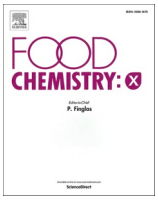
Food Chemistry: X 22 (2024) 101503

Contents lists available at ScienceDirect

Food Chemistry: X

journal homepage: www.sciencedirect.com/journal/food-chemistry-x



Effect of postharvest grape dehydration on chemical composition, antioxidant activity and sensory characeteristics of Marselan wines

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ARTICLE INFO

Keywords:
Marselan wine
Postharvest dehydration
Antioxidant activity
Aroma
Sensory evaluation

ABSTRACT

To explore the effect of postharvest dehydration on grape berries and wine quality, we determined physicochemical properties, polyphenols, antioxidant activities, volatile compounds and sensory characteristics for wines brewed by 'Marselan' (*Vitis vinifera* L.) grapes with 0%, 10%, 15%, 20%, and 25% of water loss. The result showed that postharvest dehydration improved the alcohol content, residual sugar and titratable acidity of Marselan wine. Phenolic compounds and antioxidant activities in wines with a dehydration of 20% have significantly increased. Postharvest dehydration increased the contents of isobutanol, isoamyl alcohol, phenylethyl alcohol, ethyl acetate, isoamyl acetate and ethyl butyrate in Marselan wines, and enhanced the floral, fruity and sweet taste of wines. Marselan wine had the lowest acceptability score under the condition of severe dehydration (25% dehydration), which was related to the significant increase of tannins content. In summary, postharvest dehydration was beneficial in improving the quality of Marselan wine.

1. Introduction

'Marselan' (*Vitis vinifera* L.), originated from France (Alcalde-Eon, Boido, Carrau, Dellacassa, & Rivas-Gonzalo, 2006), is a hybrid cultivar of Cabernet Sauvignon and Grenache Noir. It was introduced in 2001 and planted widely in Xinjiang, Ningxia, and Shandong provinces, China. Wines made from 'Marselan' grapes have abundant fruity aromas, such as blackberry, honey, litchi, and green pepper aroma (Lyu, Ma, Xu, Nie, & Tang, 2019). Hereinto, it is favoured by consumers all over the world and becomes a potential variety for brewing the quality wine in China (Lu et al., 2020). In recent years, the saturation of the wine industry has led to an increasing demand for the diversification of wine flavor characteristics. Therefore, the development of diversified products is of great significance to the development of the wine industry.

The pretreatment of fruit raw materials is highly correlated with the typicality of wine. In several certain regions, postharvest dehydration of grape berries, a special pretreatment method, is a dynamic process of water loss of berries in natural or controlled environment (Urcan et al., 2017). Some producing areas will control this process in a dewatering room with better ventilation conditions or temperature and humidity control (Shmuleviz et al., 2023), while others will continue to hang branches after grape maturity (Ruiz, Zea, Moyano, & Medina, 2010). During dehydration, a series of changes may occur in the physicochemical properties of berries (Wang et al., 2023). Due to concentration, synthesis, oxidation and their interactions in the berries, dehydration has a significant effect on volatile metabolites. Previous studies have shown that the general effect of dehydration treatment leads to the accumulation of volatile aldehydes, esters, alcohols, and terpenes, and changes specific compounds in wine (Moreno, Cerpa, Cohen, & Kennedy, 2006). Dehydration up-regulated some of the genes used to control the synthesis of volatile compounds, such as VviTPSs, (Yuan, Yan, Yan, Liu, & Pan, 2020; Zenoni et al., 2016), which promoted the accumulation of terpenes in dehydrated berries. Meanwhile, due to water loss, the alteration of cellular structure also leads to an enrichment of non-volatile aroma precursor compounds (amino acids, fatty acids, carbohydrates) in grape berries (Medina-Plaza et al., 2022), which are

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https://doi.org/10.1016/j.fochx.2024.101503
Received 31 January 2024; Received in revised form 24 April 2024; Accepted 22 May 2024
Available online 27 May 2024

converted into aroma substances during fermentation. In general, postharvest dehydration is considered a way to improve wine aroma.

