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COMPARATIVE ANALYSIS OF VOLATILE AROMA COMPONENTS IN DIFFERENT SWEET POTATO WINE

Lishi Xiao[1], Wenlan Mo[1], Yanfang Ye[1], Yiyang Cai[1], Simei Huang[1], Yongfeng Lin[2] and Zhiwei Huang[1*]

Fujian Agriculture and Forestry University, College of Food Science , Fuzhou 350002, China.

Keywords: Sweet potato wine, Volatile components, Aroma components, Principal component analysis, Sensory evaluation

Abstract

The methanol content and volatile aroma components were determined, and sensory evaluation and analysis were conducted. Results showed that the methanol contents of all the six sweet potato wine samples met the limits of the national standard, and a total of 258 volatile substances were detected. Among them, alcohols and phenols have the highest contents in the sample BBC-1 brewed in the family workshops, esters have the highest contents in the sample BBY-2 brewed in the distillery, acids and ketones have the highest contents in BBC-4 brewed in the family workshops, and aldehydes have the highest contents in BBY-1 brewed in the distillery. The sensory evaluation results showed that BBC-2 has the strongest and most elegant aroma, perfect typicality, and unique taste. The sweet potato wine samples BBC-2 and BBY-2 have better quality, and are suitable for promotion as the characteristic products of local sweet potato wine. These results can provide scientific basis for the improving the brewing process and quality of sweet potato wine industry in Xiapu County, Fujian Province.

Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.), also known as yam, is one of the main food crops in China (Wu and Bi 2015). Sweet potatoes are rich in nutrients and contain functional components such as starch, dietary fiber, soluble sugars, and dehydroepiandrosterone, which have high nutritional value and health benefits (Huang *et al*. 2006, Hao *et al.* 2011). The famous ancient medical book "Compendium of Materia Medica" also pointed out that sweet potatoes have a sweet and mild nature, and have the effects of tonifying the spleen and stomach, nourishing the heart and mind, benefiting strength, clearing heat and detoxifying. Therefore, sweet potatoes and their related products, such as sweet potato jerky (Feng *et al*. 2023), sweet potato bread (Suo *et al*. 2022), sweet potato biscuits (Kolawole *et al*. 2020), are deeply loved by consumers.

Sweet potato was introduced into Fujian, China in the Ming Dynasty. The introduction of sweet potato greatly promoted the development of the Baijiu industry in Fujian and even in China. Sweet potato wine refers to the Baijiu brewed from sweet potato. It tastes mellow and sweet, full mouthfeel and suitable for all ages (Zhang *et al*. 2019). The aroma of wine directly affects its sensory quality, which is an important indicator that directly reflects its quality (Xu *et al.* 2016). Han *et al.* (2015) fermented purple sweet potatoes to produce purple sweet potato wine with a color, aroma, and flavor similar to red wine, and rich in nutrients. Chen *et al.* (2017) brewed a health wine with a mixed aroma of sweet potato and wheat, and a unique flavor, using sweet potato slurry as the raw material.

Sweet potato wine was brewed since the late Song Dynasty and early Yuan Dynasty in Beibi Township, Xiapu County, Ningde City, Fujian Province, China, with a history of over 550 years.

*Author for correspondence: <hzwfau@163.com>. [1]Fujian Provincial Key Laboratory of Quality Science and Processing Technology in Special Starch, Fujian Agriculture and Forestry University, Fuzhou 350002, China. [2]Xiapu County Baibiyan Ecological Agriculture Professional Cooperative, Ningde 355116, China.

Sweet potato wine from Beibi Township was selected as a representative project of the third batch of intangible cultural heritage in Ningde City in 2010. Standing at the forefront of rural revitalization, the corresponding author, as a science and technology commissioner in Fujian Province, went deep into Beibi Township, Xiapu County to conduct research on the current development status of the sweet potato wine industry. It was found that there is only one sweet potato wine factory in Beibi Township, namely the Xiapu County Baibiyan Ecological Agriculture Professional Cooperative (abbreviated as "distillery"), and the rest were operated in a family workshop style. In order to promote the further development of the local sweet potato roasting industry, this article takes sweet potato wine brewed by different family workshops and distillery in Beibi Township as the research object, detects its methanol content, and uses gas chromatography-tandem mass spectrometry (GC-MS) technology to analyze the aroma components in different sweet potato roasting samples. Furthermore, by comparing the differences in the main aroma component composition and relative content of different wine samples, a scientific basis is provided for improving the brewing process of sweet potato wine in Beibi Township and improving the product quality of sweet potato wine.

Materials and Methods

The sweet potato wine samples were BBY-1, BBY-2, BBC-1, BBC-2, BBC-3 and BBC-4, BBY-1 and BBY-2 were from Baibiyan, and the remaining four samples were from different family workshops in Beibi Township, Xiapu County, Fujian Province.

The methanol contents of sweet potato wine samples were detected using GC-2010Pro Gas chromatograph (Shimadzu Company, Japan), according to the method of "National Food Safety Standard for the Determination of Methanol in Food and Reference Standard for the Determination of Volatile Matter" (GB 5009.266-2016).

