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Cultivar difference characterization of kiwifruit wines on phenolic profiles, volatiles and antioxidant activity

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ABSTRACT

Antioxidant activity and volatiles of kiwifruit wine with different flesh colors were investigated in this study. Green (Guichang and Xuxiang), red (Donghong and Hongyang), and yellow (Jinyan) kiwifruits were analyzed to determine their alcohol content, phenolic profiles, antioxidant activity, and aroma composition. The results showed that Hongyang and Donghong wines had higher antioxidant activity and content of antioxidant substances. Hongyang wine possessed the most abundance of polyphenolic compounds, chlorogenic acid and catechins were the main polyphenols of kiwi wines. The 101 aromatic components were detected, Xuxiang wine possessed 64 aromatic compounds, Donghong and Hongyang wines had the higher esters compositions, 79.87%, and 78.0% respectively. From PCA (Principal Component Analysis), the volatile substances of kiwi wine with the same flesh color were similar. Five kinds of kiwi wines shared 32 kinds of volatile compounds, these compounds may be the core volatiles in kiwi wine. Therefore, the color of kiwi flesh can impact wine flavor, with Hongyang and Donghong kiwis owning red flesh being the most suitable for producing kiwi wine which would be a new milestone to the wine manufactures.

Introduction

Kiwifruit, scientifically known as *Actinidia chinensis Planch*, is a highly sought-after fruit worldwide, valued for its significant economic and nutritional contributions. It originated in China's Yangtze River Basin over 2,000 years ago, and now it is planted all over the world, including China, New Zealand, Italy, and Iran, *et al.* (He et al., 2019). According to FAOSTAT, the total planted areas of kiwi are up to 247 793 ha and the production of kiwi is 4.32 million metric tons. China has the largest kiwifruit plantation in the world, covering an area of 193,000 ha and producing 0.23 million metric tons. The main kiwifruit-producing provinces in China are Shanxi, Sichuan, Guizhou, and Hunan (Lan et al., 2021; Zhang et al., 2020).

Over 70 species of kiwi have been developed all over the world (López-Sobaler, Aparicio Vizuete, & Ortega Anta, 2016), with some species differing significantly in the color of their skin and flesh. Green-fleshed *Actinidia deliciosa* and yellow-fleshed *Actinidia chinensis* have been the dominant species in the commercial market in past decades (Garcia, Quek, Stevenson, & Winz, 2012). However, nowadays consumers have shown an increasing interest in red-fleshed *Actinidia*, as different flesh colors of kiwi exhibit different nutrition levels and tastes. The *Actinidia deliciosa* (green kiwi) is the most widely cultivated species globally, with a bright green pulp and an acidic taste, and the Brix level of 12-14° (Pinto & Vilela, 2018; Richardson, Ansell, & Drummond, 2018). The *Actinidia chinensis* (yellow kiwi) is characterized by its bright yellow flesh, lower acidity, high sugar and vitamin C, E, with a tropical fruit flavor (Nishiyama, 2007; Singletary, 2012).

Kiwi wine is a type of fermented drink made from kiwi fruit. Among the different kiwi products, kiwi pulp, wine and vinegar have higher vitamin C and polyphenols than kiwi fruit and jam (Ma et al., 2019). Thus, making wine is a processing method to enhance the nutritional value of kiwi. Kiwi wine has been made in Asia for many years and is

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becoming a popular kiwi-based product. Previous research on kiwi wine production, has mainly focused on fermentation conditions, quality evaluation, and fermentation bacteria (Li et al., 2017b; Lim; & Oh., 2017; Xingchen Li, Yage Xing, Lin Cao, & Ruiz., 2017). Li *et al.* investigated the effects of six different commercial strains of *S. cerevisiae* on the phenolic profiles and antioxidant activity in kiwifruit wines, and the results indicated that *S. cerevisiae* RC212 was the most suitable for the fermentation of kiwifruit wine (Li et al., 2017a). While in Chen *et al.*'s study, they found that mixed fermentation of Jiuqu and *S. cerevisiae EC1118* could improve the quality of the kiwi wine (Chen et al., 2019).

Besides microorganisms and fermentation conditions, the quality of the raw material also plays an important role in wine performance. As it is commonly understood in the fruit wine industry, the key to successful brewing lies primarily in the quality of the raw materials used. Different cultivars of kiwi have diverse colors, tastes, aromas, etc. Nevertheless, the impact of different kiwi cultivars on the resulting kiwi wine is rarely reported. Recently, Huang *et al.* evaluated the quality of kiwi wine made from seven green-fleshed *Actinidia deliciosa* (Huang et al., 2021). However, research on the pedigree of kiwi wine made by different flesh colors is lacking.

