

## Evaluation of the color and aroma characteristics of commercially available Chinese kiwi wines via intelligent sensory technologies and gas chromatography-mass spectrometry

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### ABSTRACT

As a deeply processing product of kiwifruit, kiwifruit wine (KW) has also shown promising commercial development prospects. In this study, the color and aroma characteristics of 14 commercially available KW were evaluated using intelligent sensory technologies (electronic nose (E-nose) and colorimeter) and gas chromatography-mass spectrometry (GC-MS). Different types of KW had similar color trends, namely, yellow-green or yellow; however, individual samples showed a bright green color and had a high transparency. E-nose and GC-MS reached a relatively consistent conclusion that fermented wine and Lu Jiu were closer and significantly differed from those of distilled wine and beer. A total of 215 volatile organic compounds were identified in all KW. 50 key odor-active compounds were identified, of which ethyl caprylate, which had high OAVs in all samples (30–565.17), was considered the key odor-active compound of KW; likewise, damascenone also made a prominent aroma contribution in the different types of KW. Moreover,  $\beta$ -ionone, ethyl undecanoate, ethyl 2-methylvalerate were outstanding in different fermented wines. Acids and terpenoids were prominent in beer. The study could provide a data support and market information for the quality control, research, production and development of KW.

### Introduction

Kiwifruit (*Actinidia chinensis* Planch) is an extremely commercially valuable fruit and highly favored by consumers, as it is nutritious and palatable. The acreage and production of kiwifruit in China have ranked first in the world in recent years (FAO, 2020), and a seasonal oversupply of fresh kiwifruit gradually appeared; meanwhile, kiwifruit, as a respiratory climacteric berry fruit, is not suitable for long-term storage after ripening and is prone to rot and deteriorate. The above factors have put high pressure on the sale of fresh kiwifruit (Huang et al., 2021). Therefore, vigorously developing various finely and deeply processed products of kiwifruit is an effective way to solve the decay and waste of fresh kiwifruit and increase its added value and industrial income (Zhan et al., 2020).

Kiwifruit wine (KW), as one of the deeply processed products of kiwifruit, is popular among consumers due to its bright color, unique flavor, rich nutrition and various health benefits (Huang et al., 2022; Zeng et al., 2019). Recently, with the rise of the fruit wine consumer market, KW has also shown promising commercial development prospects (Liu, Qi, Zhao, Cao, Xu, & Fan, 2020). Currently, commercially available KW is rich and diverse, including fermented wine (Huang et al., 2021), Lu Jiu, distilled wine (López-Vázquez, García-Llobodanin, Pérez-Correa, López, Blanco, & Orriols, 2012), and beer. Research shows that compared with brands, new generations (18–35 years of age), as the drivers of consumption, focus more on the sensory attributes, alcohol content, raw fruit material quality, and sales mode of the fruit wine products (Merlino et al., 2021). Sensory attributes are important factors for fruit wine products' acceptance by consumers. Among them, the

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typical characteristics of fruit, such as color, aroma, freshness, and taste, are reflected and derived in fruit wine, which is desired by consumers (Merlino et al., 2021). Thus, understanding the sensory properties of KW is indispensable for its production and sales.

Most studies on KW that are currently known are still in the laboratory stage, mainly focusing on process optimization, such as the impact of the selection of raw materials (Huang et al., 2021), strain selection (Sun, Gao, Li, Chen, & Guo, 2021), and fermentation conditions (Chen et al., 2019; Huang et al., 2022) on KW quality. Only a small number of studies have addressed the sensory characteristics of KW such as color (Liu et al., 2019) and aroma (Li, Bi, Sun, Gao, Chen, & Guo, 2022; Liu et al., 2020; Zhan et al., 2020). However, there are few studies on the sensory characteristics of commercially available KW, which creates a disconnect among researchers, producers, and consumers, and

inhibits targeted research and improvement based on the overall advantages and disadvantages of commercially available products, thereby promoting product improvement. Therefore, fully understanding the sensory characteristics of KW is essential for promoting the development of the KW industry.

Artificial sensory evaluation is the most common method of sensory research on food. It relies on sensory assessors with professional competence to evaluate the evaluated objects through sensory perception such as smell and vision; this also determines that its conclusion is susceptible to many factors, such as the environment and the physical and mental conditions of sensory panelists, thereby drawing biased conclusions (Jiang, Ni, Chen, & Liu, 2021). Hence, intelligent sensory technology using artificial sensors to replace human perception emerged. Intelligent sensory technology is a new detection technology

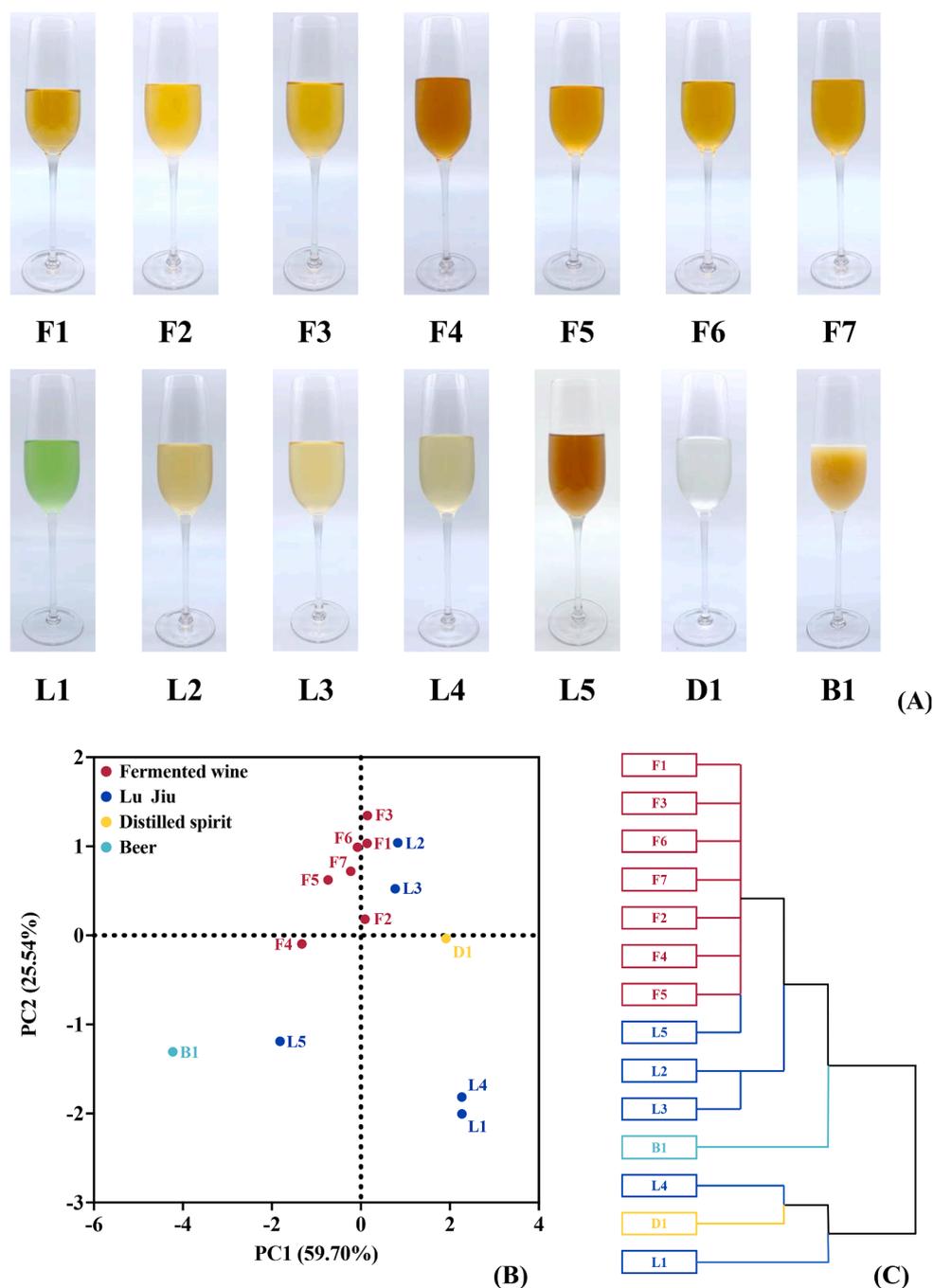


Fig. 1. The samples of KW (A); PCA score plots (B) and dendrogram of system cluster analysis (C) of 4 types of KW based on the color parameters.

that obtains sample signals and performs comprehensive analysis by imitating the perception of human sensory systems, e.g., electronic noses (E-nose) simulating human olfactory senses, electronic tongues simulating human taste senses, and colorimetric techniques simulating human visual senses. Compared with artificial sensory evaluation, it has the characteristics of simple and fast operation, accurate and efficient analysis, and strong objectivity. Moreover, intelligent sensory technology in combination with modern analytical techniques, such as gas chromatography-mass spectrometry (GC-MS), can provide more definitive information on food sensory characteristics (Borras et al., 2015).