The aroma components of sweet potato wine samples were detected using GCMS- QP2020 NX Gas Chromatography-mass Spectrometer (Shimadzu Company, Japan). By taking 2 mL of sweet potato wine sample into a 20 ml headspace bottlequickly sealed. Aging the SPME extracting fiber head at 250°C in the GC-MS injection port until there were no impurity peaks. Place the sample bottle on the solid-phase microextraction device; then place the sample bottle in the extraction device and heat it in a 60°C water bath for 10 minutes. Insert the SPME extraction head into the headspace of the sample, push out the fiber head, and extract in a 60°C water bath for 30 minutes. Withdraw the fiber head and remove the extraction head from the sample bottle. Finally, insert the extraction head into the GC-MS injection port for sample analysis.

The conditions for gas chromatography were as follows: HP-5MS chromatographic column (30 m × 0.25 mm, 0.25 μm), carrier gas: helium gas, 1.30 ml/min flow rate. The inlet temperature was 250°C. The temperature of the gas chromatography oven was maintained at 50°C for 2 minutes, rising to 160°C at a rate of 4°C/min, then rising to 280°C at a rate of 20°C/min, and then maintained for 2 min.

The conditions for mass spectrometry were as follows: EI ion source, 70 eV electron energy, 35-550 AMU/s mass range, 280°C GC-MS interface temperature, 200°C ion source temperature.

Referring to "Methods for Analysis of Baijiu" (GB/T 10345-2022), 20 students (10 males and 10 females) from the College of Food Science, Fujian Agriculture and Forestry University were selected to receive unified sensory description training on sweet potato wine samples based on the sensory evaluation table (Table1). Under white light and 20°C conditions in the sensory laboratory, approximately 50 ml of each sample was randomly placed in a standard white wine test glass labeled with 6 numbers and presented in random order to twenty group members. The score from high to low indicates a gradual decrease in the intensity of the sensation, ranging from the characteristics that high-quality sweet potato wine should possess to poor quality. The results were standardized and analyzed using radar charts.

Table 1. Scoring criteria for sensory evaluation of sweet potato wine.

Rating items	Scoring rules	Fraction
Color	Uniform color, glossy	15-20
	The color is relatively uniform and glossy	10-14
	Uneven color, glossy	5-9
	Uneven color, dull	0-4
Aroma	Flavor coordination, with pure and harmonious fruit and wine aromas	15-20
	The flavor is relatively harmonious, with light and elegant fruit and wine aromas	10-14
	Inconsistent flavor, insufficient fruit and wine aromas	5-9
	Flavor may have a peculiar or unpleasant aroma	0-4
Taste	Full bodied, smooth and delicate wine	15-20
	The taste of the wine is appropriate, and it is relatively delicate	10-14
	The wine has a light and harmonious taste	5-9
	The wine has a light body and is not harmonious	0-4
Typicalness	Typical perfection, unique style	11-20
	Not elegant enough, losing the typicality of sweet potato roasting	0-10
Overall acceptability	Easily accepted	15-20
	Better acceptance	10-14
	Generally accepted	5-9
	Cannot accepted	0-4

The data were processed using Excel 2020, and a bar chart was drawed using Origin 2021. Using R software to draw flavor heatmaps and conducting principal component analysis on the aroma compounds of six sweet potato wine samples. The Venn diagrams were drawed using network cloud platforms.

Results and Discussion

The methanol mass concentrations of the four samples (BBC-1, BBC-2, BBC-3, BBC-4) brewed in the family workshop were 0.989, 0.741, 0.781and 0.865 g/l, respectively. The methanol mass concentrations of the two samples (BBY-1, BBY-2) brewed in the distillery were 0.580 and 1.25 g/l, respectively. These test results all comply with the national standard limit for methanol content in Baijiu produced from non grain raw materials ($\leqslant$ 2.0 g/l).

A total of 258 volatile compounds were identified in different sweet potato wine samples, including 75 alcohols, 66 esters, 9 acids, 31 aldehydes, 21 ketones, 14 phenols, and other volatile compounds (Fig. 1). The analysis results revealed that the main components of sweet potato wine brewed in family workshops and distilleries are alcohols and esters, but sweet potato wine brewed by family workshops and distilleries contain different unique aroma components.

Alcohols are the main substances that make up the aroma of fermented wine, mainly secondary products produced by yeast through amino acid or sugar metabolism during alcohol fermentation. (Zhang *et al*. 2019). All the sweet potato wine brewed in family workshops and distillery have strong alcohol production capabilities, with ethanol and isoamyl alcohol being the main flavoring substances of them. Alcoholic substances can give Baijiu an elegant aroma, such as ethanol with a pleasant odor, isoamyl alcohol with apple brandy aroma and spicy taste (Ma *et al.* 2021), and 2-phenylethanol with various flavors such as rose aroma, jasmine aroma, and fruit aroma (Jiang *et al*. 2020). These alcoholic substances play a buffering and balancing role in the wine, making it rich, mellow, sweet, and full.