Postharvest dehydration also had a significant effect on the non-volatile components of grapes. The most apparent effect was a significant increase in sugar content, which was greatly related to the degree of dehydration. The rich concentrate rendered the wine a complex flavor and a strong wine body, and the osmotic stress caused by high concentration of sugar and the high concentration of ethanol produced by fermentation forced the metabolism of yeasts to change the sensory characteristics of wine (Guerrini, Calamai, Angeloni, Masella, & Parenti, 2020). It has been reported that dehydration is a process of biological deacidification (Sun et al., 2013). Anaerobic metabolism of cells causes malic acid degradation and tartaric acid precipitation, but the overall concentration of organic acids increases with the dehydration rate (0% ~ 25%) (Shmuleviz et al., 2023). This change in content may lead to a change in the ratio of sugar to acid in wine, with higher total acidity and lower pH value, showing a balanced sugar-acid ratio (Scalzini et al., 2023), which strongly affects palatability and taste. Moreover, during the fermentation process, the increase of monomeric phenolics delayed the loss of flavonols and significantly improved the stability of wine during storage (Bai, Zhao, Du, Lin, & Han, 2023). With the progress of the fermentation process, the anthocyanin responsible for the color decreased, mainly due to the oxidation and polymerization of other phenolic components such as flavanols and tannins (Panceri, De Gois, Borges, & Bordignon-Luiz, 2015). In short, moderate dehydration had an important impact on the quality of wine, and these impacts directly or indirectly altered the characteristics of the obtained wine.

Xinjiang is one of the main grape producing areas in China, and the planting area of 'Marselan' has reached the first place in China. However, most of the wine products are dry red wine, and there are few studies focusing on the Marselan dehydration wine. The aim of this study is to explore the effect of postharvest dehydration treatment on wine quality. Therefore, Marselan dry red wine was produced using grape berries with 0%, 10%, 15%, 20%, and 25% of water loss. This study further determined physicochemical properties, polyphenols, antioxidant activities, volatile compounds and sensory characteristics for wines, in order to provide new ideas for the development of characteristic wine products in Xinjiang, China.

2. Material and methods

2.1. Grape collection and dehydration treatment

The fresh 'Marselan' grapes (commercial maturity) were harvested artificially from Chateau Changyu Baron Balboa, Shihezi, Xinjiang Uygur Autonomous Region, China in September 2021. Similar plants were selected in the middle of the vineyard, and 3 bunches of grapes with no damage and no apparent plant diseases were collected from each plant. The grapes were evenly tiled in a dry and clean perforated plastic basket (1.5 m × 0.8 m × 0.2 m) and placed on a shelf 1.5 m above the ground in a well-ventilated room with a relative humidity of 50% ~ 55% to dry naturally. Water loss was checked daily and healthy grapes were selected at 0% (CK), 10% (MSL10, 8_{th} day), 15% (MSL15, 12_{th} day), 20% (MSL20, 15_{th} day), and 25% (MSL25, 17_{th} day) of water loss. 6 kg of grapes were taken from each dehydration degree and divided into three groups for winemaking, each group as a repeat.

2.2. The fermentation of Marselan dry red wine

Grape berries were selected, destemed and crushed to obtain grape juice. The juice was transfered to a 2 L sterile glass tanks, and dipped at 4 °C for 12 h under conditions protected from light after adding 20 mg/L pectinase (Zhejiang Yinuo Biotechnology Co., Ltd. Zhejiang, China) and 50 mg/L SO_2 (Potassium metabisulfite). The fermentation tank was placed in a constant temperature incubator (Youke YKHWS-300 L, Hefei, China) at 25 °C for 30 min, and then the juice was inoculated with yeast (Excellence XR, Bordeaux, France) for alcohol fermentation. During the fermentation, the soluble solid content was detected everyday. The alcohol fermentation has been completed when the content remained stable. After fermentation, 30 mg/L SO_2 was added for sterilization, and subsequent analyses were carried out after filtration.