In this study, the sensory characteristics of 14 commercially available KW (i.e., seven fermented wines, five Lu Jiu, one distilled spirit, and one beer) were evaluated based on intelligent sensory technologies, such as an E-nose and a colorimeter, and combined with GC-MS in order to provide a theoretical basis and market information for the quality control and research and development of KW, and to further promote the development of the KW industry.

## Materials and methods

### Wine samples

A total of 14 commercially available Chinese KW were collected for this study, including 7 kiwi fermented wines (KFW, F1-F8), 5 kiwi Lu Jiu (KLJ, L1-L5), 1 kiwi distilled spirit (KDS, D1), and 1 kiwi beer (KB, B1). They were purchased from Jindong Online Mall ([Jingdong.com](http://Jingdong.com)), Taobao ([taobao.com](http://taobao.com)), and a local supermarket. All KW samples were kept at  $10 \pm 2$  °C until analysis. Detailed information about these samples is provided in [Table S1](#) and [Fig. 1 \(A\)](#).

### Color analysis

The X-rite Ci7600 colorimeter (Grand Rapids, MI, USA) with a reflectance model was used to evaluate the color of the KW samples (Ma et al., 2020). The lightness ( $L^*$ ), green/red component ( $a^*$ ), yellow/blue component ( $b^*$ ), chroma ( $C^*$ ), and hue ( $h^\circ$ ) of samples were recorded. The samples were tested in triplicates.

### E-nose analysis

The E-nose (PEN 3, Aisense Analytics, Schwerin, Germany), containing 10 metal-oxidesemiconductor chemical sensors ([Table S2](#)), was used to preliminarily evaluate the overall aroma profile of the KW samples. A KW sample of 1.25 mL was volumed in a 100 mL volumetric flask with distilled water. A diluted sample (1 mL) was placed in a 20 mL sample bottle and equilibrated at 25°C for 10 min before the test. Every sample was analyzed at least 10 times. The E-nose's detection parameters included the following: detection time duration was 60 s, the cleaning time was 300 s, and the carrier gas velocity was 300 mL/min. The method was according to that of Lan et al. (2021) with minor modifications.

### GC-MS analysis

A solid-phase microextraction head coupled with GC-MS (HS-SPME-GC-MS) was used to analyze the volatile organic compounds (VOCs) in the KW samples (Ge et al., 2021). Exactly 5 mL of KW sample and 40  $\mu$ L of internal standard solution (60  $\mu$ L/L 4-methyl-1-pentanol) were added to a 20 mL headspace bottle with 1.5 g NaCl. The headspace bottle containing the sample was allowed to equilibrate at 40°C for 15 min and extracted 35 min by after-aging (250°C, 120 min) SPME fiber (50/30  $\mu$ m, DVB/CAR/PDMS, Supelco, Bellefonte, USA). Then, the fiber was inserted into the GC injector port for 3 min at 250°C to desorb. The GC-MS analyses were performed on a GC-MS TQ8050 NX system (Shimadzu, Kyoto, Japan) equipped with a DB-WAX-UI silica capillary column (60.0 m  $\times$  0.25 mm  $\times$  0.25  $\mu$ m, Shimadzu, Kyoto, Japan).

Helium was used as the carrier gas with a flow rate of 1.0 mL/min. The GC temperature program consisted of an initial temperature of 40°C held for 1 min, followed by a temperature rate of 3 °C/min to 130 °C, subsequently increasing at a rate of 4 °C/min to 250 °C, and then held for 8 min. The MS conditions used were as follows: ion source of electronic ionization (EI), ion energy of 70 eV, ion source temperature of 200 °C, full scan mode, and scan range of 50–450  $m/z$ .

According to the NIST 14 library, the tentative qualitative analysis of VOCs uses the retention index (RI) based on the mixture of *n*-alkanes (C8-C40), retention time (RT), MS, and 85 % similarity. Where possible, the identification of VOCs was confirmed by comparing an external standard method with authentic standards. The quantitative analysis included the external standard method, combined with the maximally resembled compound's chemical structure due to the lack of a pure reference standard, and corrected with an internal standard method. The contribution of each VOC to the overall KW aroma was determined by calculating the odor activity value (OAV), which is the ratio between the concentration of the VOC and its odor threshold. VOCs with  $OAV \geq 1$  were considered the key aroma compounds (Fan, Tang, Xu, & Chen, 2020).

### Statistical analysis

Microsoft Excel 16.4 was used to arrange the data for analysis and visualization. Analysis of variance, Tukey's multiple comparison test, principal component analysis (PCA), linear discriminant analysis (LDA), and their visualization were performed in SPSS 26.0 (IBM, Armonk, NY, USA) and GraphPad Prism 9.3.1. The heatmap and Venn diagram were drawn using the TBtools software (<https://github.com/CJ-Chen/TBtools/releases>). The figures were adjusted with Adobe Illustrator 2020 (Adobe Systems).

**Table 1**  
Color analysis of KW.

Code	$L^*$	$a^*$	$b^*$	$C^*$	$h^\circ$
F1	34.59 $\pm$ 2.83fgh	-0.65 $\pm$ 0.13c	5.89 $\pm$ 0.86 g	5.93 $\pm$ 0.84 g	96.47 $\pm$ 2.04 fg
F2	42.35 $\pm$ 2.28 cd	-0.89 $\pm$ 0.28 cd	7.70 $\pm$ 0.42f	7.75 $\pm$ 0.39f	96.67 $\pm$ 2.33 fg
F3	31.12 $\pm$ 0.74 h	-0.92 $\pm$ 0.08 cd	6.06 $\pm$ 0.43 g	6.13 $\pm$ 0.41 g	98.71 $\pm$ 1.34 fg
F4	38.63 $\pm$ 2.25def	-1.17 $\pm$ 0.17de	23.36 $\pm$ 1.13c	23.39 $\pm$ 1.12c	92.86 $\pm$ 0.48 fg
F5	32.88 $\pm$ 3.45 h	-2.27 $\pm$ 0.07f	18.26 $\pm$ 1.24d	18.40 $\pm$ 1.23d	97.11 $\pm$ 0.68 fg
F6	32.32 $\pm$ 2.56 h	-1.95 $\pm$ 0.56f	10.52 $\pm$ 0.70e	10.71 $\pm$ 0.61e	100.62 $\pm$ 3.57f
F7	35.21 $\pm$ 0.18fgh	-1.35 $\pm$ 0.10e	11.27 $\pm$ 0.42e	11.35 $\pm$ 0.40e	96.84 $\pm$ 0.75 fg
L1	57.62 $\pm$ 1.72a	-8.22 $\pm$ 0.23 h	0.49 $\pm$ 0.77i	8.26 $\pm$ 0.25f	176.59 $\pm$ 5.25c
L2	34.26 $\pm$ 3.53gh	-0.81 $\pm$ 0.05 cd	1.17 $\pm$ 0.63hi	1.45 $\pm$ 0.52 h	128.52 $\pm$ 15.38d
L3	39.84 $\pm$ 3.13de	-0.99 $\pm$ 0.08cde	1.84 $\pm$ 0.26 h	2.09 $\pm$ 0.25 h	118.43 $\pm$ 2.44e
L4	55.38 $\pm$ 0.88a	-3.51 $\pm$ 0.19 g	-3.55 $\pm$ 0.80 k	5.00 $\pm$ 0.69 g	224.82 $\pm$ 5.34b
L5	49.43 $\pm$ 0.31b	0.89 $\pm$ 0.04b	26.23 $\pm$ 0.19b	26.25 $\pm$ 0.19b	88.06 $\pm$ 0.08gh
D1	37.30 $\pm$ 3.43efg	-0.56 $\pm$ 0.12c	-1.91 $\pm$ 1.19j	2.00 $\pm$ 1.16 h	249.17 $\pm$ 11.97a
B1	46.19 $\pm$ 0.98bc	7.02 $\pm$ 0.43a	41.78 $\pm$ 0.48a	42.37 $\pm$ 0.54a	80.47 $\pm$ 0.46 h

The different small letters indicate a significant difference ( $p < 0.05$ ) among different KW.