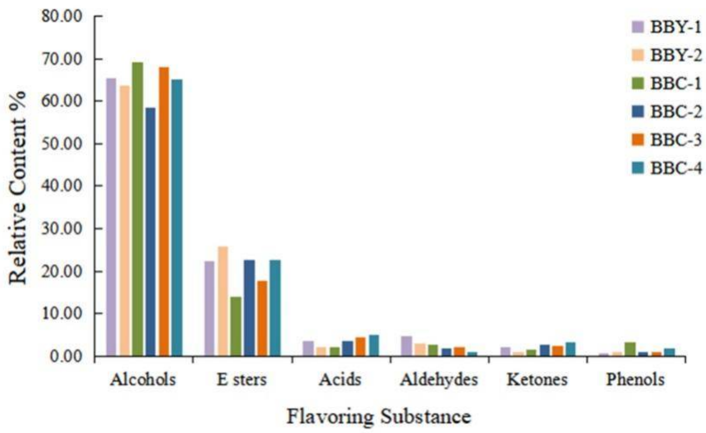


Fig. 1. The aroma component contents of different sweet potato wine samples.

The clustering heatmaps (Fig. 2A) and Venn plots (Fig. 2B) indicate that there are much differential substances in various alcohol compounds between sweet potato wine samples brewed in home workshops and distillery. The sweet potato wine brewed in family workshops contain a small amount of geraniol, which has a citrus aroma and adds a touch of fruity aroma to the wine (Zhao *et al*. 2022). The sweet potato wine brewed in family workshops contain hexanol, which is not found in that of distillery (Ma *et al*. 2021). Hexanol gives sweet potatoes a grassy aroma when burned. The citronellol contents in family workshop sweet potato wines (BBC-1, BBC-2, BBC-3, BBC-4) were 0.69, 2.03, 0.71, and 1.45%, respectively, while those in distillery wines (BBY-1, BBY-2) were 0 and 0.09%. Family workshop wines have higher citronellol contents, which imparts a sweet rose fragrance, making their aroma richer and more layered (Ma *et al*. 2023).

Esters are slowly generated through organic chemical reactions and biochemical reactions by microorganisms during the fermentation process of wine (Chen *et al*. 2017). The esters with relatively high contents in the six sweet potato wine samples are ethyl acetate, ethyl octanoate, ethyl sunflower acid, and ethyl phenethyl acetate, all of which are volatile aroma components coexisting in the six sweet potato wine samples. Most esters have floral and fruity aromas and contribute significantly to the aroma quality of sweet potato roasting. For example, ethyl acetate has a fruity aroma (Tan *et al*. 2017), ethyl octanoate has a pineapple, apple like aroma, and brandy like wine aroma (Ma *et al*. 2021), and ethyl sunflower has a grape fruit aroma and a hint of vinegar flavor (Ma *et al*. 2023).

As showed in the Venn diagram (Fig. 3A) and the heat sink diagram (Fig. 3B), there are much differential substances among various ester compounds in sweet potato wine samples brewed in home workshops and distillery. The sweet potato wine produced in family workshops contain a small amount of ethyl lactate, which have a fruity aroma and will bring a richer aroma level to the sweet potato wine (Huang *et al*. 2023). The relative contents of ethyl palmitate in sweet potato wine samples (BBY-1 and BBY-2) produced by distillery were 0.69 and 4.66%, respectively. The relative contents of ethyl palmitate in sweet potato wine samples (BBC-1, BBC-2, BBC-3, and

BBC-4) produced by home workshops were 0.08, 1.33, 1.90 and 0.45%, respectively. Ethyl palmitate can make sweet potato wine soft and smooth in taste.

