concentration of pyrazines in sauce-aroma *baijiu* was over 3000 μg/L (Moutai, 5027.60 μg/L; Moutaiyingbing, 9028.80 μg/L, and Langjiu, 3146.35 μg/L), which was much higher than those in strong-aroma *baijiu* (Wuliangye, 1271.14 μg/L; Yanghe lansejingdian, 2503.20 μg/L; Gujinggong, 608.51 μg/L; Jiannanchun, 926.14 μg/L, except for Jinshiyuan, which had a high total concentration of pyrazines, 5069.05 μg/L), light-aroma *baijiu* (Fenjiu, 30.83 μg/L), and other aroma types of *baijiu* (Xifeng, 125.11 μg/L; Site, 47.53 μg/L; Dongjiu, 1922.15 μg/L).
2. The volatile sulphur-containing compounds (VSCs) in sauce-aroma *baijiu* have been investigated in recent years. Chen et al. [49] analysed the VSCs in Moutai using HS-SPME-GC-pulsed flame photometric detection (HS-SPME-GC-PFPD). Thirteen VSCs were identified and quantified, and seven of them had OAVs $\geq 1$. Of them, 2-furfurylthiol (OAV: 390–440), methanethiol (OAV: 177–273), dimethyl trisulphide (OAV: 135–223), ethanethiol (OAV: 39–94), and methional (OAV: 34–41) had relatively high OAVs, which means these VSCs could be important to the aroma of both two Moutai *baijius*. After that, Yan et al. [50] analysed the VSCs in sauce-aroma *baijiu* by HS-SPME combined with GC $\times$ GC-TOF-MS, and 19 VSCs were identified and quantified. Seven of them had OAVs $\geq 1$ in all 4 brands of sauce-aroma *baijiu*; in addition, 2-methyl-3-(methyldisulphanyl) furan (OAV $=$ 9–18) and methyl furfuryl disulphide (OAV $=$ 7–11), with high OAVs, were found in *baijiu* for the first time, which means these VSCs could be important to sauce-aroma *baijiu*. In addition, VSCs also have synergistic effects with other compounds. Addition experiment revealed that the addition of dimethyl sulphur compounds, including dimethyl sulphide, dimethyl disulphide, and dimethyl trisulphide, reduced the threshold of fruity aromatic reconstituted sample, which means these compounds could enhance the perception of fruity aromas in *baijiu* matrices [50]. Higher or imbalanced concentrations of these VSCs could contribute off-aromas. Wang et al. [51] compared two sauce-aroma *baijiu* samples. One presented a pickle-like

off-odour, and the other was normal sample. Sensory analysis showed that floral, salty sauce, roasted, acid, sulphur, caramel, green aromas were significantly different between two *baijiu* samples. Comparative AEDA (cAEDA) was taken to analyse the aroma compounds in two different baijius, followed by aroma addition and omission tests revealed that higher concentrations of sulphur compounds, including two groups (group 1: 2-methyl-3-furanthiol, 2-furfurylthiol, methyl 2-methyl-3-furyl disulphide, and bis (2-methyl-3-furyl) disulphide, mainly contribute to meaty, roasted, and sulphur aromas; group 2: methanethiol, dimethyl disulphide, and dimethyl trisulphide, methional, mainly contribute to cabbage, putrid, and sulphur aromas), may contribute the pick-like off-odour to sauce-aroma *baijiu*.

3. Terpenes might contribute to a more elegant and delicate odour to sauce-aroma *baijiu* and were investigated [52] by using LLE coupled with normal-phase liquid chromatography fractionation followed by GC–O analysis; 55 terpenes were identified in sauce-aroma *baijiu*, and 30 of which were found in *baijiu* for the first time. Among them, $\beta$-damascenone (floral, Osme = 15), dihydro-$\beta$-ionone (floral, Osme = 13), *E*-geranylacetone (floral, Osme = 12), $\beta$-ionone (violet, Osme = 11), *E*-nerolidol (floral, Osme = 11), linalool (floral, Osme = 11), pulegone (Osme = 10), and $\alpha$-terpineol (floral, Osme = 10) had higher aroma intensities than the rest of the terpenes. In addition, an optimized HS-SPME method was applied to quantify the terpenes in different aroma types of *baijiu*; the total concentration of terpenes in sauce-aroma *baijiu* ranged from 317.95 to 530.75 μg/L, which was higher than those in other *baijiu* samples (strong-aroma *baijiu*, 109.66–218.82 μg/L; mixed-aroma *baijiu*, 210.83–225.19 μg/L), except for Laobaigan (512.68 μg/L). According to the OAV analysis, $\beta$-damascenone (OAV = 98, floral), citral (OAV = 8.3, lemon), linalool (OAV = 2.4, floral), $\alpha$-ionone (OAV = 2.3, violet), and $\beta$-ionone (OAV = 1.3, violet) were contributors to Moutai *baijiu*. In fact, some of the terpenes could be easily oxidized, such as citral, which could be oxidized to citronellol [53]. Therefore, the concentrations of some terpenes in *baijiu* were not stable, so more research is needed to better understand the contributions of terpenes to sauce-aroma *baijiu* more clearly.