In this study, five different kinds of kiwifruits with green, yellow, and red flesh were utilized. Especially, the fruit types were Guichang (*Actinidia deliciosa,* green flesh), Xuxiang (*Actinidia deliciosa,* green flesh), Donghong (*Actinidia*, red flesh), Hongyang (*Actinidia*, red flesh) and Jinyan (*Actinidia chinensis,* yellow flesh). The kiwis were fermented with *Saccharomyces cerevisiae* (*S. cerevisiae*) B0213. Various characteristics including pH value, soluble solid content, total acid, total protein, the content of Vc, phenol, and flavonoids were analyzed in kiwifruit. In addition, the content of alcohol, phenolic profiles, antioxidant activity, and aroma constitution were detected in these kiwi wines. Furthermore, the PCA of aromatic compounds of different kiwifruit wines was analyzed to explore whether the same color of flesh showed similar characterization on the wines.

Material and methods

Yeast strain and culture condition

One commercial strain of *S. cerevisiae* B0213 was selected and purchased from Dibosh Self-brewing Machine Co. (Shandong, China). This commercial strain, which owned good fermentation speed, low production of foam and growth at different temperatures (Patil, Deshannavar, Ramasamy, & Emani, 2021), was preserved at 4 °C by yeast extract peptone dextrose agar medium (2% glucose, 2% peptone, 1% yeast extract, and 2% agar), as well as in glycerol stocks at −80 °C before fermentation. It should be activated and cultured in yeast extract peptone dextrose (YEPD) agar (1% yeast extract, 2% peptone, 2% glucose, 2% agar, pH 6.0) at 28 ± 1 °C for 48 h when needed. All these agents used in this study were supplied by Sigma Aldrich, Germany.

Kiwi wine fermentation

Five different flesh colors of kiwis were purchased in Guizhou province, China. Hongyang, Donghong, and Jinyan were purchased from kiwi planted farm in Liupanshui, Guichang and Xuxiang were purchased from kiwi planted farm in Guiyang, China.

The method of making kiwi wine was referred to Liu *et al.* (Liu, Qi, Zhao, Cao, Xu, & Fan, 2020) with some modifications. The fresh kiwis, which were non-rotting, were washed with water, peeled, and then blended into a liquid using a domestic juicer. Pectinase (0.1 g/kg, enzyme activity ≥ 60000 U/mL) and SO_2 (0.04 g/kg) were then added to the kiwi pulp at room temperature (25 °C) for 12 h of enzymatic hydrolysis, which was placed into a fermentation jar (three copies for each sample). Finally, sugar was dissolved in water (1:2) and poured into the fermentation jar until the SSC of the kiwi pulp reached 20° Brix.

The kiwifruit pulp was inoculated with *S. cerevisiae* B0231 at a final concentration of 10^6 CFU/mL, fermented at 28 ± 1 ℃ for 15 days. The kiwi wines were centrifuged at 5 000 rpm for 15 min, and cell-free supernatants were collected and stored at −80 ℃ before analysis for phenol profiles, and antioxidants. For aromatic analysis, the supernatants were sealed stored in a glass bottle at room temperature and sealed for three months.

Physico-chemical parameters analysis

The soluble solid content (SSC) was determined by a hand-held refractometer (WZS32, Shanghai Instrument Electric Light Co., Ltd., China). Titratable acidity (TA) was detected by titrating a sample (4 mL of pulp or wine diluted with 20 mL of distilled water) with 0.1 N NaOH, which was conducted according to the methods described by Oba *et al.* (Oba, Okunola, Oranusi, & Okagbue, 2018) with some modifications. The ethanol concentration (% v/v) in kiwi wine was determined by gas chromatography (Agilent 7890A-5975C, USA).

Antioxidant analysis

The ascorbic acid content was determined by the method specified in Porto *et al.* (Porto, Santos Neto, dos Santos, Gomes, & Ferreira, 2019) with some modifications.

The total phenol content of wine samples was determined by the Folin-Ciocalteu method (Guo, Yuan, Dou, & Yue, 2017), the results were expressed as grams of gallic acid equivalent (GAE). The total flavonoid content in kiwi wine was determined by the aluminum chloride assay (Jiao, Kilmartin, Fan, & Quek, 2018), the results were expressed as milligrams of rutin equivalent (RE).

2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging ability was tested followed by Olejar *et al.* (K. J. Olejar, B. F., & Kilmartin., 2015). The DPPH (Sigma Aldrich) solution (0.5 mL, 25 mg/L) in methanol (Sigma Aldrich) was mixed with the sample (5 mL). Hydroxyl radical (•OH) (Sigma Aldrich) produced by salicylic-acid system by Zhu *et al.*'s (Zhu et al., 2019) description with a slight modification. The DPPH index was calculated by measuring the absorbance of a DPPH solution before and after the addition of a sample containing antioxidants. The percentage of DPPH scavenging activity was then calculated using the following formula (Re, Pellegrini, Proteggente, Pannala, Yang, & Rice-Evans, 1999)

$$*\text{DPPH scavenging activity (\%)} = [(A0 - A1)/A0] \times 100$$

*where A0 was the absorbance of the DPPH solution without the sample, and A1 was the absorbance of the DPPH solution with the sample.