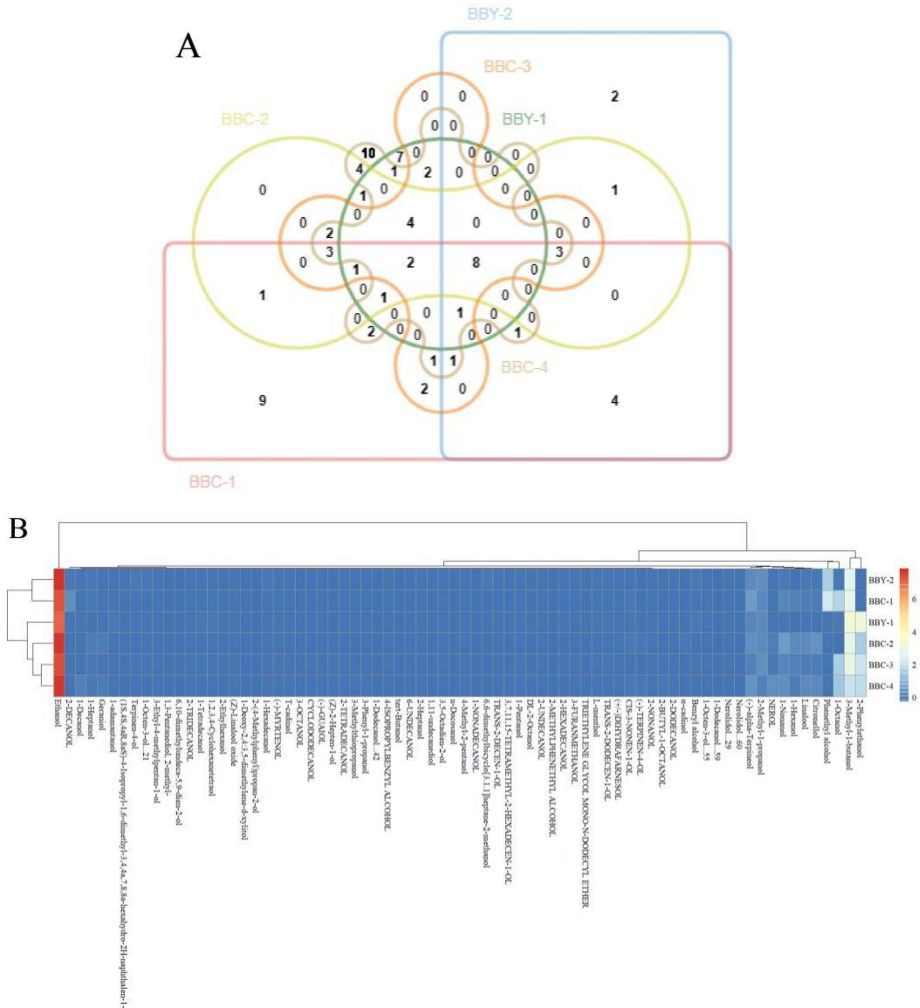


Fig. 2. Wayne analysis and clustering heatmap of alcohol differential substances in different sweet potato wine samples. (A) Wayne analysis; (B) Cluster heat map.

Acids are the secondary metabolites produced by yeast fermentation (Ivanova *et al*. 2013), as well as the final products formed by oxidation of alkanes (Moshonas and Shaw 2000). Acid plays a coordinating and balancing role in the aroma of Baijiu. An appropriate amount of acid can increase the richness of the liquor, eliminate bitterness, reduce impurities, and increase sweetness. It is one of the important flavors of Baijiu. As showed in the Venn diagram (Fig. 4A) and the heat sink diagram (Fig. 4B), octanoic acid and acetic acid are common acidic substances in the six sweet potato wine samples. Acetic acid can bring a certain spicy taste to sweet potato roasting (Jiang *et al*. 2020), increasing the aroma of the wine. Capric acid has a fatty aroma giving the wine a mellow feel (Yang *et al*. 2020),. Stearic acid has a higher content in sweet potato wine brewed in home workshops, and is the main acidic substance in sweet potato wine brewed in home workshops. Caproic acid is a unique volatile component of BBY-1, with a sour odor (Niu *et al.* 2023).

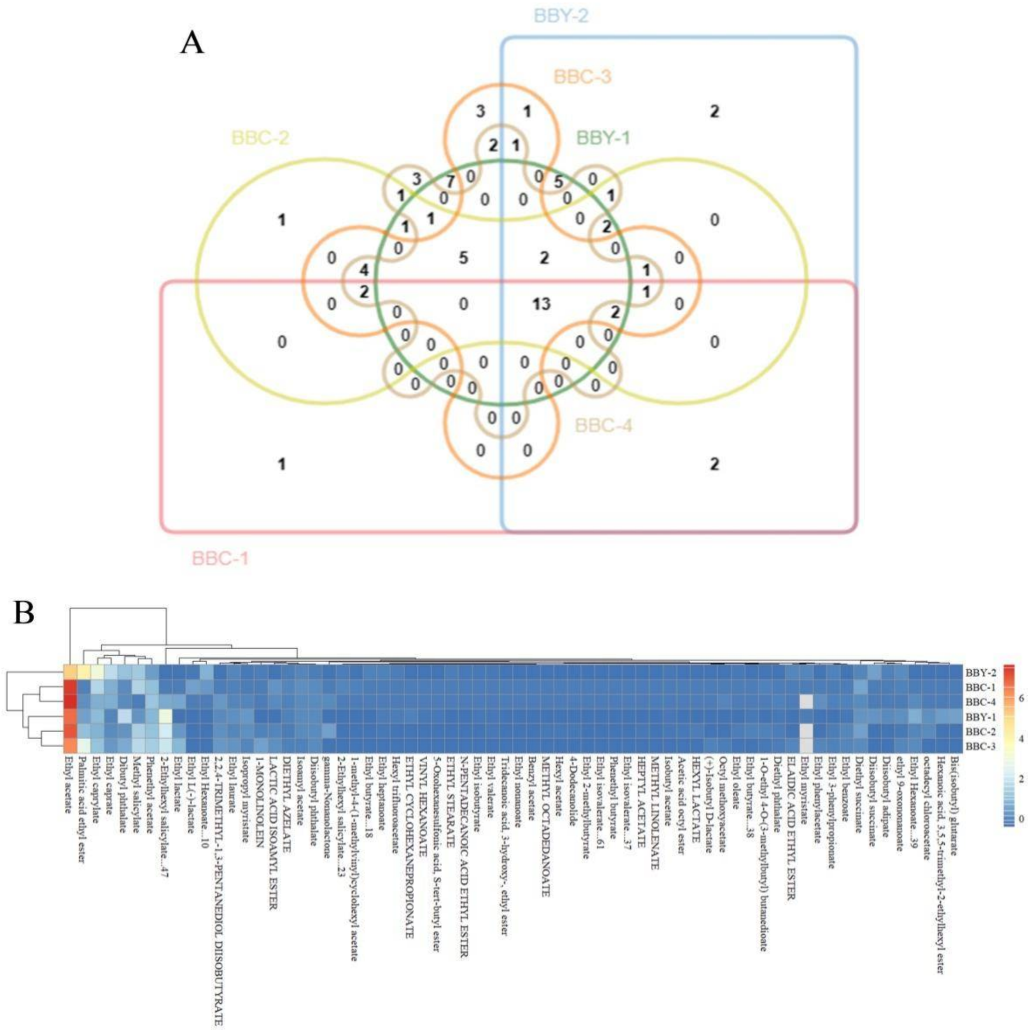


Fig. 3. Wayne analysis and clustering heatmap of ester differential substances in different sweet potato wine samples. (A) Wayne analysis; (B) Cluster heat map.