#### 7.2.1.4 *Chi*-Aroma *Baijiu*

*Chi*-aroma *baijiu* is popular in southern China because of its unique fatty flavour and taste. Yubingshao is the most famous brand. *Chi*-aroma *baijiu* has particular attributes: (1) it has a low alcohol content (30–40% alcohol, v/v); (2) its main raw materials are rice and beans, different from other aroma types of *baijiu*; (3) it is produced via semisolid-state fermentation; and (4) a slice of cooked pork meat is added to the base distillate at the beginning of storage.

The volatile composition of *chi*-aroma *baijiu* was first researched by Jin et al. [54] in 1984. More than 150 peaks were detected in the chromatogram of Yubingshao. This research started the exploration of *chi*-aroma *baijiu*. Later, Feng and Qian [55] identified 85 volatile compounds, 66 of which were quantified, including esters, alcohols, carbonyl compounds, acids, and acetals. 2-Phenylethanol, benzyl alcohol,

**Table 7.3** OAVs of 34 odourants in *chi*-aroma *baijiu* (Reprinted with permission from [2])

| Compound | Con. [a] | OAV | Compound | Con. [a] | OAV |
|---|---|---|---|---|---|
| Ethyl 2-methylpropanoate | 19.3 | 336 | 2-methylpropanoic acid | 9.30 | 6 |
| Ethyl octanoate | 2.03 | 157 | 3-hydroxy-2-butanone | 1.39 | 5 |
| Hexanal | 1.76 | 69 | Ethyl lactate | 585 | 5 |
| Ethyl 3-methylbutanoate | 0.344 | 50 | (E, E)-2,4-decadienal | 0.0356 | 5 |
| Ethyl butanoate | 3.69 | 45 | 2-phenylethanol | 127 | 4 |
| (E)-2-decenal | 0.375 | 31 | Octanoic acid | 11.3 | 4 |
| Ethyl hexanoate | 1.60 | 29 | Ethyl pentanoate | 0.108 | 4 |
| (E)-2-octenal | 0.422 | 28 | Heptanal | 1.18 | 3 |
| 3-methylbutyl acetate | 2.51 | 27 | (E)-2-nonenal | 0.156 | 3 |
| Butanoic acid | 19.2 | 20 | Ethyl 3-phenylpropanoate | 0.314 | 3 |
| Octanal | 0.759 | 19 | 3-methylbutanol | 354 | 2 |
| Ethyl acetate | 385 | 12 | Heptanoic acid | 25.6 | 2 |
| γ-Nonalactone | 0.866 | 10 | 1-propanol | 88.2 | 2 |
| Pentanoic acid | 3.47 | 9 | Acetic acid | 260 | 2 |
| 2-methylpropanol | 233 | 8 | Methionol | 3.09 | 1 |
| Nonanal | 0.854 | 7 | Ethyl benzoate | 1.88 | 1 |
| Hexanoic acid | 17.4 | 7 | 3-methylbutanoic acid | 1.09 | 1 |

[a]The concentration of aroma compounds, mg/L

3-(methylthio)propanol, diethyl pimelate, diethyl suberate, and diethyl azelate were proposed to be important aroma compounds of *chi*-aroma *baijiu*, but there were no sensory-related experiments on these compounds to support this hypothesis.

The aroma compounds of *chi*-aroma *baijiu* were first systematically analysed by using a sensomic approach by Fan et al. [2]; a total of 56 odourants were identified by AEDA analysis, 34 of which were further indicated to be contributors to *chi*-aroma *baijiu* according to OAVs ($\geq$1, see Table 7.3), and these 34 odourants with their certain concentrations could successfully mimic the overall aroma of *chi*-aroma *baijiu*. Furthermore, omission experiment was also taken to confirm that (E)-2-nonenal (fatty) was the key odourant of *chi*-aroma *baijiu*, and (E)-2-octenal (fatty) and 2-phenylethanol (rosy, honey) also play important roles to the overall aroma of *chi*-aroma *baijiu*.

#### 7.2.1.5 Sesame-Aroma *Baijiu*

Sesame-aroma *baijiu* is newer than other types of baijiu, which was developed in 1949 and possesses the aroma characteristics of strong-, sauce-, and light-aroma *baijiu*. Sesame-aroma *baijiu* is mainly produced in Shandong province of China. Jingzhi is the most representative brand of sesame-aroma *baijiu*; in addition, Bandaojing, Guojing, Meilanchun, etc. also belong to this aroma type *baijiu*.

3-Methylthio-1-propanol was first detected by a GC-flame photometric detector (FPD) in 1994 [56] and was indicated to be important for sesame-aroma *baijiu*. Since then, studies have focused on the aroma contribution of 3-methylthio-1-propanol [57, 58]. Quantitative analysis reported that the concentration of this compound in sesame-aroma *baijiu* was 2.5–3.8 mg/L [59]. However, the odour threshold of 3-methylthio-1-propanol was recently determined to be 2.11 mg/L in 46% (v/v) aqueous ethanol solution (Table 7.5) [60], and the calculated OAV was only 1.2–1.8, so it may not contribute as much as initially thought to the overall aroma. Furthermore, 3-methylthio-1-propanol has an earthy and boiled potato-like aroma quality, which differs from the aroma quality of this type of *baijiu*. Therefore, there may be other aroma compounds in sesame-aroma *baijiu* which were more important contributions to the overall aroma.