Phenolic profile analysis

Polyphenols in kiwifruit wine samples were determined with an Agilent 1260 HPLC (High performance liquid chromatography, Agilent, Inc., Agilent, USA) system using the methods reported by Porgali *et al.* (Porgalı & Büyüktuncel, 2012) with slight modifications.

The samples, including kiwi wines and standard solutions, were filtered through a filter membrane (0.25 μm) and then 10 μL filtrate was injected into the HPLC system. Chromatographic separation was conducted on an Agilent C18 column (250 mm × 4.6 mm × 5 μm; Agilent Technologies, Santa Clara, CA). Mobile phase A was methanol and mobile phase B was a 13% aqueous acetic acid solution. The optimized gradient programs for phases A and B were as follows: 0–10 min, 10% A, 90% B; 10–20 min, 10–13% A, 90–87% B; 20–27 min, 13–18% A, 87–82% B; 27–35 min, 18–22% A, 82–78% B; 35–47 min, 22–25% A, 78–75% B; 47–50 min, 25–32% A, 75–68% B; 50–58 min, 32–35% A, 68–65% B; 58–62 min, 35–25% A, 65–75% B; 62–70 min, 25–10% A, 75–90% B;. Flow rate was 1 mL/min during analysis time and injection volume was 10 μL. The detection wavelengths were 280 nm according to the spectra obtained from Agilent Chem Station Software.

Analysis of aroma compounds

The sample aroma compounds were isolated and preconcentrated following a solid-phase microextraction (SPME). For each SPME analysis, 10 mL of samples (7.0 g/L tartaric acid, 12% v/v), 20 μg of methyl caprate (1 mg/mL, totaling 20 μL) as an internal standard substance were placed in 20 mL vials, capped with a poly(tetrafluoro ethylene) (PTFE)-silicon septum, and heated up to 60 ℃. After 20 min of stirring at 500 rpm, the SPME fiber (50/30 μm PDMS; Supelco, USA) was exposed to the sample headspace for 20 min and then extracted for 30 min by the extraction needle.

The analysis and GC–MS technology were operated according to a previous description by Rebiere *et al.* (L. Rebiere, A. C. Clark, L. M. Schmidtke, P. D. Prenzler, & Scollary, 2010). The samples were analyzed on an Agilent 7890A-5975C gas chromatograph (Agilent Technologies, Santa Clara, CA). Chromatographic conditions were inlet at 250 ℃ with an injection volume of 2 μL in pulsed splitless mode. During the analysis period, the flow rate (He) was 1.5 mL/min. The temperature program was set from 50 ℃ (1 min) to 100 ℃ at a rate of 5 ℃/min for 2 min, followed by an increase to 180 ℃, at a rate of 4 ℃/min and holding for 3 min, then from 180 ℃ to 250 ℃ at a rate of 5 ℃/min, and finally 250 ℃ for 5 min. Other conditions included an ion source of 230 ℃, a four-stage bar of 150 ℃, en electron impact (EI) mode with an ionization voltage of 70 eV, and a mass range of 35–350 amu/s.

Statistical analysis

The results were presented as the mean ± SD (standard deviation) of triplicate analyses. SPSS20.0 software was used for data processing via analysis of variance (ANOVA) and Dunnett's multiple range tests. OriginPro2021 (OriginLab, Hampton, USA) was applied in PCA, and a Venn diagram was created for the phenolic profiles and aroma compounds of different kinds of kiwi wines. The $P < 0.05$ were considered significant.

Results and discussion

Physico-chemical parameters of kiwi pulp

SSC, TA, pH, total protein, and anti-oxidants of kiwi pulp were shown in Table 1. The SSC is an important quality metric related to taste, and can also be a substance for *S. cerevisiae* growth (Towantakavanit, Park, & Gorinstein, 2011). The SSC in 5 kiwi pulps showed significant differences ($P < 0\ 0.05$), the highest SSC of pulp was in Hongyang up to 17.1 ± 0.81 °Bix, while Jinyan had the lowest SSC, among all of the pulps.

TA is also related to taste, as well as pH. In a previous study, the pH value in kiwi wines was 2.91–3.03, which was lower than cherry wine and red wine. The lower pH and higher TA levels in wine create acidity, which can limit the consumption of fruit wine. Thus, pH and TA in raw materials are highly significant (Olejar, Fedrizzi, & Kilmartin, 2015; Sun et al., 2013). No significant differences were observed among the 5 kiwi pulps in terms of pH value, however, there were differences in the TA. The lowest TA content was found in the case of Jinyan at 17.67 ± 0.29 mmol/100 mL, and the highest was in Guichang at 32.67 ± 1.04 mmol/100 mL. The total protein content ranged from 101.59 ± 1.21 mg/mL to 157.21 ± 1.55 mg/mL, with Donghong displaying the highest total protein content.