Carbonyl compounds mainly include aldehydes and ketones, which are mainly generated by the oxidation or dehydrogenation reaction of alcohols (Torrens *et al*. 2008). The main aldehydes in sweet potato wine samples brewed by distillery and home workshops are benzaldehyde and nonanal. The presence of aldehydes in sweet potato wine contributes to its aroma, such as benzaldehyde having almond, cherry, and nut aromas, and nonanal having rose and grass aromas (Si *et al*. 2021, Zhao *et al*. 2022). Ketones are important aroma compounds in sweet potato wine, with the main aromas being 2-nonone and 2-heptanone.

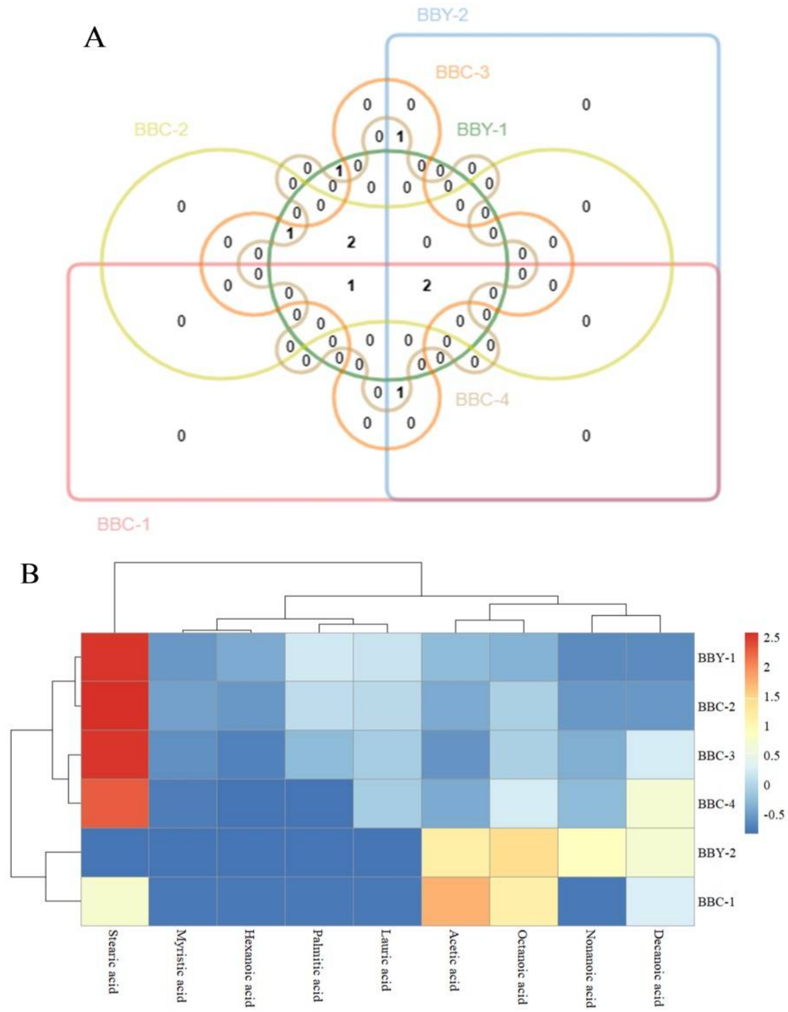
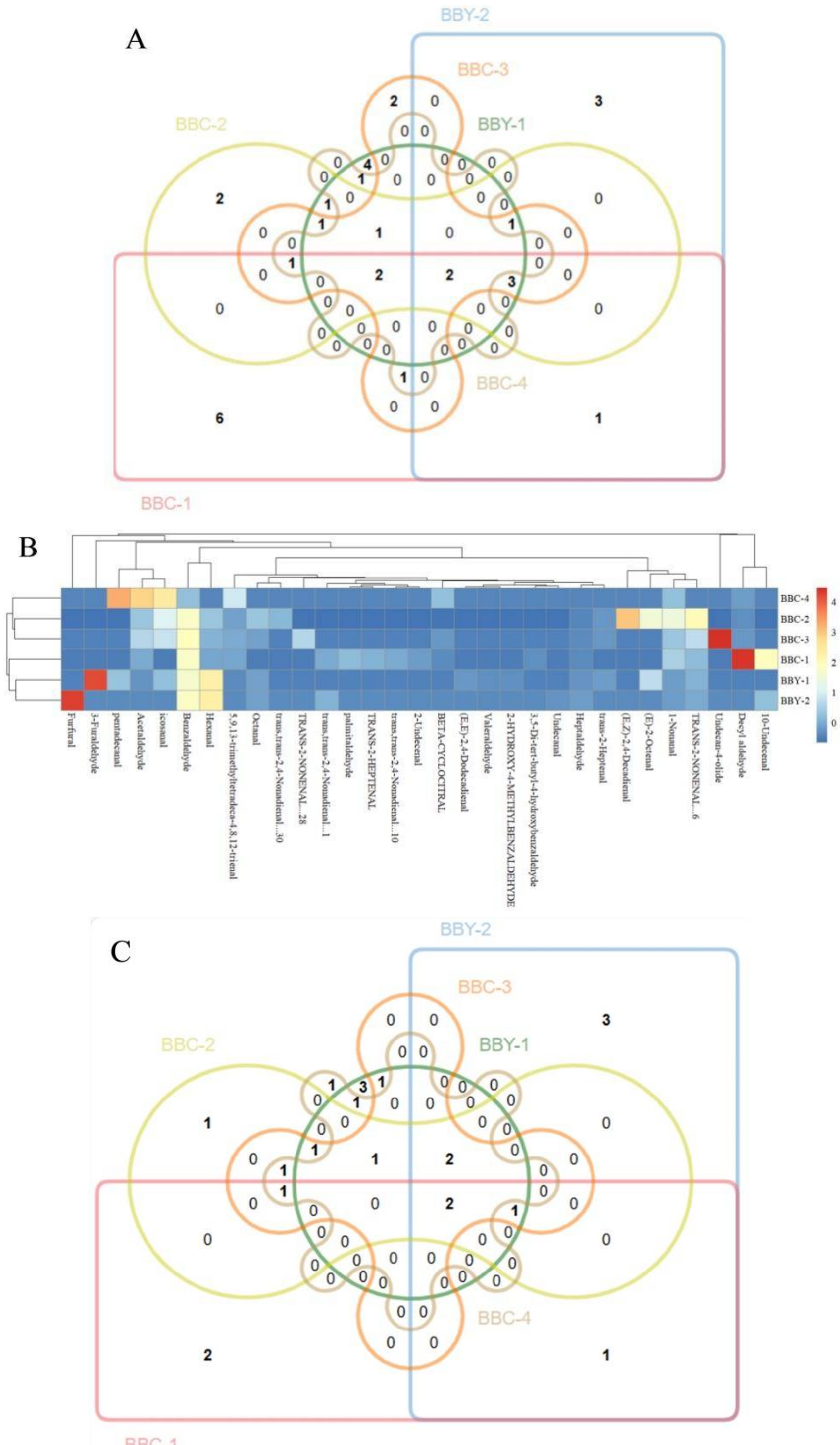