2.3. Determination of physiochemical properties

In this study, the pH value, total sugar, titratable acid and total SO_2 of wine were determined. The pH value was measured using a pH meter (pHS—3C, Shanghai Yitian Scientific Instrument Co. Ltd., China). Referring to the method developed by the International Organization of Grapes and Wine (OIV, 2020), the content of total sugar and titratable acid was determined by direct titration, and the content of total SO_2 was determined by iodometry.

2.4. Determination of phenolic compounds

The total anthocyanin content was determined by sampling pH differential method (Liu, He, Shi, Zhang, & Duan, 2018), Wine samples were diluted 20 times with hydrochloric acid-potassium chloride buffer (pH 1.0) and acetic acid-sodium acetate buffer (pH 4.5), respectively, and reacted for 100 min in the dark. The absorbance was measured at 510 nm and 700 nm, respectively. Finally, the total anthocyanin content was calculated according to the absorbance value, and the result was expressed as equivalent anthocyanin-3-glucoside (mg/L). The tannin content was determined by Folin-Denis method (Makkar, 1989), and the absorbance of the wine sample at 760 nm was determined. The equation was obtained by using tannic acid as the standard substance, and the tannin content was calculated. (mg/L, $R^2 = 0.9988$, $y = 0.0012\times + 0.0035$). The total phenol content was determined by Folin-Ciocalteu method (Jayaprakasha, Singh, & Sakariah, 2001), the absorbance of wine samples at 765 nm was measured, and the equation was obtained with gallic acid as the standard, and the total phenol content was calculated. (mg/L, $R^2 = 0.9991$, $y = 0.0009\times + 0.0222$). The total flavonoid was determined according to the method of Peinado, de Lerma, Moreno, and Peinado (2009), the absorbance of the wine sample at 510 nm was determined. The equation was obtained with rutin as the standard substance. (mg/L, $R^2 = 0.996$, $y = 0.0835\times + 0.002$).

The phenolic compounds in wine was extracted by the previous methods with slight modifications (Tenore, Basile, & Novellino, 2011), 15 mL wine sample and 15 mL ethyl acetate were added into a 50 mL centrifuge tube, mixed for 30 s by the spiral oscillator, extracted ultrasonically for 30 min, and centrifuged for 15 min at 10000 rpm, 4 °C, in which the extraction process was repeated three times for each wine samples, and the supernatant was collected. The combined supernatant was evaporated in a round bottom flask at 35 °C under reduced pressure, and the residue was dissolved in 5 mL methanol and stored in a refrigerator at −20 °C for further analysis.

Phenolic compounds were determined by the High Performance Liquid Chromatography (HPLC) equipped with a PDA detector, a C18 column (5 μm, 4.6 mm × 250 mm; diamonsil Plus Technology, China). The mobile phase was methanol (A) and 1% acetic acid water (B). The samples were detected at 30 °C column temperature, the 10 μL injection volume, and 210–400 nm detection wavelength. The gradient elution procedure was as follows: 5% A for 0 min, 40% A for 35 min, 95% A for 55 min, 5% A for 60 min, and flow rate with 1 mL/min. Phenolic compounds were identified and quantified by chromatograms and standard curves prepared by external standard method at the maximum absorption wavelength.

2.5. Determination of antioxidant activities in vitro

The DPPH free radical scavenging rate was determined according to the method proposed by Peinado et al. (2009). 0.1 mL of the sample was diluted 10 times with purified water and added to 3.9 mL of 6.25×10^{-5}

mol/L DPPH methanol solution. The absorbance value was measured at 517 nm after dark reaction for 30 min and the sample was replaced with the same volume of ethanol as a control.