Then GC-O technology was firstly used to analyse sesame-aroma *baijiu*: (1) Zhou et al. analysed the aroma compounds of two brands of sesame-aroma *baijiu* (Jingzhi and Guojing) in 2015 [61], and 59 aroma compounds were detected. Ethyl hexanoate (fruity, Osme = 4.3), hexanoic acid (cheesy, sweaty, Osme = 4.0), butanoic acid (cheesy, rancid, Osme = 4.0), ethyl octanoate (fruity, Osme = 3.5), acetic acid (sour, vinegar, Osme = 3.5), 2,6-dimethylpyrazine (baked, nutty, Osme = 3.5), 2,3,5,6-tetramethylpyrazine (baked, nutty, Osme = 3.4), 2-phenylethanol (rosy, honey, Osme = 3.3), and 2-heptanol (mushroom, Osme = 3.0) were considered as important aromas because of their high intensities ($\geq$3.0). In addition, the OAV analysis showed that ethyl hexanoate, ethyl octanoate, ethyl butanoate, ethyl 2-methylpropanoate, 3-methylbutanal, dimethyl trisulphide, ethyl 3-methylbutanoate, ethyl pentanoate, ethyl 2-methylbutanoate, 3-methylbutyl acetate, 1,1-diethoxyethane, dimethyl disulphide, and methanethiol had the highest OAVs ($\geq$100 in all sesame-aroma *baijiu* samples), which means these compounds were important contributors to this aroma type *baijiu*. An aroma description, aroma contribution, and aroma addition experiment in simulation *baijiu* further proved that 3-methylthio-1-propanol, which was considered as key aroma of this aroma type *baijiu* before, was not the critical aroma compound, actually. (2) The aroma-active compounds from sesame-aroma *baijiu* were further investigated by Zheng et al. [62], 56 aroma compounds were identified by GC-O analysis, and 26 of them were further confirmed as important aroma-active compounds due to OAVs $\geq$1. The overall aroma of sesame-aroma *baijiu* could be replicated though recombination of these aroma-active compounds. Omission experiments further corroborated the importance of methional and ethyl hexanoate to the overall aroma. (3) Sha et al. [63] systematically studied the key aroma compounds of Jingzhi by AEDA, OAV, and aroma omission experiments. In this study, ethyl hexanoate, 3-methylbutanal, ethyl butanoate, ethyl 2-methylbutanoate, ethyl pentanoate, ethyl 4-methylpentanoate, dimethyl trisulphide, 2-furfurylthiol, propyl hexanoate, terpineol, ethyl 2-phenylacetate, 2-phenylethyl acetate, and 2-phenylethanol appeared to have the highest FD factors ($\geq$200). This result was different from which of Zhou's, it may because of the different extract and analysis methods but the result of OAVs was similar to which of Zhou's, 13 aromas was considered as important to the overall aroma of this type *baijiu* (Table 7.4). And aroma recombination experiment with these 36 aroma compounds was successful. Furthermore, 2-furfurylthiol was first proposed to be the key aroma of this aroma type *baijiu* by an omission experiment.

VSCs could be important for sesame-aroma *baijiu*. VSCs were the most abundant in sesame-aroma *baijiu*, and most of them have low aroma thresholds and unique

**Table 7.4** OAVs of odour-active compounds in sesame-aroma *Baijiu* (Reprinted with permission from [63])

| Compound | Con. [a] | OAV | Compound | Con. [a] | OAV |
|---|---|---|---|---|---|
| Ethyl hexanoate | 627 | 11,329 | Ethyl 2-phenylacetate | 5.05 | 12 |
| Ethyl octanoate | 98.1 | 7608 | Ethyl lactate [c] | 1.46 | 11 |
| Ethyl butanoate | 578 | 7094 | 2-methylpropanol | 235 | 8 |
| 3-methylbutanal | 22.8 | 1339 | 1-propanol | 350 | 6 |
| 2-furfurylthiol [b] | 118 | 1182 | Ethyl 3-phenylpropanoate [b] | 661 | 5 |
| Ethyl pentanoate | 26.9 | 1004 | 3-methylbutyl butanoate | 4.02 | 4 |
| Ethyl 3-methylbutanoate | 6.49 | 942 | Naphthalene [b] | 557 | 3 |
| Ethyl 2-methylpropanoate | 34.5 | 600 | 1-hexanol | 13.9 | 3 |
| 3-methylbutyl acetate | 46.5 | 495 | Hexanoic acid | 6.49 | 3 |
| 2-methylpropanoic acid | 357 | 226 | Furfural | 110 | 2 |
| Dimethyl trisulphide [b] | 79.0 | 220 | 2-phenylethyl acetate | 2.07 | 2 |
| Ethyl 2-methylbutanoate | 2.15 | 120 | 3-methylbutyl hexanoate | 2.70 | 2 |
| *β*-Damascenone [b] | 14.0 | 116 | Acetic acid | 280 | 2 |
| Methional [b] | 703 | 99 | 4-methylphenol [b] | 266 | 2 |
| Butanoic acid | 78.3 | 81 | Ethyl propanoate | 27.5 | 1 |
| Ethyl acetate [c] | 1.83 | 56 | Ethyl decanoate | 1.09 | 1 |
| 3-methylbutanoic acid | 47.4 | 45 | 2-phenylethyl hexanoate [b] | 794 | 1 |
| Pentanoic acid | 11.6 | 30 | Ethyl dodecanoate [b] | 524 | 1 |
| Geosmin [b] | 2.43 | 22 | 2-phenylethyl butanoate [b] | 527 | 1 |
| Dimethyl sulphide [b] | 237 | 14 | Ethyl nonanoate | 1.63 | 1 |
| *S*-methyl thioacetate [b] | 266 | 13 | | | |