## Results and discussion

### Color analysis

The color parameters of the KW samples are presented in Table 1, and they were further subjected to PCA and cluster analysis (Fig. 1 (B) & (C)). Kiwifruit fermented wine was obtained by the alcoholic fermentation of fresh kiwifruit with *Saccharomyces cerevisiae* inoculation (Liu et al., 2020). The results showed that the color characteristics of all KFW were similar (Table 1, Fig. 1 (B) & (C)), showing  $a^* < 0$ ,  $b^* > 0$ , located in the  $90^\circ$ – $100^\circ$  h range, and an  $L^*$  value range of 30–42. This indicated that the overall color of KFW was dark and was seen in yellow with slight green. This was mainly because during the fermentation process of KFW, the raw kiwifruit materials change from green or greenish-yellow to yellow or yellowish-brown due to the browning reaction and the degradation of chlorophyll, thereby increasing the  $b^*$  value and reducing the  $a^*$  value and  $L^*$  value, making the color of KFW dark (Liu et al., 2019; Xu, Zhou, & Wang, 2020).

Previous studies showed that the selection of kiwifruit cultivars, the pretreatment of raw materials, the fermentation strains, the methods of inoculation, and the addition of color fixatives would all affect the fermentation and coloring process of KFW. Liu et al. (2019) found that using glutathione-enriched inactive dry yeast (g-IDY) to ferment kiwifruit juice may be effective in improving the color parameters of KW and significantly increasing the  $L^*$  value. A study by Sun et al. (2021) demonstrated that inoculation methods were closely associated with the color characterizations of KW, and mixed inoculated fermentation could significantly inhibit the browning of KW. Furthermore, soaking raw kiwifruit materials with antioxidants, such as ascorbic acid (Xu et al., 2020), and adding color fixatives, such as cyclodextrins (Zhu et al., 2022), could effectively inhibit browning during the processing of kiwifruit. In summary, during the production process of KFW, browning can be prevented or slowed down by pretreatment of raw kiwifruit materials, adding color fixations, and selecting appropriate fermentation strains and inoculation methods so as to improve the color characteristics of KFW and make it easier for consumers to accept the appearance (Huang et al., 2022; Liu et al., 2019).

KLJ is a kind of integrated alcoholic beverages from plants, which meet the definition of China national standard (CNS) GB/T 27588–2011. The color of KLJ will significantly be affected by different wine bases, raw material forms, and extraction methods. Both L1 and L4 used kiwifruit juice as raw materials, for which L1 presented as bright green and preserved well the original color of kiwifruit, while L4 exhibited a nearly transparent teal (blue-green). Although their raw material forms were consistent, they also showed great color differences, which was mainly due to the different selection of wine bases. L2 and L3 used KFW as raw materials, which caused them to have a similar color to KFW (Fig. 1), that is, yellow-green; however, because of the addition of wine bases, their  $C^*$  value was reduced, and the transparency was increased. In addition, L5 selected kiwifruit as the raw materials for extraction, due to the long-term immersion of kiwifruit, the browning was very serious; therefore, it showed a more pronounced yellow with a slight trend of red. In summary, different raw material forms are very important for the color of KLJ.

D1 is a KDS, which was obtained by low-temperature fermentation and negative pressure distillation. It had obvious characteristics of distilled wine, namely, a high transparency and high degree of alcohol. From Fig. 1 (A) & (C), D1 was the closest to the color characteristics of L4, which also had high transparency. B1 was a KB that exhibited the highest  $a^*$ ,  $b^*$ , and  $C^*$  values, and h was  $80.47^\circ$ , indicating that the overall hue of B1 was yellow with slightly red, and high color saturation. This was mainly because the raw material used was yellow-fleshed kiwifruit, and a certain browning occurred during the fermentation of beer. In general, different types of KW showed similar color trends, with only a few samples showing significant differences. The differences in preparation processes, kiwifruit cultivars, and raw material form will

affect the color of KW; however, the bright yellow or green which was closer to the color of kiwifruit itself was more acceptable to consumers.

### E-nose analysis

The overall odor profiles of different commercially available KW were evaluated using an E-nose. During the test, all samples showed stable response values via E-nose sensors over a period from 50 to 60 s long. The response values at the stable stage were chosen for the data analysis. According to the different response values of the E-nose sensors to the odor characteristics of different commercially available KW, a parallel coordinate system and a heatmap were established as shown in Fig. 2 (A) & (B). The E-nose sensors provided roughly the same sensitivities for the aroma components of KW samples, but their response values were different. Overall, sensor S2 had the strongest response, followed by S7, S6, and S8, while the response values of other sensors were smaller. The D1 showed the maximum response value to the above four sensors, while the B1 showed the lowest response value. This may be due to the high alcoholic degree (52 % vol.) of distilled wine, which makes the odor of the sample more prominent and richer, resulting in a higher response from the electronic nose sensor (Wei, Ma, Cao, Sun, & Fan, 2018), while the odor of KB was relatively bland.

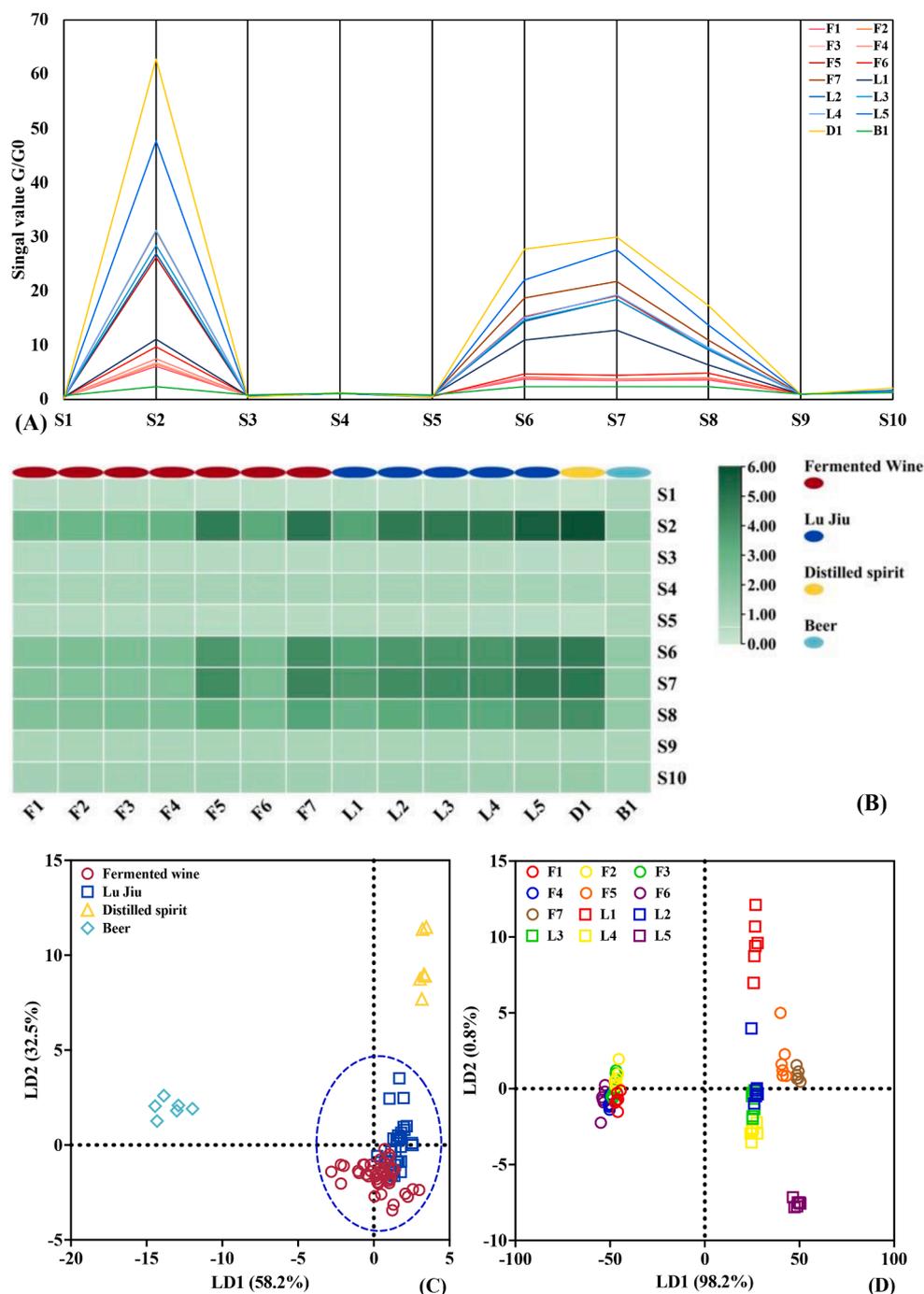
KLJ generally showed higher response values than KFW, which might be due to the distilled wine base commonly used in KLJ, making its overall odor characteristics more prominent and closer to KDS. Particularly, the overall odor characteristics of L5 were the closest to KDS due to the fact of its high alcohol degree and brewing method of fruit extraction. Although the response values of KFW were low, it had relatively balanced odor characteristics, which might make the consumers' sensory perceptions more pleasant.