Kiwi is popular throughout the world due to its high nutritional value and high levels of V_C. Bedsides V_C, it's also full with other antioxidants, such as phenols and flavonoids. Antioxidants contained in kiwifruit reduce oxidative stress and support the cardiovascular system (Leontowicz et al., 2016). Then the contents of antioxidant substances, including V_C, total phenolic acid and flavonoids were determined. The V_C content ranged from 108.3 mg/100 g to 148.7 mg/100 g, with Hongyang showing the highest content of V_C. Guichang had the highest total phenols at 1.48 g/L and Hongyang had the highest flavonoids at 1.93 mg/mL.

Table 1
Chemical indexes of different varieties of kiwifruit pulp.

Physico-chemical parameters	Kiwifruit pulp				
	Guichang	Xuxiang	Donghong	Hongyang	Jinyan
pH	3.72 ± 0.006[a]	3.73 ± 0.006[a]	3.76 ± 0.011[a]	3.90 ± 0.006[b]	3.75 ± 0.006[a]
Soluble solid content (°Brix)	15.0 ± 0.00[b]	12.9 ± 0.06[a]	13.9 ± 0.40[c]	17.1 ± 0.81[d]	12.9 ± 0.23[a]
TA (mmol/100 mL)	32.67 ± 1.04[a]	21.42 ± 0.14[b]	24.33 ± 0.29[c]	24.83 ± 0.76[c]	17.67 ± 0.29[d]
Total protein (μg/mL)	103.69 ± 2.01[a]	101.59 ± 1.21[a]	157.21 ± 1.55[c]	130.63 ± 1.09[b]	103.69 ± 0.99[a]
V_C (mg/100 g)	117.8 ± 1.27[a]	135.2 ± 1.99[b]	148.7 ± 2.49[c]	108.3 ± 0.48[d]	116.1 ± 1.73[a]
Total phenols (g/L)	1.48 ± 0.07[a]	0.91 ± 0.03[b]	0.78 ± 0.02[c]	0.88 ± 0.05[d]	0.50 ± 0.04[e]
Total flavonoid (mg/mL)	1.11 ± 0.05[a]	0.43 ± 0.00[b]	0.53 ± 0.01[c]	1.93 ± 0.02[d]	0.30 ± 0.01[e]

values were expressed as means ± standard deviation (n = 3). Different letters within the same column indicate statistical differences at a significant level of P by 0.05 or less.

The changes of SSC and alcohol content during fermentation

Sugar is a necessary carbon source for the growth and reproduction of *S. cerevisiae*. *S. cerevisiae* consumed sugar via oxidative metabolism, then reduced sugar content, lowering SSC and alcohol production (Lei, Xu, Feng, Yu, Zhao, & Zhao, 2016). The changes of SSC and alcohol content during fermentation were measured, as shown in Fig. 1. The SSC of all samples decreased, especially in the first 6 days, from 20.0 °Brix to 6.5 °Brix. The two wines with the lowest SSC found were Jinyan wine and Xuxiang wine.

Alcohol content was another important index of fruit wine, which generally ranges from 8 to 12 vol% (Varavuth, Jiraratananon, & Atchariyawut, 2009). As the alcohol content changed, there was a rapid increase during the first 6 days, followed by a smooth increase from days 6 to 15. Wines made by different cultivars ranged from 8.2 to 10.8 vol%; Guichang wine had the lowest alcohol content, and Donghong fruit wine showed the highest alcohol content.

Antioxidant activity of kiwi wine

Polyphenols and total flavonoids are the main antioxidant components in kiwi wine, which could reflect the antioxidant capacity of fruit wines (Ivana Generalić Mekinić, Živko Skračić, Kokeza, et al., 2020). V_C ranged from 106.13 mg/100 g to 146.05 mg/100 g in kiwi wine samples, Hongyang wine had the highest V_C content, this was consistent with that in raw materials (Table 2). After undergoing fermentation, the total flavonoid and phenol content in kiwi wines differed from that in fresh pulp. The total content of flavonoids and phenols decreased in Xuxiang wine, Guichang wine, and Jinyan wine, but increased in Donghong wine and Hongyang wine. The drop in these antioxidant compound levels could have been due to fermentation process condensation and polymerization reactions as well as the formation of oxidative products and precipitations (Revilla, Gonzalez-San Jose, & L., 2003).

The content of antioxidants and their radical scavenging ability were shown in Table 2. Total phenol content ranged from 0.65 to 1.41 g/L, and total flavonoid content varied from 0.30 to 0.50 mg/mL. Hongyang wine exhibited the highest total phenol and flavonoid content, followed by Guichang wine and Donghong wine. The scavenging ability of DPPH and •OH was measured. The radical scavenging abilitities in different kiwi wines showed significant differences. The DPPH scavenging ability in Hongyang wine, Donghong wine, Guichang wine, Xuxiang wine, and