[a]The concentration of aroma compounds, mg/L
[b]The concentration of aroma compounds, μg/L
[c]The concentration of aroma compounds, g/L

aroma characterization. To date, 25 VSCs have been found in sesame-aroma *baijiu* [64], although some of them have not been confirmed.

GC × GC-TOF-MS has been used to characterize sesame-aroma *baijiu*. More than 1000 peaks were separated and detected through this method by Chen et al. [64]. Of them, 340 volatile compounds were further confirmed by different strategies. Eleven VSCs and 12 terpenes in sesame-aroma *baijiu* were identified.

### 7.2.2 Taste Research of Chinese *Baijiu*

The taste of *baijiu* is often judged by experience, and there are microscopic in-depth studies on the taste compounds in *baijiu*, but much fewer than in the research on the taste compounds in wine [65–67]. The typical protocol for taste compound study starts with the separation and identification of taste compounds, followed by the determination of the taste threshold and taste reorganization and omission test.

Yang [68] explored the influence of organic acids on the taste (including astringent, bitter, and sweet tastes) of *baijiu* and confirmed that lactic acid was the key compound in the sour and astringent tastes of *baijiu* according to a taste recombination test. In this research, vacuum rotating evaporation and reversed-phase-high-performance liquid chromatography (RP-HPLC) were applied to separate the taste compounds in *baijiu*. Then, ultra-performance liquid chromatography (UPLC), liquid chromatography-mass spectrometry (LC–MS) and derivatization with *N,O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) combined with GC-MS were used to identify non-volatile organic acids. Finally, determination of the taste thresholds of taste compounds and recombination and omission experiments of taste were undertaken to evaluate the effect of non-volatile compounds on *baijiu* flavour. Based on the dose-over-threshold factor (DoT, the ratio of the concentration to the taste threshold), the result revealed that (1) lactic acid, 2-hydroxy-4-methylpentanoic acid, glycolic acid, 2-furoic acid, and succinic acid made important contributions to the sour taste of *baijiu*; (2) lactic acid, 2-furoic acid, and succinic acid contributed to the astringent taste of *baijiu*; and (3) 2-hydroxy-4-methylpentanoic acid made important contributions to the sweet taste of *baijiu*.

Wang et al. [69] investigated volatile and non-volatile contributions to the taste of *baijiu*. They proved that the contributors of bitter, astringent, and sweet tastes were in volatile fraction of *baijiu* sample, and which of bitter and sour tastes were in non-volatile fractions based on the taste after vacuum distillation. In order to identify the volatile compounds with bitter and astringent tastes in *baijiu*, gradient vacuum distillation coupled with semipreparative HPLC was used to separate the *baijiu* sample to several fractions, then each fraction was extracted by polar and non-polar solvent, then, taste dilution analysis (TDA, sample was washed with pure water and evaporated under vacuum to remove solvent) and GC-MS (sample was directly concentrated) analysis were carried out simultaneously for each organic phase. The results revealed that 2-phenylethanol and ethyl lactate contributed only astringency taste, and furfural, 2-methylpropanol, 3-methylbutanol, 1-butanol, and 1-propanol provided both bitter and astringent tastes.

On the other hand, Zhao et al. [70] identified the compounds which contributed the bitter and sour taste in the non-volatile fraction of sauce-aroma *baijiu* by TDA analysis. SPE and HPLC separation was used to extract and select the fractions which have the strongest bitter or sour taste, then high resolution MS (HRMS) and nuclear magnetic resonance (NMR) was applied to identify the bitter and sour taste compounds. As a result, (*E*)-9, 12, 13-trihydroxyoctadec-10-enoic acid and (*E*)-9, 10, 13-trihydroxyoctadec-10-enoic acid were indicated as the main contributors of bitter taste, and lactic acid and 2-hydroxy-4-methylpentanoic acid were indicated as the main contributors of sour taste compounds in non-volatile fraction of baijiu.