On this basis, LDA was performed on the E-nose results of different types of KW samples (Fig. 2 (C) & (D)). The total contribution rates of LD1 and LD2 were >85 %, which implied that the results of the E-nose could be well explained by LD1 and LD2. As shown in Fig. 2 (C), there was a clear distinction among KDS, KB, KFW, and KLJ but with some overlap between KFW and KLJ. This indicated that the odor characteristics of KFW were relatively close to that of KLJ, both were indistinguishable by E-nose. These results were consistent with those obtained from the heatmap based on the response values of the E-nose (Fig. 2 (B)). Moreover, the LDA was further performed on the E-nose data of KFW and KLJ as displayed in Fig. 2 (D). As for KLJ, the odor characteristics of L2, L3, and L4 were the closest, while L1 and L5 were significantly different from them. This difference may have been caused by the difference in wine bases, material forms, and extraction methods. In terms of KFW, the odor characteristics of F1, F2, F3, F4, and F6 were extremely similar, while F5 and F7 were closer to those of KLJ, especially L2 and L3. This might be due to the addition of KFW in L2 and L3 as a source of aroma and nutrition.

### GC-MS analysis

#### Vocs identification

In this study, VOCs were identified by RT, RI, and MS, when possible further by comparison of standard compounds (Table S3). A total of 215 VOCs were detected in 14 commercially available KW samples (Table S4), including 87 esters, 40 alcohols, 13 ketones, 11 aldehydes, 17 acids, 23 terpenoids, 8 volatile phenols, and 16 hydrocarbons. For four types of KW, the most VOCs were detected in KFW, with 157 VOCs, followed by KLJ (123) and KB (75), and the least in the KDS with 23 VOCs. A total of 13 VOCs co-existed in four types of KW (Fig. 3 (A) & Table S4), including 7 esters (i.e., ethyl acetate [E1], ethyl butyrate [E2], ethyl hexanoate [E6], ethyl lactate [E10], ethyl caprylate [E14], ethyl decanoate [E25], and diethyl succinate [E29]), 4 alcohols (i.e., isobutanol [A3], isoamyl alcohol [A7], 1-hexanol [A11], and 2-phenylethanol [A35]), 1 aldehyde (furfural [a5]) and 1 acid (acetic acid [C1]). Specifically, the VOCs of F4 were the most among the 14 samples, with



**Fig. 2.** Parallel coordinate plots (A) and heatmap (B) the shifting shades of green from light to dark represent the value changing from low to high of E-nose sensor response values of KW samples; LDA for 4 types of KW based on E-nose (C); and LDA for KFW and KLJ based on E-nose (D). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

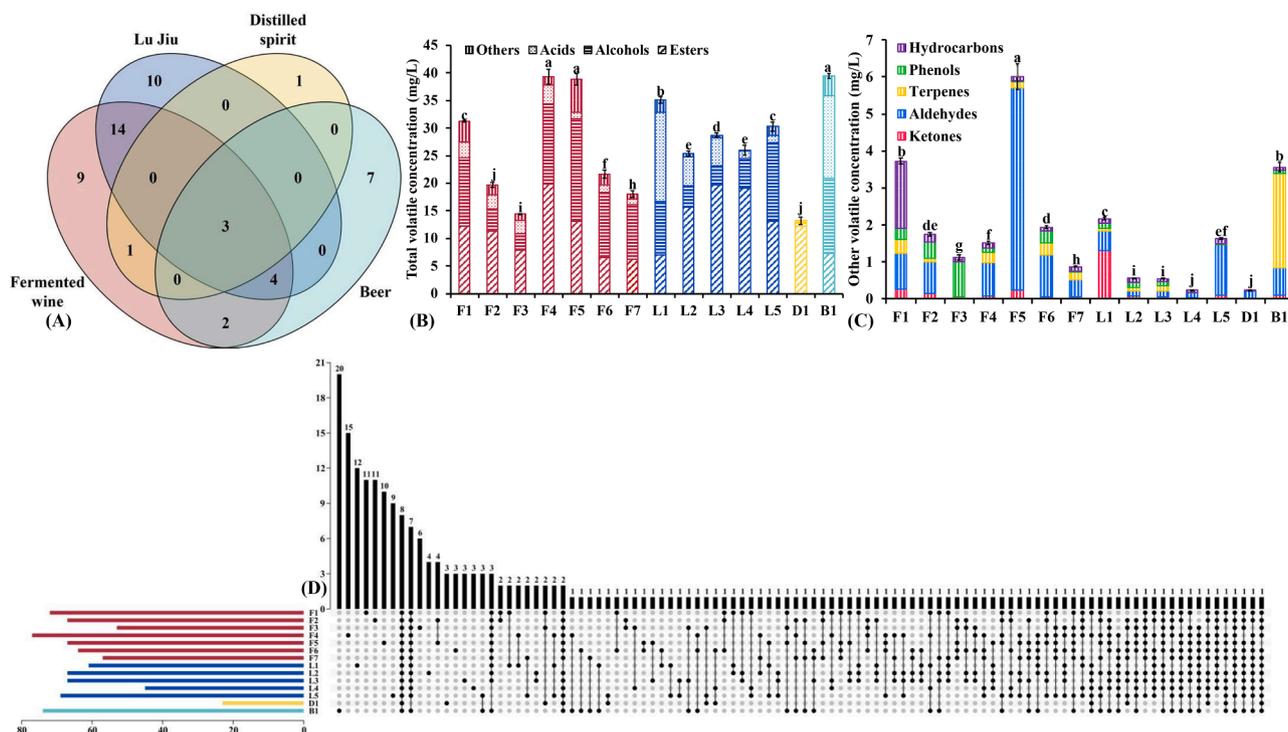
76, and D1 was the least, with only 23. Eight VOCs co-existed in 14 samples (Fig. 3 (C) & Table S4), namely, E1 (ethyl acetate), E10 (ethyl lactate), E14 (ethyl caprylate), E25 (ethyl decanoate), E29 (diethyl succinate), A7 (isoamyl alcohol), A11 (1-hexanol), and C7 (acetic acid).