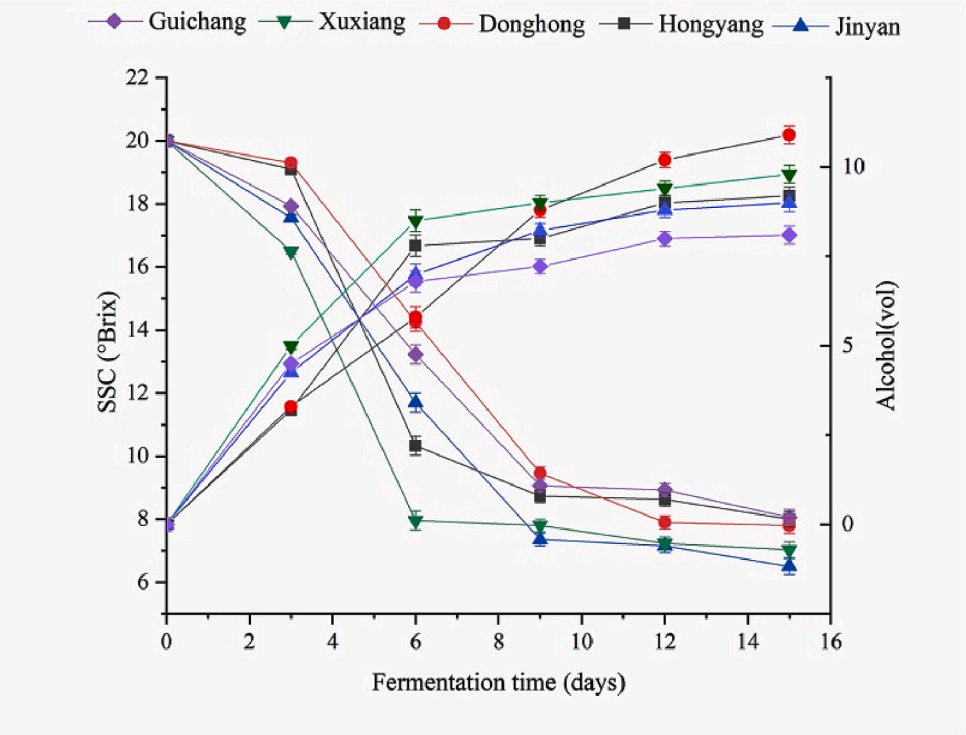

Fig. 1. SSC and alcohol content of kiwifruit wine during the fermentation process.

Table 2
Antioxidant substances in five kinds of kiwifruit wines, with corresponding, OH• radical scavenging activity, and DPPH radical scavenging activity (n = 3).

Indexes	Guichang	Xuxiang	Donghong	Hongyang	Jinyan
V_C (mg/100 g)	116.15 ± 0.21^{c}	129.20 ± 1.18^{d}	146.05 ± 1.29^{e}	106.13 ± 1.27^{a}	113.09 ± 2.23^{b}
Total phenol (g/L)	1.18 ± 0.02^{b}	0.65 ± 0.01^{a}	1.03 ± 0.04^{d}	1.41 ± 0.01^{c}	0.50 ± 0.03^{e}
Total flavonoid (mg/mL)	0.38 ± 0.004^{b}	0.34 ± 0.012^{a}	0.42 ± 0.002^{d}	0.50 ± 0.006^{c}	0.30 ± 0.073^{a}
Scavenging rate of DPPH (%)	57.47 ± 2.94^{c}	48.03 ± 1.47^{b}	56.68 ± 1.78^{c}	71.92 ± 3.10^{d}	38.35 ± 3.16^{a}
Scavenging rate OH• (%)	42.76 ± 2.09^{b}	31.97 ± 1.08^{a}	44.17 ± 0.65^{b}	50.82 ± 2.42^{c}	45.31 ± 0.93^{b}

Note:values were expressed as means ± standard deviation (n = 3). Different letters within the same column indicate statistical differences at a significant level of 0.05.

Jinyan wine were found to have 71.92%, 56.68%, 57.47%, 48.03%, and 38.35%, respectively. However, Hongyang wine possessed the highest scavenging ability of DPPH and •OH. Fruit wines possessing more antioxidants indicated a higher nutritional value. Therefore, in terms of the activity of antioxidant substances shown in Table 2, Hongyang was found more suitable to produce kiwi wine than the other four cultivars.

Phenolic compounds in kiwi wine of different varieties

Polyphenolic compounds are well-known to influence the color and flavor of wines and also play a major role in their nutrition and health benefits (Pascottoab;, Cheynierc;, Williamsc, et al., 2020). The phenolic compounds in kiwifruit wines were also determined and evaluated further. The contents of gallic acid, protocatechuic acid, catechins, chlorogenic acid, epicatechin, coumaric acid, and ferulic acid were determined in these 5 kiwi wines (Table 3). Significant differences were

Table 3
Phenolic compounds content of different varieties of kiwifruit wines.