## 7.3 Odour Threshold and Odour Activity

### 7.3.1 Aroma Compound Threshold in *Baijiu*

The determination of the threshold in *baijiu* usually employs the ASTM E679–04 standard [71]. The threshold is often determined in 46% alcohol, (v/v), hydroalcoholic solution because the ethanol content of *Baijiu* is 40–55% by volume.

The odour threshold can be divided into a detection threshold (the panellist indicates that the sample is different from the two others) and a recognition threshold (the panellist indicates that the sample exhibits a recognizable odour of the substance). In this chapter, all odour thresholds were recognition thresholds. Currently, the thresholds of 143 volatile aroma compounds were determined (Table 7.5). Of these, diethyl azelate had the highest threshold (1.28 g/L), and 2-furfurylthiol had the lowest threshold (0.10 μg/L).

### 7.3.2 Perceptual Interactions of Aroma Compounds in Chinese *Baijiu*

The overall aroma of *baijiu* is formed by the integrated perception of various volatile compounds rather than a simple addition of odours.

There are four main methods for profiling the perceptual interactions of aroma compounds [74, 75]: (1) threshold [76]; (2) Feller's additive model [77, 78]; (3) OAV [79]; and (4) $\sigma - \tau$ plot [80]. These methods profiled perceptual interactions by comparing the threshold, OAV, and aroma intensity values before and after mixing the aroma compounds.

The perceptual interactions of aroma compounds of various foods, such as beer [81], wine [79, 82, 83], fruit [84], and other beverages [85, 86], have been widely discussed, but there are few relevant studies on *baijiu*, mainly about esters. Niu et al. [87] selected 35 binary mixtures of 18 esters to investigate the perceptual interaction of esters in light-aroma *baijiu*, only 4 of them presented making effect, and the others revealed either synergistic effect or additive action. In addition, ethyl phenylacetate with different concentrations (100, 2500, and 58,000 μg/L) were added to the fruit recombination sample, the result revealed the masking effect of fruity note. The floral notes were enhanced with the addition of phenylethyl acetate at low (1400 μg/L) or high levels (11,500 μg/L). The sweet notes were significantly enhanced with the addition of phenylethyl acetate at the peri-threshold (3200 μg/L). After that, they explored the perceptual interactions of esters in sauce-aroma *baijiu* combined with GC-O technology. (1) Langjiu [88]. In this study, five esters were selected, because of their importance to the overall aroma of *baijiu* based on the omission test, to study with regard to perceptual interactions by using Feller's additive model, OAVs, and a vector model. The result revealed an additive interaction happened in the binary mixture of ethyl acetate and ethyl 2-methylbutanoate, and synergistic interactions occurred when ethyl acetate was mixed with ethyl 3-methyl butanoate, ethyl hexanoate, or ethyl phenylacetate. Synergistic effects were also observed when

**Table 7.5** Odour thresholds of aroma compounds in *baijiu*

| Compound | Threshold (mg/L) | Odour description |
|---|---|---|
| *Esters* | | |
| Ethyl acetate | 32.6 [60] | Pineapple, apple, fruity |
| Ethyl propanoate | 19.0 [60] | Banana, fruity |
| Ethyl butanoate [b] | 81.5 [60] | Apple, pineapple, fruity, floral |
| Ethyl pentanoate [b] | 26.8 [60] | Peach, fruity, floral, sweet |
| Ethyl hexanoate [b] | 55.3 [60] | Sweet, fruity, cellar, cucumber |
| Ethyl heptanoate | 13.1 [60] | Floral, fruity, honey, sweet |
| Ethyl octanoate [b] | 12.8 [60] | Pear, litchi, fruity, sweet, lily |
| Ethyl nonanoate | 3.15 [60] | Honey, fruity |
| Ethyl decanoate | 1.12 [60] | Pineapple, fruity, floral |
| Ethyl lactate | 128 [60] | Sweet, fruity, grass |
| Propyl hexanoate | 12.8 [60] | Fruity, cellar, pineapple, sweet |
| Butyl hexanoate [b] | 678 [21] | Pineapple |
| Hexyl acetate | 5.56 [21] | Fruity, floral |
| Hexyl hexanoate | 1.89 [21] | Fruity, apple |
| Pentyl hexanoate | 13.8 [61] | Fruity |
| Ethyl 2-methylbutanoate [b] | 18.0 [2] | Berry |
| 2-methylpropyl acetate [b] | 922 [72] | Fruity |
| Ethyl 2-methylpropanoate [b] | 57.5 [60] | Osmanthus, apple, peach, fruity |
| Ethyl 3-methylbutanoate [b] | 6.89 [60] | Apple, pineapple, banana, fruity |
| 3-methylbutyl acetate [b] | 93.9 [2] | Banana |
| 3-methylbutyl hexanoate | 1.40 [2] | Fruity |
| 2-methylpropyl hexanoate | 5.35 [61] | Fruity |
| Ethyl 2-hydroxyhexanoate | 51.4 [21] | Floral |
| Isopentyl butanoate [b] | 915 [21] | Floral, fruity |
| Diethyl succinate | 353 [60] | Fruity, floral, pollen |
| Diethyl pimelate | 396 | |
| Diethyl suberate | 641 | |
| Diethyl azelate [a] | 1.28 | |
| Ethyl trans-4-decenoate [b] | 112 [61] | Floral |
| *Alcohols* | | |
| 1-propanol | 54.0 [60] | Fruity, floral, grass |
| 1-butanol | 2.73 [60] | Fruity |
| 2-butanol | 50.0 [21] | Fruity |
| 1-octanol | 1.10 [2] | Fruity |