Fig. 4. Wayne analysis and clustering heatmap of acid differential substances in different sweet potato wine samples. (A) Wayne analysis; (B) Cluster heat map.

As showed in the Venn diagram (Fig. 5A and 5C) and the heat sink diagram (Fig. 5B And 5D), various aldehydes and ketone compounds have much differential substances in sweet potato wine samples brewed in home workshops and distillery. Acetaldehyde is prone to volatilization, with a pleasant apple aroma when the concentration is low, and a pungent odor when the concentration is high. The relative contents of acetaldehyde in sweet potato wine samples (BBY-1 and BBY-2) brewed by distillery were 0.90 and 0.67%, respectively. The relative contents of acetaldehyde in sweet potato wine samples (BBC-1, BBC-2, BBC-3, and BBC-4) brewed in home workshops were 0.07, 0.09, 0.08 and 0%, respectively. Therefore, the sweet potato wine brewed by the distillery has a stronger aroma and a more pronounced apple aroma. Damascus ketone has a rose aroma (Guo *et al*. 2023; Zhao *et al*. 2023) and is unique to sweet potato wine brewed in the family workshops.


A
BBY-2
BBC-3
BBC-2
BBY-1
BBC-4
BBC-1
B
BBC-4
BBC-2
BBC-3
BBC-1
BBY-1
BBY-2
Furfural
3-Furaldehyde
pentadecanal
Acetaldehyde
icosanal
Benzaldehyde
Hexanal
5,9,13-trimethyltetradeca-4,8,12-trienal
Octanal
trans,trans-2,4-Nonadienal...30
TRANS-2-NONENAL...28
trans,trans-2,4-Nonadienal...1
palmitaldehyde
TRANS-2-HEPTENAL
trans,trans-2,4-Nonadienal...10
2-Undecenal
BETA-CYCLOCITRAL
(E,E)-2,4-Dodecadienal
Valeraldehyde
2-HYDROXY-4-METHYLBENZALDEHYDE
3,5-Di-tert-butyl-4-hydroxybenzaldehyde
Undecanal
Heptaldehyde
trans-2-Heptenal
(E,Z)-2,4-Decadienal
(E)-2-Octenal
1-Nonanal
TRANS-2-NONENAL...6
Undecan-4-olide
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C
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BBY-1
BBC-4
BBC-1