Phenolic compounds (mg/L)	Guichang	Xuxiang	Donghong	Hongyang	Jinyan
Gallic acid	ND	0.96 ± 0.021^{a}	4.05 ± 0.032^{c}	3.53 ± 0.021^{b}	ND
Protocatechuic acid	0.62 ± 0.017^{a}	4.24 ± 0.015^{c}	4.81 ± 0.026^{d}	2.68 ± 0.045^{b}	ND
Catechins	22.51 ± 0.102^{a}	27.68 ± 0.198^{c}	24.05 ± 0.448^{b}	36.62 ± 0.682^{d}	ND
Chlorogenic acid	33.39 ± 0.113^{e}	10.36 ± 0.111^{c}	5.36 ± 0.035^{b}	30.08 ± 0.145^{d}	3.04 ± 0.266^{a}
Epicatechin	2.38 ± 0.035^{a}	3.92 ± 0.035^{c}	ND	5.000 ± 0.017^{d}	3.16 ± 0.057^{b}
Coumaric acid	0.25 ± 0.006^{a}	ND	ND	0.348 ± 0.003^{b}	ND
Ferulic acid	ND	ND	ND	0.593 ± 0.035	ND

Note: values were expressed as means ± standard deviation (n = 3). Different letters within the same column indicate statistical differences at a significant level of 0.05."ND- not detected.

observed in phenol composition among all other samples of wine ($P < 0.01$). Only Hongyang wine possessed these 7 kinds of phenol profiles, Guichang wiki owned 5 kinds of phenol profiles (except gallic acid and ferulic), Xuxiang also had 5 kinds of phenol profiles (except coumaric acid, and ferulic). For Hongyang wine, the phenolic compounds that were most abundant were catechins and chlorogenic acid, with concentrations of up to 36.62 mg/L, and 30.09 mg/L, respectively.

Later, PCA was performed on the phenolic attributes in an effort to further understand how these differences impacted the overall quality of the wines (Fig. 2). As shown in Fig. 2, the spots of different kiwifruit wines were scattered in different areas. All the phenolic compounds had a positive effect on the first PC (48.8%), while some compounds, including epicatechin, coumaric acid, and chlorogenic acid had negative effects on the second PC (29.8%). The wines made by Hongyang were in

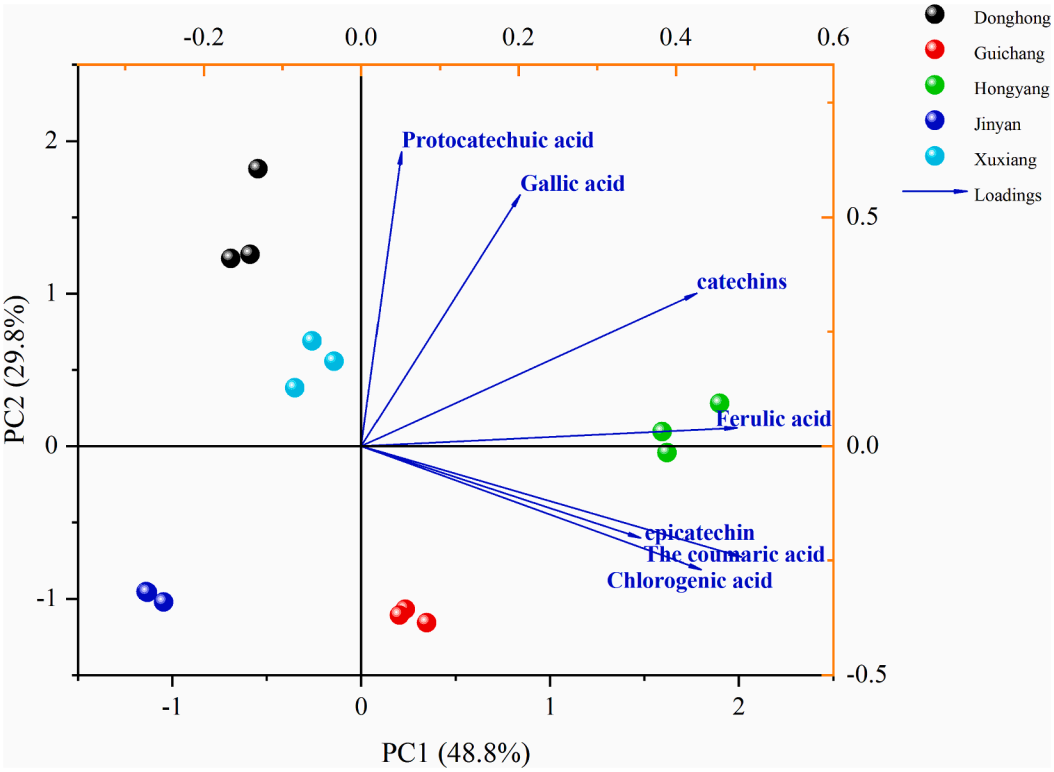

Fig. 2. Principle component analysis biplot of phenolic Substances from kiwifruit wines.

the first quadrant, which contributes to both the first and second PCs, and is highly correlated with the components of ferulic acid. The vineyards where the wines were produced were situated underground. The wines made by Donghong and Xuxiang were located in the second quadrant. The wines produced by Donghong received higher scores than those produced by Xuxiang in the first PC. Conversely, in the second PC, the wines produced by Xuxiang received higher scores.