(continued)

**Table 7.5** (continued)

| Compound | Threshold (mg/L) | Odour description |
|---|---|---|
| 3-octanol [b] | 393 [21] | Green, mushroom |
| 3-methyl-1-butanol | 179 [60] | Fruity, floral, fumes |
| 2-heptanol | 1.43 [60] | Peach, fruity, floral, honey |
| 1-heptanol | 26.6 [2] | Alcoholic |
| 1-octen-3-ol [b] | 6.12 [60] | Grass, fruity, dusty, grease |
| 2-methylpropanol | 28.3 [72] | Malty |
| 1-hexanol | 5.37 [72] | Floral |
| 1-pentanol | 37.4 [21] | Fruity |
| 2-pentanol | 194 [21] | Alcoholic |
| 1-nonanol [b] | 806 [21] | Green |
| *Aldehydes* | | |
| Acetaldehyde | 1.20 [21] | Fruity |
| 2-methylpropanal | 1.30 [21] | Fruity |
| Butanal | 2.90 [60] | Fruity, floral |
| 3-methylbutanal [b] | 16.5 [60] | Floral, fruity |
| Pentanal [b] | 725 [60] | Fatty, oily, greasy |
| Hexanal [b] | 25.5 [60] | Floral, fruity |
| Heptanal [b] | 410 [60] | Grass, cucumber |
| Octanal [b] | 39.6 [60] | Grass, fruity |
| Nonanal [b] | 122 [60] | Soapy, grass, watery |
| Decanal [b] | 71.0 [72] | Oily |
| (E)-2-decenal [b] | 12.1 [2] | Fatty |
| (E)-2-octenal [b] | 15.1 [2] | Fatty |
| (E)-2-nonenal [b] | 50.5 [2] | Fatty |
| (E)-2-undecenal [b] | 240 [2] | Fatty |
| (E, E)-2,4-decadienal [b] | 7.71 [2] | Fatty |
| *Acids* | | |
| Acetic acid | 160 [72] | Acidic, vinegar |
| Propanoic acid | 18.1 [72] | Vinegar |
| 2-methylpropanoic acid | 1.58 [72] | Sweaty, acidic |
| Butanoic acid [b] | 965 [60] | Sweaty, sour |
| 2-methylbutanoic acid | 5.93 [60] | Sweaty, sour |
| 3-methylbutanoic acid | 1.05 [60] | Sweaty, sour |
| Pentanoic acid [b] | 389 [60] | Sweaty, sour |
| 4-methylpentanoic acid [b] | 144 [21] | Sweaty, sour |
| Hexanoic acid | 2.52 [60] | Sweaty, sour, animal, sweet, fruity |
| Heptanoic acid | 13.8 [60] | Sweaty, sour, musty |
| Octanoic acid | 2.70 [60] | Fruity, floral, fatty |
| Nonanoic acid | 3.56 [60] | Fatty |

(continued)

**Table 7.5** (continued)

| Compound | Threshold (mg/L) | Odour description |
|---|---|---|
| Decanoic acid | 13.7 [60] | Goat, rubber, paint, animal |
| Lauric acid | 9.15 [60] | Greasy, pine, woody |
| *Ketones* | | |
| 3-hydroxy-2-butanone [b] | 259 [2] | Buttery |
| 2-decanone [b] | 186 [2] | Fruity |
| 2-nonanone [b] | 483 [21] | Sweet, fruity |
| *Pyrazines* | | |
| 2-methylpyrazine | 122 [60] | Toast, roasted almond, roasted peanut |
| 2,3-dimethylpyrazine | 10.8 [60] | Toast, fried corn, roasted peanut |
| 2,5-dimethylpyrazine | 3.20 [60] | Grassy, fired bean |
| 2,6-dimethylpyrazine [b] | 790 [60] | Pepper |
| 2-ethylpyrazine | 21.8 [60] | Fired sesame, roasted peanut |
| 2-ethyl-5-methylpyrazine | 91.9 [61] | Baked |
| 2,3,5-trimethylpyrazine [b] | 730 [60] | Pepper, coffee, toast |
| 2,3,5,6-tetramethylpyrazine | 80.1 [60] | Sweet, fruity, floral, peach |
| *Furans* | | |
| Furfural | 44.0 [60] | Burnt, nutty, rotten |
| 2-acetylfuran | 58.5 [60] | Almond, sweet, cream |
| 5-methylfurfural | 466 [60] | Almond, sweet, cream |
| 2-acetyl-5-methylfuran | 40.9 [60] | Cookies, roasted almond, soapy |
| 2-furanmethanol | 54.7 [21] | Baked |
| Ethyl 2-furanoate | 132 [61] | Ointment |
| Furfuryl hexanoate | 24.2 [61] | Sweet |
| *Aromatics* | | |
| Benzaldehyde | 4.20 [60] | Almond, nutty |
| Phenylacetaldehyde [b] | 262 [72] | Floral |
| 2-phenyl-2-butenal [b] | 472 [60] | Fruity, floral |
| Benzyl alcohol | 41.0 [60] | Floral, fruity, sweet |
| Phenethyl alcohol | 28.9 [60] | Rose, floral, pollen |
| Acetophenone [b] | 256 [60] | Soapy, jasmine |
| 4-(4-methoxyphenyl)-2-butanone | 5.57 [60] | Licorice, cinnamon, star anise, like seasoning |
| Ethyl benzoate | 1.43 [60] | Honey, floral, acacia flower, rose |
| Ethyl phenylacetate [b] | 407 [60] | Rose, osmanthus, acacia flower, honey, floral |
| Ethyl 3-phenylpropionate [b] | 125 [60] | Pineapple, fruit candy, honey, fruity, floral |
| 2-phenylethyl acetate [b] | 909 [60] | Rose, floral, rubber |