The ABTS free radical scavenging rate was determined by the previous method (Xiong, Zhang, Luo, Johnson, & Fang, 2019). The 7-mmol/L ABTS solution were mixed with the 2.45-mmol/L potassium persulfate solution according to a 1:5 ratio and placed in dark at room temperature for 12 h. It was diluted with phosphate buffer (0.01 mol/L, pH 7.4) to an absorbance of 0.70 ± 0.02 at 734 nm before use. The absorbance value was determined at 732 nm after the 20-μL wine sample was added into 2 mL of ABTS solution, reacting for 10 min under a dark condition, and using a solution without the wine sample as a blank control.

The determination of CUPRAC in Marselan wine was performed according to the method (Apak, Güçlu, Özyürek, & Karademir, 2004). Wine sample was diluted 10 times and 0.1 mL of wine diluent was taken, adding 1 mL of copper sulfate solution (5 mmol/L), 1 mL of new cuprous reagent (3.75 mmol/L), 1 mL of NH4Ac (1 mol/L, pH 7.0) acetic acid-ammonium acetate buffer solution and 1 mL of distilled water in turn. The total volume of the reaction system was 4.1 mL, and the reaction was carried out under dark conditions for 30 min. The absorbance value was measured at 450 nm, and the results were expressed as Trolox equivalent value (μmol Trolox/L).

The determination of FRAP in wine was performed according to the method proposed by Griffin and Bhagooli (2004). The 0.1-mL sample was mixed with 2 mL FRAP solution (pH 3.6 acetic acid buffer solution, 10 mmol/L TPTZ solution, 20 mmol/L $FeCl_3$ according to 10:1:1, reacted at 37 °C for 10 min), and the absorbance value was measured at 593 nm.

2.6. Determination of volatile compounds

The extraction of volatile compounds in wines were performed according to the previous method (Tenore et al., 2011). Briefly, 5 mL wine and 1 g saturated NaCl were added into a 20-mL capped vial. 2 μL standard (3-octanol solution, 330 μg/kg) was added into the mixture. The mixed samples were equilibrated for 20 min (45 °C, 500 r/min) and extracted for 40 min (45 °C, 500 r/min). The SPME fiber (57329-U, Supelco Inc. Bellefonte, PA, USA) coated with a 50/30 μm divinylbenzene/Carboxen/polydimethylsiloxane (DVB/CAR/PDMS) (Supelco, Sigma-Aldrich Corp., St. Louis, MO, USA) was inserted into the gas chromatography (GC) injector after extracting. The desorption volatiles were conducted in split-less mode at 230 °C for 5 min.

Volatile compounds were detected by a gas chromatography–mass spectrometry (GC–MS) (Agilent 7000 D, Agilent Technologies Inc., Palo Alto, CA, USA) equipped with an HP-Innowax (30 m × 0.25 mm × 0.25 μm, Agilent, USA) fused-silica capillary column. The GC oven program was as follows: initial oven temperature was set at 40 °C for 5 min, increased to 90 °C at a rate of 3 °C/min, held for 2 min, and then with a ramp of 4 °C/min up to 180 °C, then increased to 230 °C at a rate of 10 °C/min and held for 5 min. The temperature of the injection port was 230 °C and the flow rate of the carrier gas (Helium) was 1 mL/min. Mass spectrometry conditions were operated in electron ionization (EI) mode with 70 eV electron impact energy, and ionization source temperature was 230 °C, scanning range *m/z* 35 to 350 with 5 scan/s.

Volatile compounds were identified by automated retrieval of mass spectra with NIST 98 and Wiley 6 mass spectral libraries. The retention index values for compounds were calculated by injecting of a series of alkanes (C8-C30) (Sigma, St. Louis, MO, USA) under the same experimental conditions. Compounds were quantified using an internal standard (3-octanol). The calculation formula is as follows:

$$C(\mu g/L) = Ac/As \times C0\ (\mu g/L),$$

C: The concentration of volatile compounds, μg/L; C0: The internal standard substance concentration, μg/L; Ac: peak area of analyte; As: peak area of internal standard.

The contribution of volatile compounds in dehydration wines was evaluated with reference to the method of odor activity value (OAV), and the key flavor compounds were identified. The OAV is calculated based on the ratio of the concentration of volatile compounds to the olfactory threshold in water (Niu, Deng, Xiao, & Zhu, 2021).