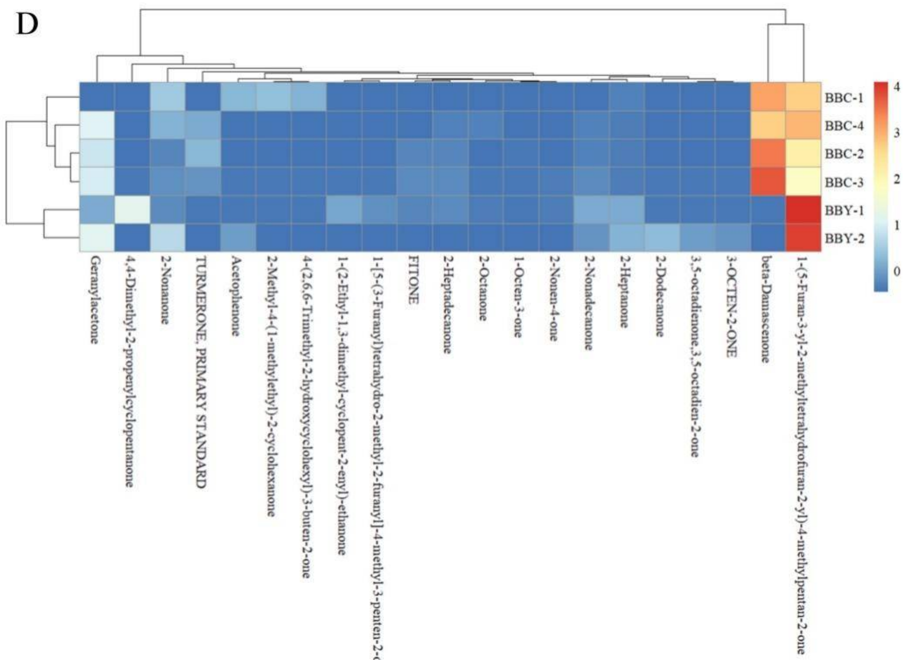

Fig. 5. Wayne analysis and clustering heatmap of aldehyde and ketone differential substances in different sweet potato wine samples. (A) Wayne analysis of aldehyde substances; (B) Cluster heat map of aldehyde substances ; (C) Wayne analysis of ketone substances; (D) Cluster heat map of ketone substances.

There are also small amounts of volatile components such as phenols, olefins, ethers, and alkanes in sweet potato wine samples brewed in family workshops and distillery. Phenolic compounds generally exhibit aromas such as woody aroma, incense aroma, and medicinal aroma (Zhao *et al*. 2022, Lan *et al.* 2023). As shown in the Venn diagram (Fig. 6A) and the heatmap (Fig. 6B), there are many types of phenolic compounds in sweet potato wine (BBC-1, BBC-2, BBC-3, and BBC-4) brewed in home workshops, with relative contents of 3.3, 1.03, 1.07 and 1.81%, respectively. The relative contents of phenolic substances in sweet potato wine samples (BBY-1 and BBY-2) brewed in distillery were 0.65% and 0.86%, respectively. In addition, sweet potato wine brewed in home workshops contain a small amount of laurel, which has a light fatty aroma (Liu *et al.* 2022). Therefore, the flavor of sweet potato wine brewed in home workshops will be more layered than that of sweet potato wine brewed in distillery, with more special aromas.

The aroma components of sweet potato wine samples are complex and diverse. In order to observe the distribution of volatile compounds, this study used principal component analysis (PCA) to analyze the aroma components. As shown in Fig. 7, the contribution rate of the first principal component (PC1) to the overall variance is 53.2%, and that of the second principal component (PC2) is 26.34%, with a cumulative contribution rate of 79.54%. Among them, the difference between the four samples of sweet potato wine samples in the family workshops is relatively small, while the four samples of sweet potato wine samples brewed in the family workshops have differences from the two samples brewed in the distillery.