(continued)

**Table 7.5** (continued)

| Compound | Threshold (mg/L) | Odour description |
|---|---|---|
| 2-phenylethyl butyrate [b] | 961 [21] | Fruity |
| 2-phenylethyl hexanoate [b] | 94.0 [21] | Fruity |
| Styrene | 1.40 [2] | Plastic |
| Naphthalene [b] | 159 [60] | Mothballs |
| (E)-cinnamaldehyde | 4.80 [2] | Cinnamon |
| *Phenolics* | | |
| Phenol | 18.9 [60] | Glue-like, ink |
| 4-methylphenol [b] | 167 [60] | Leather, rubber, animal |
| 4-ethylphenol [b] | 618 [60] | Stable |
| Guaiacol [b] | 13.4 [60] | Fruity, floral, sweet, grass |
| 4-methylguaiacol [b] | 315 [60] | Smoky, soy sauce, tobacco |
| 4-ethylguaiacol [b] | 123 [60] | Melon, fruity, sweet, floral, smoky, rubber |
| 4-vinylguaiacol [b] | 209 [60] | Sweet, floral, fruity, melon |
| Eugenol [b] | 21.2 [60] | Clove, cinnamon, cantaloupe |
| Isoeugenol [b] | 22.5 [60] | Vanilla, fruit candy, melon, cantaloupe |
| Vanillin [b] | 439 [60] | Sweet, cream, fruity, floral, honey |
| Ethyl vanillate | 3.36 [60] | Fruity, floral |
| Vanillin acetate | 5.59 [60] | Cantaloupe, banana, fruity, raisin, oak, sweet, floral |
| *Lactones* | | |
| γ-Octanolactone | 2.82 [60] | Cream, coconut oil |
| γ-Nonanolactone [b] | 90.7 [60] | Cream, coconut, butter cookies |
| γ-Decanolactone [b] | 10.9 [60] | Fruity, sweet, floral |
| γ-Dodecanolactone [b] | 60.7 [60] | Fruity, honey, cream |
| *Sulphurs* | | |
| Methional [b] | 7.12 [2] | Cooked potato |
| Dimethyl disulphide [b] | 9.13 [60] | Glue, boiled radish, rubber |
| Dimethyl trisulphide [b] | 0.360 [60] | Ether-like, cabbage, pickles, coal gas, rotten vegetables, garlic, salted carrot |
| 3-(methylthio)-1-propanol | 2.11 [60] | Glue, boiled radish, rubber |
| Ethyl 3-methylthiopropionate | 3.08 [61] | Herbal |
| Methanethiol [b] | 2.21 [61] | Rotten cabbage, burnt rubber |
| 2-furfurylthiol [b] | 0.100 [63] | Roasted sesame seeds |
| Dimethyl sulphide [b] | 17.0 [63] | Cooked onion |
| S-methyl thioacetate [b] | 21.0 [63] | Rotten cabbage |
| Ethyl 2-mercaptoacetate | 120 [63] | Cooked vegetable |
| Ethanethiol [b] | 0.800 [49] | Onion, rubber |

(continued)

**Table 7.5** (continued)

| Compound | Threshold (mg/L) | Odour description |
|---|---|---|
| 3-methylthiophene [b] | 360 [49] | Plastic, sulphurous |
| Diethyl disulphide [b] | 4.30 [49] | Onion, sulphurous |
| Thiazole [b] | 740 [49] | Nut, sulphurous |
| Ethyl (methylthio) acetate [b] | 120 [49] | Garlic, sulphurous |
| *Acetals* | | |
| 1,1-diethoxyethane | 2.09 [72] | Fruity |
| 1,1,3-triethoxypropane | 3.70 [2] | Vegetal |
| *Terpenes* | | |
| Geosmin [b] | 0.11 [73] | Earthy off-odour note |
| β-Damascenone [b] | 0.12 [72] | Floral, honey |
| α-Cedrene | 11.9 [61] | Woody |
| α-Terpineol | 1.96 [61] | Floral |
| Geranyl acetate | 636 [60] | Rose, floral |

[a]The threshold was g/L
[b]The threshold was μg/L

mixing other esters. (2) Moutai [89]. In this study, isobutanoate and isovalerate were selected, based on their FD factors and OAVs, to investigate the perceptual interaction to the overall aroma of Moutai *baijiu* by vector model, Feller's additive model, and OAV analysis. The result revealed that additive or synergistic effects occurred after adding with different concentrations. As the concentration of ethyl isobutanoate increased, the degree of interaction also increased.