Overall, the main types of VOCs were esters, alcohols, and acids (Table S4 and Fig. 3 (B)), and some samples also showed higher aldehyde contents. However, the accumulation pattern of VOCs was different among different KW samples. Esters were the most abundant in D1, F2, F3, F4, L2, L3, and L4, accounting for 50.53–92.13 % of the total VOCs content; the alcohol content in F1, F5, F6, F7, and L5 was the highest, accounting for 39.57–55.17 % of the total VOCs content; while the acid content had the highest content in L1 and B1, accounting for

46.14 % and 38.20 % of the total VOCs content, respectively. Taken together, VOCs have a strong dependence on raw wine-making materials and processes, and are also related to environmental factors, such as storage conditions, which is consistent with previous studies (Huang et al., 2021; Li et al., 2022; Ma et al., 2022).

#### Total VOC contents

As shown in Fig. 3 (B), there was variation in the total VOC contents between the different commercially available KW samples. D1 had the least total VOC content (13.21 mg/L) and B1 had the most (39.45 mg/L), the total VOC contents of different KLJ varied between 25.35 and 35.04 mg/L. The total VOC contents among the KFW were vastly different,



**Fig. 3.** Venn diagram representing the distribution of VOCs in 4 types of KW (A) and 14 KW samples (D); total VOCs concentrations (B) and other VOCs concentrations (expect esters, alcohols, and acids) (C) of KW samples (the different small letters indicate a significant difference ( $p < 0.05$ ) among different KW).

among them, F4 and F5 had the highest total VOC contents, 39.28 and 38.81 mg/L, respectively; F3 had the least total VOC content, 14.42 mg/L. This large difference was primarily due to the more complex fermented processes of KFW and the more influencing factors.

#### Vocs analysis

The VOC contents of 14 KW samples are available in Table S4, of which there were 27 main VOCs with concentrations  $>1.00$  mg/L as shown in Fig. 4 (A). There were 13 main VOCs in esters (Fig. 4 (A)). Some esters contained in the fresh kiwifruit were also retained in KW such as ethyl acetate (E1), ethyl butyrate (E2), ethyl hexanoate (E6), ethyl decanoate (E25), ethyl benzoate (E28), dibutyl phthalate (E37) (Lan et al., 2021). While some esters were generated during the process of KW, including ethyl lactate (E10), ethyl caprylate (E14), ethyl sorbate (E16), diethyl succinate (E29), ethyl palmitate (E45), and diisobutyl phthalate (E36) and so on. The majority of esters provided fruity, cognac, floral, and sweet flavors for food (Niu, Wang, Xiao, Zhu, Sun, & Wang, 2019). Among the 14 KW, L4, L3, and L4 showed higher esters contents, with 19.85, 19.65, and 19.10 mg/L, respectively ( $p > 0.05$ ), whereas the lowest was F7, with 6.24 mg/L (Fig. 4 (B)). In terms of the proportion of total VOCs, the esters accounted for the highest proportion of 92.13 % in D1, while the lowest proportion of 18.54 % was in B1. Therefore, esters were the most important aroma components of the KDS, of which the concentrations of ethyl acetate (E1) and ethyl hexanoate (E6) were the highest. Both of them were the main esters and key aroma substances in the fresh kiwifruit (Cozzolino et al., 2020; Lan et al., 2021), which could provide fruity for food. These indicated that KDS well retained the aroma of kiwifruit itself. In beer, the loss of esters was caused by the heating treatment in beer production (Fanari et al., 2019). In KFW and KLJ, ethyl acetate (E1) was the highest ester in F3, F4, F6, L2, and L3. Diethyl succinate (E29) was the most abundant ester in F5 and F7, and it was present in all KW samples, which provided KW with aroma and a fruity flavor (Niu et al., 2019). Diethyl succinate (E29) was mainly produced during the fermented process (Fan et al., 2020). A similar phenomenon was also reported by Liu et al. (2020).

A total of 40 alcohols were identified in the 14 KW samples

(Table S4), which accounted for 5.13–55.17 % of the total VOC contents. During the fermentation of KW, the yeast produced higher alcohols through catabolism and anabolism (amino acid metabolism), and a small amount of higher alcohols were also produced through the reduction of the corresponding aldehydes (Fan et al., 2020). In most KW samples (11 of the 14), isoamyl alcohol (A7) showed the highest content with 0.37–14.82 mg/L and existed in all KW samples (Fig. 4 (A) & Table S4). Isoamyl alcohol was mainly formed by the deamination and decarboxylation of leucine (Lin et al., 2020) and was considered to have a nail polish odor (Fan et al., 2020); therefore, when its concentration was above the odor threshold, it could have caused a negative effect on wine quality (Van Gemert, 2018; Lin et al., 2020). In addition, 2-phenylethanol (A35) was the most abundant alcohol in F3 and B1 and existed in all samples except F5 (Fig. 4 (A) & Table S4). It provided sweet, rose, and honey flavors for KW (Fan et al., 2020) and contributed to improving the wine's quality, and is also an important aroma component of wine (Darıcı & Cabaroglu, 2021), cider (Hou et al., 2022), Chinese rice wine (Chen, Xu, & Qian, 2013), Chinese baijiu (Niu, Zhang, Xiao, & Zhu, 2020), and Qingke Jiu (Fan et al., 2020). Moreover, 1-hexanol (A11), having a floral note, presented more prominently in L1 (Fan et al., 2020). Zhao et al. (2020) found that the contents of A7, A11, and A37 were significantly increased in KFW compared with kiwifruit juice, which indicated that they were formed abundantly during the fermentation.

Seventeen acids were detected in all samples, which accounted for 0.92–46.41 % of the total VOC contents (Table S4). Most of the acids were produced by acid precursors during wine-making (Zhan et al., 2020). Among the 14 KW samples, the content of acids was the highest in L1, mainly benzoic acid (C16) and sorbic acid (C11) (Fig. 4 (A)). In Wei et al.'s (2019) study on apple, pear, grape, and kiwifruit wines, benzoic acid was only found in KW, which might be the characteristic flavor substance in kiwifruit.

However, acids showed the highest proportion of total VOC content in B1, with 46.14 %. This showed that acids contributed extremely to the aroma characteristics of KB. The main acids in B1 were octanoic acid (C10) and sorbic acid (C11) (Fig. 4 (A)). However, due to the fact of their