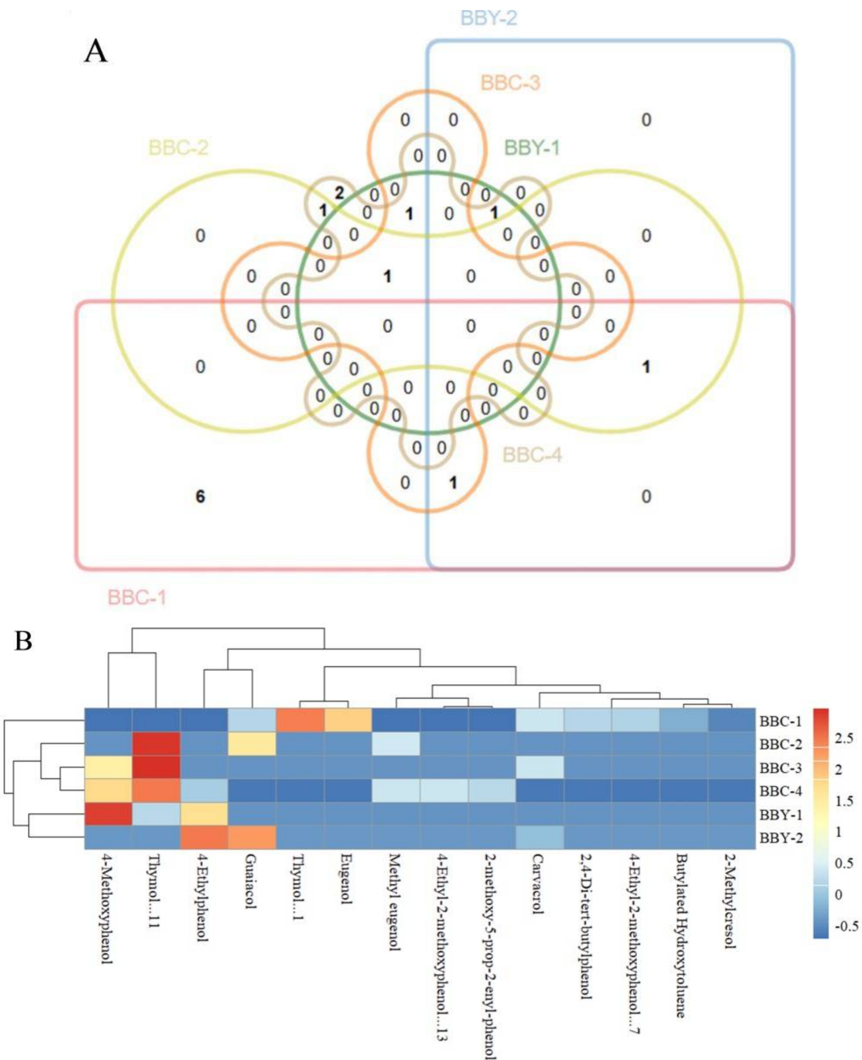

Fig. 6. Wayne analysis and clustering heatmap of phenol differential substances in different sweet potato wine samples. (A) Wayne analysis; (B) Cluster heat map.

Twenty trained wine tasters rated the color, aroma, taste, typicality, and overall acceptability of six types of sweet potato wine samples, with a total score of 100. The score of six sweet potato wine samples is shown in Fig. 8.

As showed in Figure 8, the typicality of the six wine samples is generally typical and perfect, with a unique style. Among them, BBY-1 has a more color score. In terms of aroma, all six wine samples have light and elegant fruit and wine aromas, but BBY-1 has a slightly weaker aroma performance, while BBY-2 and BBC-2 have more prominent aromas among the six wine samples; In terms of taste, BBC-2 has a fuller and smoother taste. In terms of overall acceptability, BBC-2 has a better acceptance, while BBY-1 has a lower acceptance compared to other samples. The comprehensive evaluation results show that the sensory quality of wine samples BBC-2 is the best.

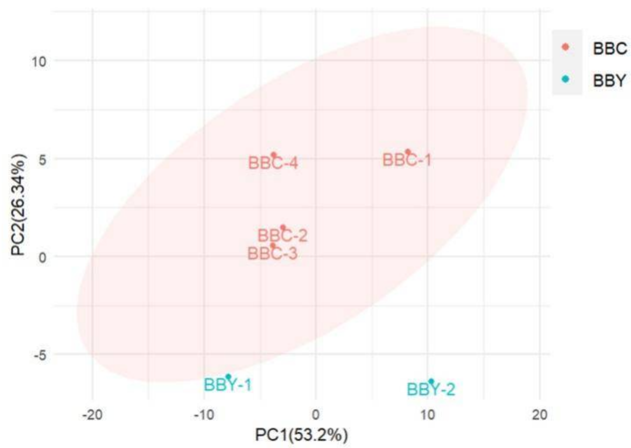

Fig. 7. Analysis of principal components of aroma substances in different sweet potato wine samples.

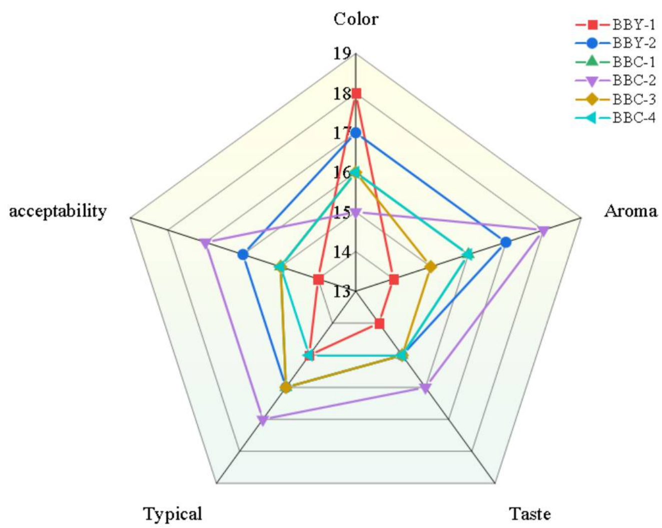

Fig. 8. Sensory radar maps of different sweet potato wine samples.

This study investigated the differences in methanol content, aroma components, and sensory quality of sweet potato wine samples brewed by the distillery and various home workshops in Beibi Township, Xiapu County, Fujian Province, China. The results showed that the methanol contents of the six sweet potato wine samples met the national standard limit regulations. A total of 258 volatile substances were detected in six samples of sweet potato wine, including 75 alcohols, 66 esters, 9 acids, 31 aldehydes, 21 ketones, 14 phenols, and other volatile substances. Among them, alcohols and phenols have the highest contents in BBC-1, esters have the highest content in BBY-2, acids and ketones have the highest contents in BBC-4, and aldehydes have the highest contents in BBY-1. The sensory evaluation results show that BBC-2 has the strongest and most elegant aroma, perfect typicality, and unique taste. The flavor of sweet potato wine brewed in family workshops is more layered than that of distillery. Overall, the sweet potato wine samples BBC-2 and BBY-2 have better quality, and are suitable for promotion as characteristic products of local sweet potato wine. The results of this study can provide scientific basis for improving the brewing process and quality of sweet potato wine industry in Xiapu County, Fujian Province.

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