## 7.4 Sensory Evaluations of *Baijiu*

### 7.4.1 National *Baijiu* Evaluation Conference

The appraisal of the quality of *Baijiu* has been mainly dependent on comprehensive sensory evaluation, including colour, aroma, and taste. Therefore, the National *Baijiu* Evaluation Conference is an important event for the quality appraisal and ranking of *baijiu*.

The first national *Baijiu* evaluation conference was held in 1952. Four more sessions have been held since then, with the last in 1989. Each session of the national *Baijiu* evaluation conference selected several famous *baijiu* brands [90].

**Session 1 (1952)**: According to market sales, combined with the results of physical and chemical analysis, the top four *baijiu* brands were selected (ranking): Fenjiu, Moutai, Luzhoulaojiao, and Xifeng.

**Session 2 (1963)**: According to the colour, aroma, and taste, on a hundred-point system, eight aroma types of *baijiu* with the highest scores were selected:

Wuliangye, Gujinggong, Luzhoulaojiao, Quanxing, Moutai, Xifeng, Fenjiu, and Dongjiu.

**Session 3 (1979)**: According to the aroma type, production process and saccharifying starter, all the *baijiu* samples were divided into subgroups, and eight *baijiu* received the highest scores:

Strong-aroma *baijiu*: Wuliangye, Jiannanchun, Gujinggong, Yanghe, and Luzhoulaojiao.
Light-aroma *baijiu*: Fenjiu.
Sauce-aroma *baijiu*: Moutai and Langjiu.
Other aroma types of *baijiu*: Dongjiu.

**Session 4 (1984)**: The same standards as those in session 3 were used, and 13 *baijiu* were selected:

Strong-aroma *baijiu*: Wuliangye, Jiannanchun, Gujinggong, Yanghe, Luzhoulaojiao, Quanxing, and Shuanggou.
Light-aroma *baijiu*: Fenjiu and Huanghelou.
Sauce-aroma *baijiu*: Moutai.
Other aroma types of *baijiu*: Dongjiu and Xifeng.

**Session 5 (1989)**: More detailed classification of samples was performed:

1. Aroma type: strong-aroma *baijiu*, light-aroma *baijiu*, sauce-aroma *baijiu*, rice-aroma *baijiu,* and other aroma types of *baijiu*.
2. Alcohol content: 40–55% alcohol, (v/v), below 40% alcohol, (v/v).
3. Starter: daqu, fuqu, xiaoqu.

According to the scores, the best 8 aroma types of *baijiu* was selected:

Strong-aroma *baijiu*: Wuliangye, Yanghe, Jiannanchun, Gujinggong, Luzhoulaojiao, Quanxing, Shuanggou, Songhe, and Tuopai.
Light-aroma *baijiu*: Fenjiu, Huanghelou, and Baofeng.
Sauce-aroma *baijiu*: Moutai, Langjiu, and Wuling.
Other aroma types of *baijiu*: Dongjiu and Xifeng.

### 7.4.2 Sensory Evaluation of *Baijiu*

Sensory evaluation is a very important and decisive method for assessing the quality of *baijiu*. According to the China national standard GB/T 33404 < Guidelines for Sensory Evaluation of *baijiu*> [91], there are standard requirements for the environmental conditions, facilities and equipment, basic panel requirements, evaluation specifications, and statistical analysis. A series of Chinese national standards have been established for the sensory evaluation of *baijiu*. The sensory descriptors for *baijiu* are a set of standard comments based on different aroma types of *baijiu* [92]. However, compared with other well-known international liquors (wine, beer, whiskey, and brandy), these sensory descriptors lack detailed definitions, are difficult to understand, and need the support of sensory science theory. Therefore, more work is needed in the future.

## 7.5 Conclusion

Various flavour chemistry approaches have been widely applied to *Baijiu*, including aroma isolation, GC-O analysis (AEDA, Osme, etc.), quantification, aroma recombination, and aroma omission. As a result, the understanding of aroma-active compounds in *baijiu* has been greatly improved in the last 15 years. An increasing number of important aroma compounds that make special contributions to the aroma of *baijiu*, such as lactones, terpenoids, and sulphur-containing compounds, have been gradually identified with the help of comprehensive extraction in combination with advanced analytical instrumentation. In addition, novel flavour chemistry research methods have been developed to understand the contributions of individual aroma compounds to the overall flavour. However, more research is needed to understand the taste compounds, the flavour perceptual interaction, and the overall sensory evaluation.

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