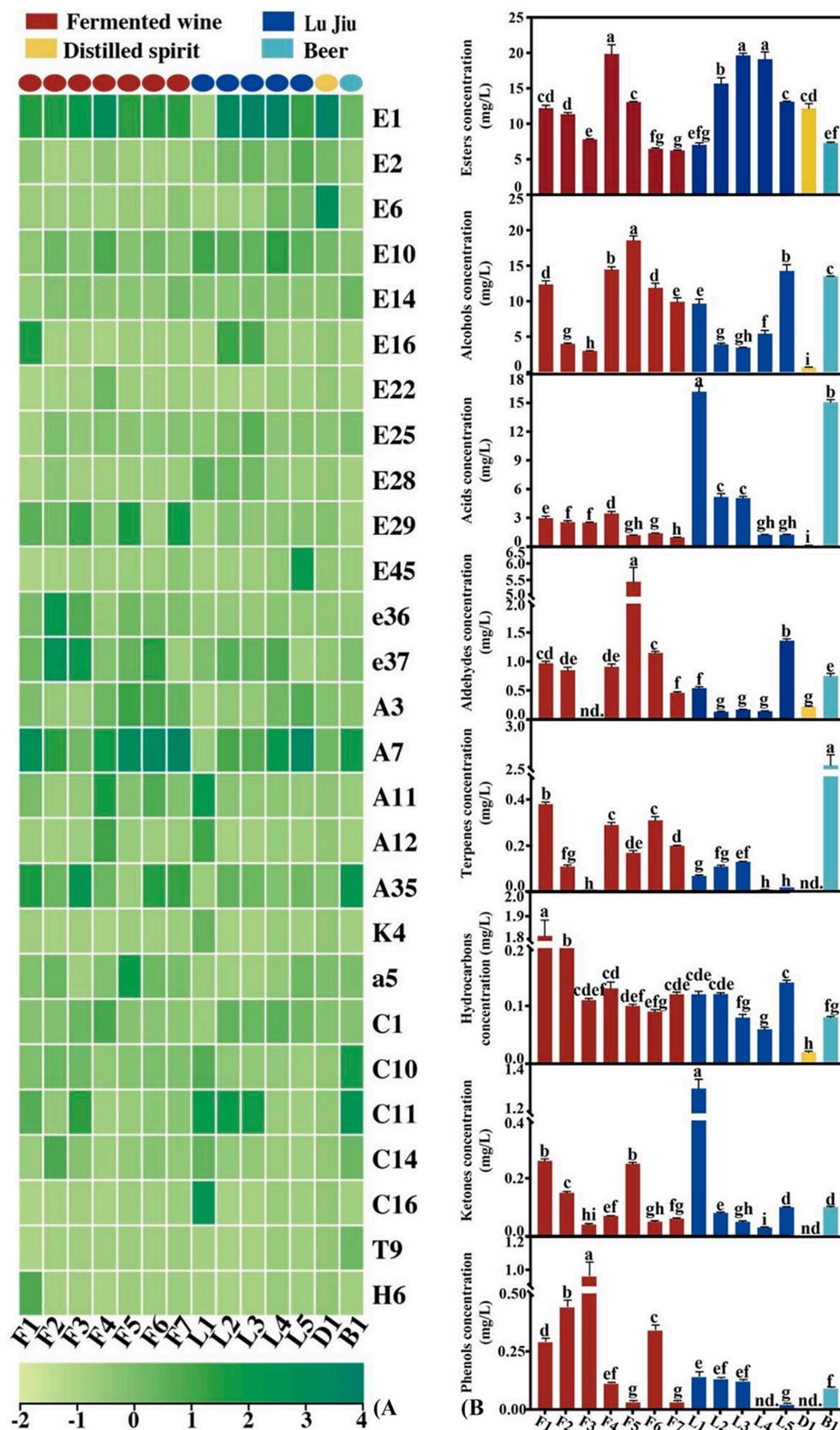


Fig. 4. (A) Heatmap of the contents of the main VOCs in KW (the shifting shades of green from light to dark represent the value changing from low to high) and (B) different classes of VOCs concentrations of KW (the different small letters indicate a significant difference ( $p < 0.05$ ) among different KW, nd. indicates compound not detected). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

high odor threshold values (Van Gemert, 2018), they often manifested the modified odor substances in wine and were used to improve the odor of KW (Fan et al., 2020).

Ketones, aldehydes, terpenoids, volatile phenols and hydrocarbons were also detected in all samples, except esters, alcohols and acids. Among them, the ketones and aldehydes mainly provided a grassy flavor (Acree, & Arn, 2004). While the content of terpenoids was the highest in B1, specifically linalool (T9), which could offer a fruity and lemon flavor for KB. Studies found that a significant amount of terpenoids in KB were mainly derived from the hops, which helped to improve the beer quality (Holt et al., 2019).

#### Oavs analysis

The VOC content alone did not represent its odor contributions to food, so OAV was introduced. The contribution of VOCs in food was further clarified by calculating the ratio of the concentration of VOCs in the sample to its odor threshold. Compounds with  $OAV > 1$  were identified as key odor-active compounds, which directly contributed to the odor of samples (Grosch, 1994). The OAV calculations were carried out on the VOCs identified in the study. A total of 50 key odor-active compounds were found in KW, including 27 esters, 7 alcohols, 1 ketone, 2 aldehydes, 1 acid, 7 terpenoids, 2 volatile phenols, and 3 hydrocarbons (Table S5).

Among them, ethyl caprylate (E14) exhibited a higher OAV in all samples, ranging from 30 to 565.17 (Fig. 5 (A) & Table S5). Therefore,

E14 was considered a key odor-active compound in all KW samples, which could provide KW with a fruity and sweet aroma similar to an apricot, banana, and pear, and brandy flavor. Damascenone (T18), with honey, apple, and rose flavors, had the highest OAVs in F7, L2, L3, and B1. It was also considered the key odor-active compound in wine (Ge et al., 2021), Qingke Jiu (Fan et al., 2020), roasted chicory “coffee” brews (Wu & Cadwallader, 2019), and various fruit wines (Niimi et al. 2020). The formation of damascenone was mainly due to the degradation of carotenoids (Wu & Cadwallader, 2019); thus, the carotenoids content in raw kiwifruit materials was largely determined by the content of damascenone in KW. Similar to damascenone, the precursors of  $\beta$ -Ionone (T20) were also carotenoids, which were prominent in F1. Its OAV was as high as 34,285.71, providing F1 with a floral and woody flavor. Additionally, the OAV of ethyl hexanoate (E6) was the highest in L4, L5, and D1, and as a key odor-active compound of fresh kiwifruit, ethyl hexanoate was well preserved and displayed in the KLJ and KDS with a high degree of alcohol. Thus, the preparation process of KW with a high alcohol degree might be more conducive to the embodiment of kiwifruit’s original aroma. Ethyl undecanoate (E34) made the highest contribution to the odor of F4, mainly manifested as a coconut and fat flavor, while ethyl 2-methylvalerate (E5), which exhibited melon, pineapple, and apple peel flavor, made the highest contribution to F7.

Three key odor-active compounds co-existed in four types of KW (Fig. 3 (A) & Table S4), namely, ethyl butyrate (E2), ethyl hexanoate (E6), and ethyl caprylate (E14). There were 14 key odor-active compounds co-existing in KFW and KLJ, which indicated that the aroma

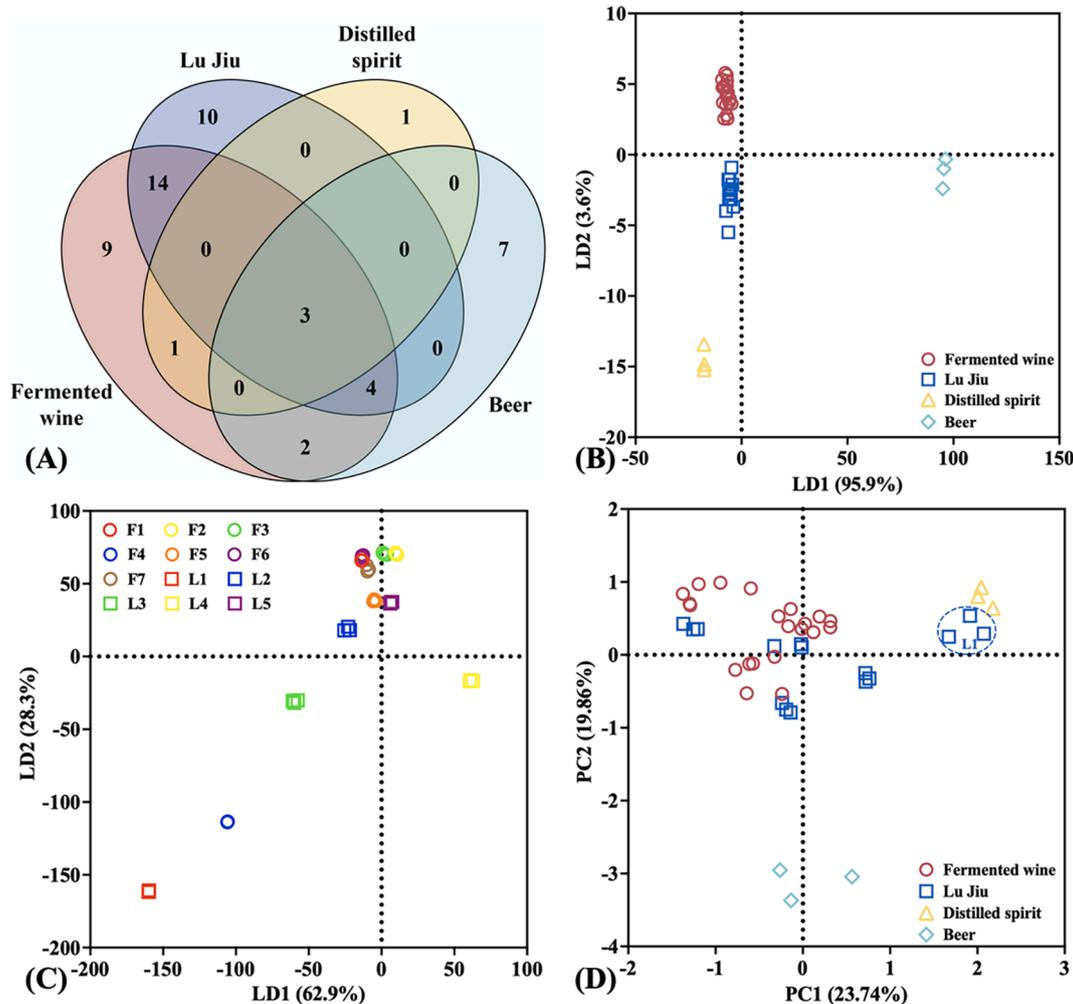


Fig. 5. Venn diagram representing the distribution of key odor-active compounds in 4 types of KW (A); LDA (B) and PCA (D) score plots for 4 types of KW based on key odor-active compounds; and LDA for KFW and KLJ based on key odor-active compounds (C).