Analysis of volatile compounds in kiwifruit wines

In total, 101 volatile components were detected in different varieties of kiwifruit wines, including alcohols (9), esters (58), hydrocarbons (22), aldoketones (10), and acids (2). The details were shown in supplementary form.1. The aromatic components in different varieties of kiwifruit wines showed differences.

As shown in Fig. 3(a), a total of 52 volatile components were detected in the fruit wine made by Donghong and Hongyang. 55 volatile components (5 alcohols, 38 esters, 9 hydrocarbons, 2 aldoketones, and 1 acid) were detected in Guichang kiwi wine. In Jinyan kiwi wine, there are 61 types of volatile components comprising 5 types of alcohols, 33 types of esters, 9 types of hydrocarbons, 5 types of aldoketones, and 1 type of acid. The quantity of aromatic compounds in Xuxiang kiwi wine was the highest, up to 64 among all these wines. As shown in Fig. 3(b), the proportion of ester substances in each sample of kiwifruit wine exceeded 69.6% of the total ingredient content, with Hongyang and Donghong varieties having particularly high levels of esters at 78% and 79.87% respectively. Esters are a substance produced by the hydrolysis and oxidation of acid, and they are the primary volatiles responsible for the sweet aroma of fruit wines (Belda et al., 2017; Dombre, Rigou, Wirth, & Chalier, 2015). Thus, the constitution of kiwi wine is very important. Even though, Hongyang and Donghong wines had lower esters amounts, but had the highest content (79.87% and 78%, respectively).

Besides, the main esters consisted of ethyl octanoate, ethyl laurate, and ethyl decanoate. Most of the esters impart the fragrance and floral sent to the fruit, of which ethyl acetate, ethyl butyrate, ethyl octanoate, ethyl nonanoate, ethyl decanoate, ethyl benzoate, and ethyl laurate add to the fresh fruity and floral flavor of the kiwifruit wines. Alcohols gave kiwi fruit wine its aroma, among which phenyl ethanol gave kiwi fruit wine its sweetness and rose fragrance. Alcohol accounted for 14.66–23.54% of the total, hydrocarbon substances accounted for 2.23–9.2%, other two kinds of aroma components accounted for a proportion below 3%. In terms of the content of aromatic compounds, Donghong and Hongyang owned the most aromatic components.

As shown in Fig. 3(c), these five different kinds of kiwifruit wines shared 32 common aromatic compounds, including 1-butanol, 3-methyl-, phenethyl alcohol, ethyl caproate, 1-butanol, 3-methyl-, acetate, ethyl laurate and so on. There were 45 kinds of compounds shared in Guichang and Xuxiang wines. Donghong and Hongyang wines shared 41 common compounds. There were 5, 14, 7, 3, and 11 different types of compounds found in Guichang, Xuxiang, Donghong, Hongyang, and Jinyan kiwifruit wines, respectively, which were completely distinct from the four other types of wines. The unique substances like Heptadecanoic acid, ethyl ester, 9(E),11(E)-conjugated linoleic acid, ethyl ester, 3-methylbutyl hexadecanoate, etc. were only detected in Xuxiang kiwi wine. While Hongyang had only three kinds of compounds, including eucalyptol, *n*-hexyl formate and trichloroacetic acid, 4-methylpentyl ester was different from the other four kinds of wine.

As shown in Fig. 3(d), the contribution of PC1 was 56.21%, and the contribution of PC2 was 24.08%, the total contribution was 80.29%, indicating the flavor in different kinds of kiwifruit wines was independent from each other. Besides, these two principal components can represent the main characteristic of flavor in the samples. The measured data of each group of samples can be grouped, indicating that all data showed good stability and repeatability. From the view of PC1, Guichang and Xuxiang wines were on the positive end, while Jinyan, Donghong, and Hongyang were on the negative end; From the view of PC2, the Jinyan was on the positive end, while the other four kinds of kiwifruit wines were on the negative end. According to the above analysis, the PCA method can be used to extract the aroma compounds