2.7. Sensory evaluation

Sensory evaluation of wine was performed based on the method described by Liu, Gronbeck, Di Monaco, Giacalone, and Bredie (2016) with a slight modification. Twelve teachers and postgraduate students (7 males and 5 females, age 23–30, average age 26) from the School of Food Science and Technology of Shihezi University were recruited as panelists to form a sensory evaluation team. The panelists had received about 20 h of aroma recognition training before evaluating wine samples. The wines are left at room temperature for 1 h before tasting. At the time of tasting, the wine is poured into a clear tasting glass to assess the color, aroma, flavor, typicality and acceptability of the wine. Samples were tasted at 3-min intervals and then rinsed. Sensory scores ranged from 1 (disliked) to 10 (liked very much).

2.8. Statistical analysis

All test data were the average value of the three repeated test data, which was expressed as Mean ± SD. Duncan test in SPSS 20 software was used to evaluate the significant differences between the data of each group at the level of 5% ($p < 0.05$), and Origin 8.0 software were used to generate a histogram and Pearson correlation coefficient values. Principal component analysis (PCA) and VIP value were performed using SIMCA 14.1 software, and clustered heatmaps were generated using TBtools v1.068 to analyze the flavor trends of the wines during fermentation.

3. Results and discussion

3.1. The differences in physiochemical properties of Marselan wines

Wine fermentation was a dynamic process in which yeast converts reducing sugar into alcohol. In our study, 'Marselan' grapes with different dehydration degrees were used to brew wine, and the alcohol content, residual sugar, total acid, pH and total SO_2 of the wine were determined and were shown in Table S1. The contents of alcohol, residual sugar and titratable acid in wine were increased by dehydration treatment, which is resulting from the concentration effects during the dehydration process. The concentration of reducing sugar directly led to the increase of alcohol content (from 11.17%vol to 15.50%vol), and the pH value also changed slightly due to the change of acid content. The increase in acid content from 8.25 g/L to 9.97 g/L contradicted the previous report that grape dehydration led to biological deacidification, which accounted for the fact that the concentration effect compensated for the loss of acid. It is worth noting that the rational use of SO_2 is to maintain the wine quality, and there is no clear connection with dehydration treatment. The total SO_2 content of the samples in this study was between 45.75 mg/L and 57.18 mg/L, which was lower than the standard of wine. (< 100 mg/L).

3.2. Effects of postharvest dehydration on phenolic compounds and antioxidant activity of Marselan wines

The effect of dehydration treatment on the contents of total phenols, total flavonoids, total anthocyanins and tannins in wine depends on the degree of water loss (0% ~ 25%), which was similar to the results of previous studies (Wang et al., 2023). The total phenols and total flavonoids of wine reached the maximum concentrations when grape berries were dehydrated by 20%, which increased by 15.9% and 48.0%

compared with the CK, respectively (Fig. 1A). The total anthocyanins and tannins of wine showed the maximum levels when grape berries were dehydrated by 25%, increasing by 32.8% and 75.9%, respectively (Fig. 1B). Some studies have shown that moderate dehydration promotes the biosynthesis of anthocyanins and flavonoids by changing the expression of some key genes (Liu et al., 2016), and the increase of anthocyanin and flavonoid content is also related to the release of phenol precursors promoted by cell wall degrading enzymes during berry dehydration (Sanmartin et al., 2021). At the same time, tannins are also continuously polymerized during berry dehydration, which shows significant differences in wine. These results indicated that the changes in polyphenol content in dehydration wines are caused by complex changes in the berry dehydration process. Notably, in our study, the content of total phenols and total flavonoids decreased during dehydration of 25%, compared to dehydration of 20%. It was reported that prolonged dehydration could increase polyphenol oxidase (PPO) and intracellular laccase activity, which would induce the degradation or oxidative polymerization of phenolic compounds (Constantinou et al., 2018).