characteristics of KFW and KLJ were closer. Among the 14 KW samples, D1 had the least key odor-active compounds, only five kinds, and all of them were esters. L1 had the largest number of key odor-active compounds, with 18, followed by F1, F4, and B1, all of which were 16. It is worth noting that more terpenoids (six kinds) in KB were evaluated as key odor-active compounds, which was different from KFW, KLJ, and KDS, and these terpenoids provided KB with more spiciness. Most of the other categories of key odor-active compounds enriched the fruity and floral flavor of the KW. Taken together, esters and terpenoids, as the main contributors to the aroma in KW, mainly provided a sweet, fruity, floral, woody, and grassy flavor.

To further understand the differences in the aroma characteristics of the different types of KW, an LDA of key odor-active substances was performed. In a data matrix of  $50 \times 14$ , the generated data explained 99.5 % of the total contribution (Fig. 5 (B)). The results demonstrated that the different types of KW were clearly distinguished, and the aroma characteristic of KFW was relatively close to that of KLJ and KDS, while that of KB was quite different from the above three, which was consistent with those obtained from the E-nose analysis. Meanwhile, the PCA of the key odor-active compounds also confirmed this and found that the aroma characteristics of L1 and KDS were the closest. The LDA of KFW and KLJ was based on key odor-active compounds (Fig. 5 (C)). The results showed that KFW, other than F4, were all similar to KLJ, and closer to L5 and L2, which were different from the results of the E-nose analysis, but it was consistent in that F5 and F7 were more similar to the aroma characteristics of KLJ. The more prominent aroma characteristics of F4 might be contributed to by its unique key aroma compound ethyl undecanoate (E34), and compared with other KFW, F4 contained various alcohols, which was consistent with L1; therefore, the aroma characteristics of F4 were closer to L1 than other KFW.

## Conclusions

The research showed that the color and aroma characteristics of different types of KW were significantly different, and KFW and KLJ were more similar and different from KDS and KB. Specifically, the color trends of the different types of KWs were similar. The E-nose and GC-MS results showed that the odor characteristics of KFW and KLJ were closer and significantly differed from KDS and KB. Ethyl butyrate (E2), ethyl hexanoate (E6), and ethyl caprylate (E14) were identified as the common key odor-active compounds in all types of KW. The study could provide a theoretical basis and market information for the quality control, research, production and development of KW.

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## CRedit authorship contribution statement

**Tian Lan:** Methodology, Investigation, Data curation, Visualization, Writing – original draft. **Jiaqi Wang:** Methodology, Investigation. **Quyu Yuan:** Methodology, Investigation, Data curation. **Yushan Lei:** Resources. **Wen Peng:** Methodology, Investigation, Data curation. **Min Zhang:** Methodology, Investigation, Data curation. **Xinyi Li:** Methodology, Investigation, Data curation. **Xiangyu Sun:** Conceptualization, Writing – review & editing. **Tingting Ma:** Conceptualization, Methodology, Writing – review & editing.

## 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.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.fochx.2022.100427>.

## References

- Acree, T., & Arn, H. (2004). *Flavornet and human odor space*. Retrieved from <http://www.flavornet.org/flavornet.html>. Accessed March 31, 2022.
- Borras, E., Ferre, J., Boque, R., Mestres, M., Acena, L., & Busto, O. (2015). Data fusion methodologies for food and beverage authentication and quality assessment - A review. *Analytica Chimica Acta*, 891, 1–14. <https://doi.org/10.1016/j.aca.2015.04.042>
- Chen, S., Xu, Y., & Qian, M. C. (2013). Aroma characterization of Chinese rice wine by gas chromatography–olfactometry, chemical quantitative analysis, and aroma reconstitution. *Journal of Agriculture and Food Chemistry*, 61, 11295–11302. <https://doi.org/10.1021/jf4030536>
- Chen, A., Fu, Y., Jiang, C., Zhao, J., Liu, X., Liu, L., ... Zhang, Z. (2019). Effect of mixed fermentation (*Jiuqu* and *Saccharomyces cerevisiae* EC1118) on the quality improvement of kiwi wine. *CyTA - Journal of Food*, 17(1), 967–975. <https://doi.org/10.1080/19476337.2019.1682678>
- Cozzolino, R., Giulio, B. D., Petriccione, M., Martignetti, A., Malorni, L., Zampella, L., ... Pellicano, M. P. (2020). Comparative analysis of volatile metabolites, quality and sensory attributes of *Actinidia chinensis* fruit. *Food Chemistry*, 316, Article 126340. <https://doi.org/10.1016/j.foodchem.2020.126340>
- Darici, M., & Cabaroglu, T. (2021). Chemical and sensory characterization of Kalecik Karasi wines produced from two different regions in Turkey using chemometrics. *Journal of Food Processing and Preservation*, 00, Article e16278. <https://doi.org/10.1111/jfpp.16278>
- Fan, S., Tang, K., Xu, Y., & Chen, S. (2020). Characterization of the potent odorants in Tibetan *Qingke Jiu* by sensory analysis, aroma extract dilution analysis, quantitative analysis and odor activity values. *Food Research International*, 137, Article 109349. <https://doi.org/10.1016/j.foodres.2020.109349>
- FAO-Food and Agriculture Organization of the United Nations. FAOSTAT-Crops and livestock products. (2020). (Taken from: <https://www.fao.org/faostat/en/> Accessed: 03.27.2022).
- Fanari, M., Forteschi, M., Sanna, M., Piu, P. P., Porcu, M. C., D'hallewin, G., Zinellu, M., & Pretti, L. (2019). Pilot plant production of craft fruit beer using Ohmic-treated fruit puree. *Journal of Food Processing and Preservation*, 44, Article e14339.
- Grosch, W. (1994). Determination of potent odorants in foods by aroma extract dilution analysis (AEDA) and calculation of odour activity values (OAVs). *Flavour and Fragrance Journal*, 9, 147–158. <https://doi.org/10.1002/ffj.2730090403>
- Ge, Q., Guo, C., Zhang, J., Yan, Y., Zhao, D., Li, C., ... Yuan, Y. (2021). Effects of simultaneous co-fermentation of five indigenous non-*Saccharomyces* strains with *S. cerevisiae* on Vidal icewine aroma quality. *Foods*, 10, 1452. <https://doi.org/10.3390/foods10071452>
- Holt, S., Mijs, M. H., de Carvalho, B. T., Foulque-Moreno, M. R., & Thevelein, J. M. (2019). The molecular biology of fruity and floral aromas in beer and other alcoholic beverages. *FEMS Microbiology Reviews*, 43, 193–222. <https://doi.org/10.1093/femsre/fuy041>
- Huang, J., Li, H., Wang, Y., Wang, X., Ren, Y., Yue, T., & Gao, Z. (2021). Evaluation of the quality of fermented kiwi wines made from different kiwifruit cultivars. *Food Bioscience*, 42, Article 101051. <https://doi.org/10.1016/j.fbio.2021.101051>
- Hou, C., Huang, P., Lai, Y., Lin, S., Liou, B., Lin, H., ... Cheng, K. (2022). Screening and identification of yeasts from fruits and their coculture for cider production. *Fermentation*, 8, 1. <https://doi.org/10.3390/fermentation8010001>
- Huang, J., Wang, Y., Ren, Y., Wang, X., Li, X., Liu, Z., ... Gao, Z. (2022). Effect of inoculation method on the quality and nutritional characteristics of low-alcohol kiwi wine. *LWT - Food Science and Technology*, 156, 13049. <https://doi.org/10.1016/j.lwt.2021.113049>
- Jiang, S., Ni, C., Chen, G., & Liu, Y. (2021). A novel data fusion strategy based on multiple intelligent sensory technologies and its application in the quality evaluation of Jinhua dry-cured hams. *Sensors & Actuators: B. Chemical*, 344, Article 130324. <https://doi.org/10.1016/j.snb.2021.130324>
- López-Vázquez, C., García-Llobodanin, L., Peñáz-Correa, J. R., López, F., Blanco, P., & Orriols, I. (2012). Aromatic characterization of pot distilled kiwi spirits. *Journal of Agricultural and Food Chemistry*, 60, 2242–2247. <https://doi.org/10.1021/jf204310v>
- Liu, D., Xu, J., Cao, Y., Qi, Y., Yang, K., Wei, X., ... Fan, M. (2019). Effect of glutathione-enriched inactive dry yeast on color, phenolic compounds, and antioxidant activity of kiwi wine. *Journal of Food Processing and Preservation*, 44, Article e14347. <https://doi.org/10.1111/jfpp.14347>