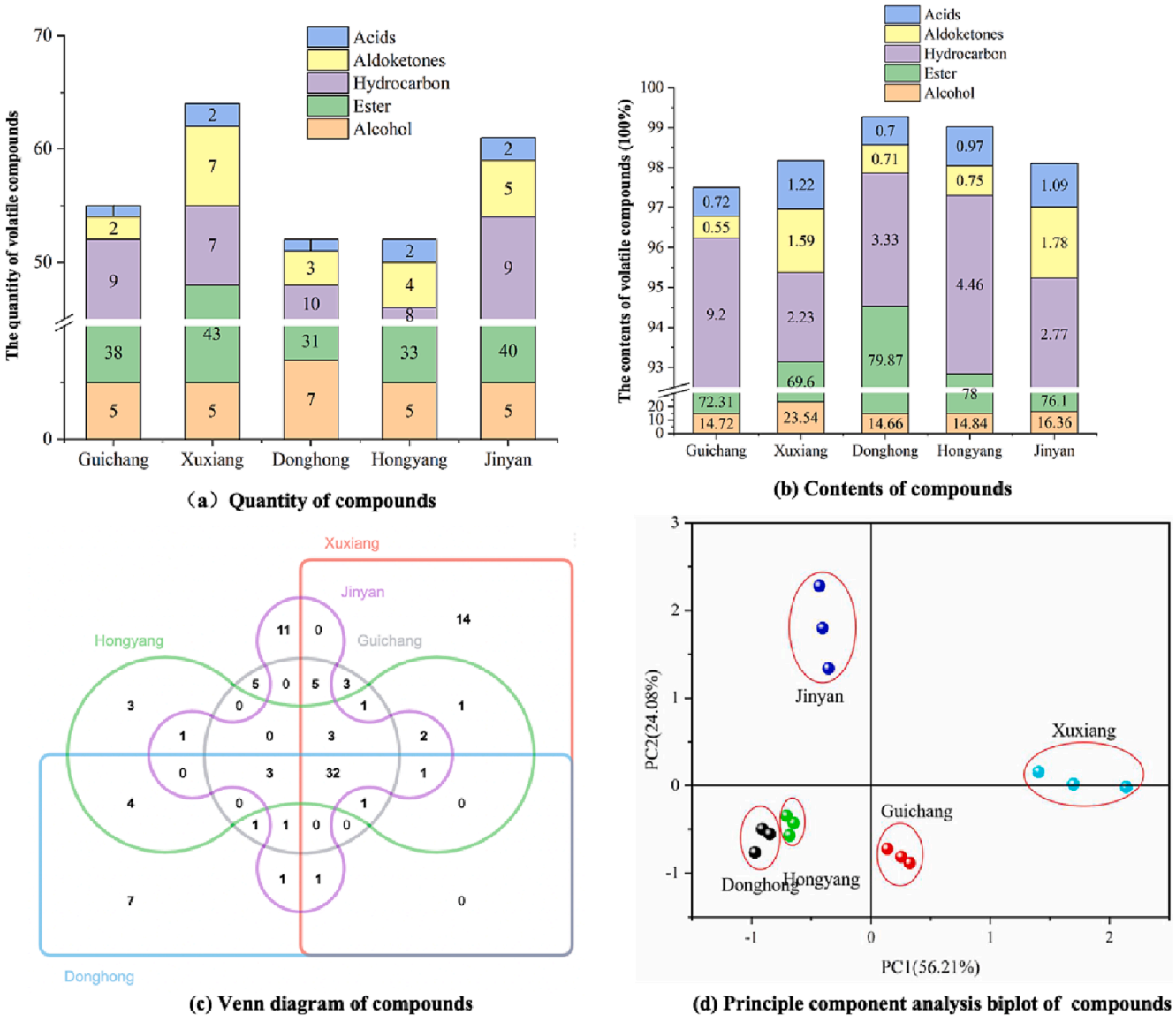

Fig. 3. Analysis of Volatile Compounds in different kinds of kiwifruit wines. (a)Quantity of compounds; (b) Contents of compounds; (c) Venn diagram of compounds; (d) Principle component analysis biplot of compounds.

of different kiwi wines. According to the results, the aromatic substances of Donghong and Hongyang wines were found similar. On the other hand, Xuxiang and Guichang were similar, which indicated that the same cultivar had the same constitution for aromatic compounds.

Conclusion

This current study has provided valuable insights into the physicochemical properties and antioxidant activity of different flesh colors of kiwi wines. Phenolic profiles, antioxidant activity, and aroma constitution were investigated further. According to the obtained results, following conclusions can be drawn:

1) Compared to the other three kiwi wines, Hongyang and Donghong wines had higher levels of total phenols and flavonoids, as well as superior free radical scavenging abilities and ester compositions. As a result, they are more suitable for producing high-quality kiwi wines.

2) Through multivariate statistical analysis of volatiles, it was discovered that the color of kiwi flesh has an impact on the composition of volatiles. Additionally, it was observed that volatiles from kiwis with the same flesh color are more alike in composition.

3) Thirty-two volatile compounds were detected in the kiwi wines made from green, red, and yellow flesh kiwis. These compounds could potentially be considered as the key volatiles responsible for the distinct aroma of kiwi wine.

The findings of this study can be useful in shaping the creation of novel kiwi wine products and provide insights into the role of specific compounds in the flavor and health benefits of kiwi wine.

CRediT authorship contribution statement

Yan Zhou: Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Gangxiang Fei:** Methodology, Validation, Formal analysis, Investigation. **K.M. Faridul Hasan:** Supervision, Resources, Writing – review & editing. **Yingqian Kang:** Resources, Methodology. **Yingmei Wu:** Conceptualization. **Haoxin Li:** Methodology. **Shaoqin Zhou:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

Data availability

Data will be made available on request.

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Data Availability

Data available on request from the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.100691.

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