The antioxidant properties of wine have gained significant attention in recent years, making it an important functional property that cannot be ignored. Free radical scavenging ability and metal ion chelating ability are commonly used indicators to evaluate the antioxidant properties of wine. ABTS and DPPH were used to study the free radical scavenging ability of dehydration wine (Fig. 1C). With the increase of dehydration degree, ABTS free radical scavenging ability reached the peak at MSL20 (472.14 mg TEs/L), and then decreased, while DPPH continued to increase, reaching the peak at MSL25 (470.44 mg TEs/L), considering the difference caused by the different structure and free radical scavenging mechanism of the two. At the same time, based on FRAP and CUPRAC, the reduction ability was explored (Fig. 1D). The reduction ability of dehydration wine was generally higher than that of the CK. CUPRAC showed a relatively stable trend between MSL10 and MSL20, and decreased at MSL25. FRAP showed a trend of increasing first and stabilizing from MSL20 to MSL25, which was worthy of further exploration. In summary, the antioxidant capacity of wine after dehydration treatment was enhanced. Although different dehydration degrees showed slight differences, they were generally higher than those of control group CK wine samples. This is similar to the results of Bai et al. (2023) that post-harvest dehydration of grapes improves the antioxidant

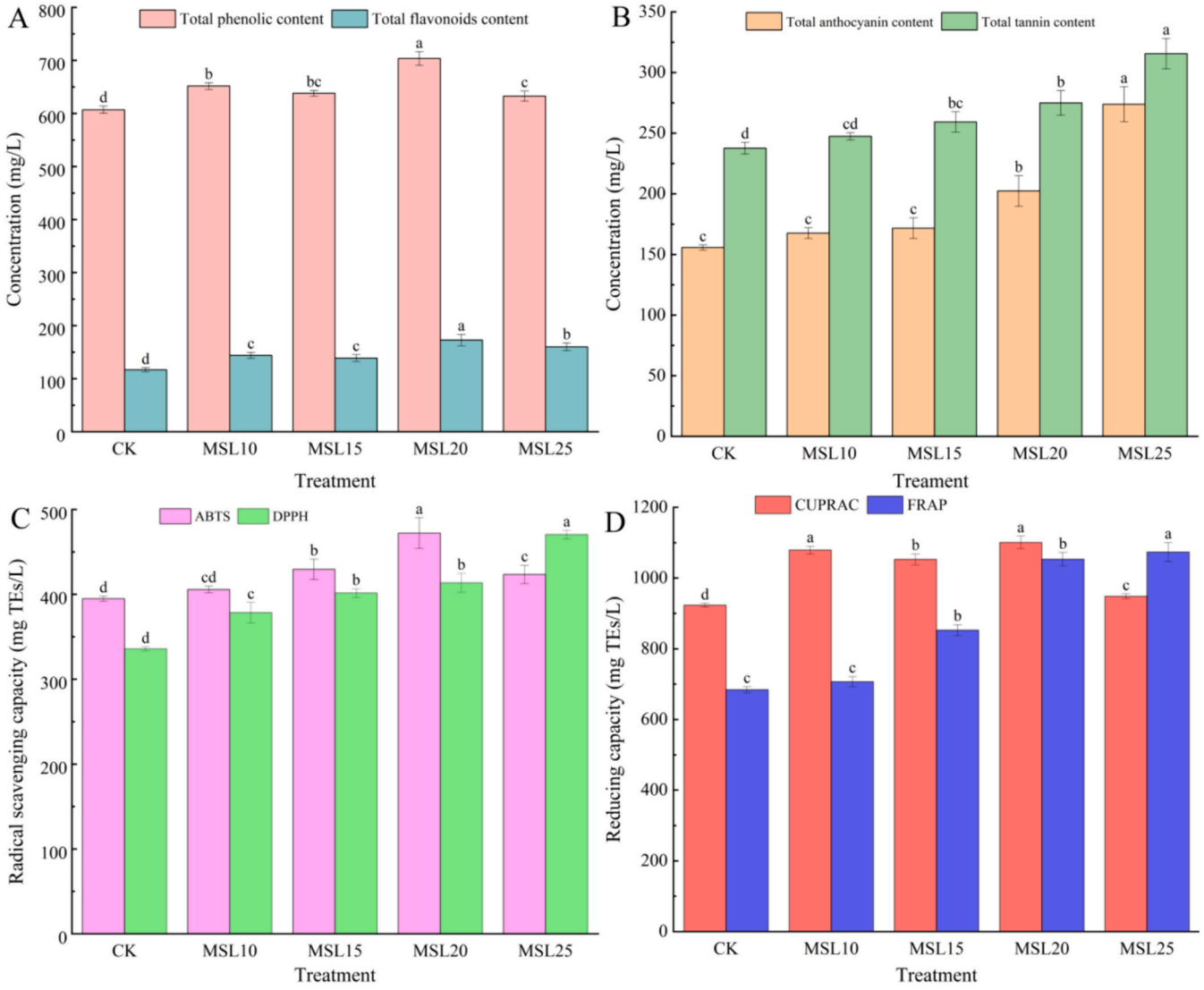

Fig. 1. The changes of total phenol content, total flavonoid content, total anthocyanin content, total tannin content and antioxidant capacity in Marselan dehydration wine. Values are means ± standard deviation. Different lowercase letters indicate significant differences between samples at different dehydration degrees ($p < 0.05$). CK represents control, while MSL10, MSL15, MSL20, and MSL25 represent postharvest dehydration at 10%, 15%, 20%, and 25% berry dehydration, respectively.

properties of wine.

3.3. Effects of postharvest dehydration on monomeric phenol concentration in Marselan wines