- Liu, D., Qi, Y., Zhao, N., Cao, Y., Xu, J., & Fan, M. (2020). Multivariate analysis reveals effect of glutathione-enriched inactive dry yeast on amino acids and volatile components of kiwi wine. *Food Chemistry*, 329, Article 127086. <https://doi.org/10.1016/j.foodchem.2020.127086>
- Liu, J., Liu, M., Ye, P., Lin, F., Huang, J., Wang, H., ... Cai, L. (2020). Characterization of major properties and aroma profile of kiwi wine co-cultured by *Saccharomyces* yeast (*S. cerevisiae*, *S. bayanus*, *S. uvarum*) and *T. delbrueckii*. *European Food Research and Technology*, 246, 807–820. <https://doi.org/10.1007/s00217-020-03439-6>
- Lin, X., Hu, X., Wang, Q., & Li, C. (2020). Improved flavor profiles of red pitaya (*Hylocereus lemairei*) wine by controlling the inoculations of *Saccharomyces bayanus* and *Metschnikowia* *agaves* and the fermentation temperature. *Journal of Food Science and Technology*, 57, 12. <https://doi.org/10.1007/s13197-020-04484-5>
- Lan, T., Gao, C., Yuan, Q., Wang, J., Zhang, H., Sun, X., ... Ma, T. (2021). Analysis of the aroma chemical composition of commonly planted kiwifruit cultivars in China. *Foods*, 10, 1645. <https://doi.org/10.3390/foods10071645>
- Li, S., Bi, P., Sun, N., Gao, Z., Chen, X., & Guo, J. (2022). Characterization of different non-*Saccharomyces* yeasts via mono-fermentation to produce polyphenol-enriched and fragrant kiwi wine. *Food Microbiology*, 103, Article 103867. <https://doi.org/10.1016/j.fm.2021.103867>
- Ma, T., Wang, J., Wang, L., Yang, Y., Yang, W., Wang, H., ... Sun, X. (2020). Ultrasound-combined sterilization technology: An effective sterilization technique ensuring the microbial safety of grape juice and significantly improving its quality. *Foods*, 9, 1512. <https://doi.org/10.3390/foods9101512>
- Merlino, V. M., Fracassetti, D., Canito, A. D., Pizzi, S., Borra, D., Giuggioli, N. R., & Vigentini, I. (2021). Is the consumer ready for innovative fruit wines? Perception and acceptability of young consumers. *Foods*, 10, 1545. <https://doi.org/10.3390/foods10071545>
- Ma, T., Wang, J., Wang, H., Zhao, Q., Zhang, F., Ge, Q., ... Sun, X. (2022). Wine aging and artificial simulated wine aging: Technologies, applications, challenges, and perspectives. *Food Research International*, 153, Article 110953. <https://doi.org/10.1016/j.foodres.2022.110953>
- Niu, Y., Wang, P., Xiao, Z., Zhu, J., Sun, X., & Wang, R. (2019). Evaluation of the perceptual interaction among ester aroma compounds in cherry wines by GC-MS, GC-O, odor threshold and sensory analysis: An insight at the molecular level. *Food Chemistry*, 275, 143–153. <https://doi.org/10.1016/j.foodchem.2018.09.102>
- Niu, Y., Zhang, J., Xiao, Z., & Zhu, J. (2020). Evaluation of the perceptual interactions between higher alcohols and off-odor acids in Laimao Baijiu by  $\sigma$ - $\tau$  plot and partition coefficient. *Journal of Agriculture and Food Chemistry*, 68, 14938–14949. <https://doi.org/10.1021/acs.jafc.0c05676>
- Niimi, J., Guixer, B., & Splivallo, R. (2020). Odour active compounds determined in the headspace of yellow and black plum wines (*Prunus domestica* L.). *LWT - Food Science and Technology*, 130, Article 109702. <https://doi.org/10.1016/j.lwt.2020.109702>
- Sun, N., Gao, Z., Li, S., Chen, X., & Guo, J. (2021). Assessment of chemical constitution and aroma properties of kiwi wines obtained from pure and mixed fermentation with *Wickerhamomyces anomalus* and *Saccharomyces cerevisiae*. *Journal of the Science of Food and Agriculture*, 102(1), 175–184. <https://doi.org/10.1002/jsfa.11344>
- The Good Scents Company Information System. (2021). *TGSC Information System*. Retrieved from <http://www.thegoodscentscompany.com/index.html>. Accessed March 31, 2022.
- Van Gemert, L. J. (2018). *Compilations of Odor Threshold Values in Air, Water and Other media (Second Enlarged and Revised Edition)*.
- Wei, X., Ma, X., Cao, J., Sun, X., & Fan, Y. (2018). Aroma characteristics and volatile compounds of distilled Crystal grape spirits of different alcohol concentrations: Wine sprits in the Shangri-La region of China. *Food Science and Technology*, 38, 50–58. <https://doi.org/10.1590/fst.12117>
- Wei, J., Zhang, Y., Yuan, Y., Dai, L., & Yue, T. (2019). Characteristic fruit wine production via reciprocal selection of juice and non-*Saccharomyces* species. *Food Microbiology*, 79, 66–74. <https://doi.org/10.1016/j.fm.2018.11.008>
- Wu, T., & Cadwallader, K. R. (2019). Identification of characterizing aroma components of roasted chicory “coffee” brews. *Journal of Agriculture and Food Chemistry*, 67(50), 13848–13859. <https://doi.org/10.1021/acs.jafc.9b00776>
- Xu, R., Zhou, X., & Wang, S. (2020). Comparative analyses of three pretreatments on color of kiwifruits during hot air drying. *International Journal of Agricultural and Biological Engineering*, 13(2), 228–234. <https://doi.org/10.25165/j.ijabe.20201302.5489>
- Zeng, Q., Song, H., Xu, X., Mao, W., Xie, H., Liang, J., ... Zhan, Y. (2019). Health effects of kiwi wine on rats: An untargeted metabolic fingerprint study based on GC-MS/TOF. *RSC Advances*, 9, 13797. <https://doi.org/10.1039/c9ra02138h>
- Zhan, N., Zhang, Y., Liu, D., Zhang, J., Qi, Y., Xu, J., ... Fan, M. (2020). Free and bound volatile compounds in ‘Hayward’ and ‘Hort16A’ kiwifruit and their wines. *European Food Research and Technology*, 246, 875–890. <https://doi.org/10.1007/s00217-020-03452-9>
- Zhu, Y., Zhang, M., Mujumdar, A. S., & Liu, Y. (2022). Application advantages of new non-thermal technology in juice browning control: A comprehensive review. *Food Reviews International*. <https://doi.org/10.1080/87559129.2021.2021419>