Polyphenols affect the quality and volatile compounds of wine through intermolecular interactions and play an important role in the nutritional value and health characteristics of wine (Rescic, Mikulic-Petkovsek, & Rusjan, 2016). A total of 19 monomeric phenolic compounds in wine were determined, and their concentrations were summarized in Table 1. All the monomeric phenolic substances were detected in the CK wine. There was no kaempferol in MSL10, no isorhamnetin in MSL15, no syringic acid in MSL20, no neochlorogenic acid and syringic acid in MSL25. The main phenolic substances in Marselan wine were catechin, epicatechin, rutin, coumaric acid and vanillic acid. These results indicated that although the dehydration wine increased the content of most phenols, it also led to the loss of some phenols.

The content of trans-ferulic acid, salicylic acid and resveratrol increased with the increase of dehydration degree. Gallic acid, coumaric acid, neochlorogenic acid, catechin, vanillic acid, chlorogenic acid, epicatechin, caffeic acid, benzoic acid, rutin and quercetin all showed the highest value in MSL20 and decreased to MSL25. Syringic acid and ferulic acid, myricetin and kaempferol showed the highest value in MSL15. These differences may be the result of molecular oxidation induced by polyphenol oxidase. To a certain extent, the complexity of the dehydration process and the critical value of the concentration of different monomer phenolic substances are explained, and the necessity of exploring the optimal dehydration degree is also explained. It is worth noting that the content of ferulic acid and trans-ferulic acid increased with the increase of dehydration degree below 15%, but showed the opposite trend after 15%, which was similar to the results of previous studies (De Rosso et al., 2016). From the perspective of species, there were 7 kinds of flavonoids in the monomeric phenols determined in this study, which were the main monomeric phenols in Marselan wine, mainly catechins and epicatechins, with the highest contents in MSL20, reaching 108.18 mg/L and 75.75 mg/L, respectively. Resveratrol, a stilbene compound, was also detected, and its content increased significantly in air-dried wine, with MSL25 as the highest value, 26.96 mg/L. Based on the above, dehydration treatment has a tendency to increase the content of monomeric phenols in wine.

Table 1
Content of phenolic compounds in Marselan wines (mg·L^{-1}).

Phenolic compound	CK	MSL10	MSL15	MSL20	MSL25
Gallic acid	16.55 ± 0.44b	16.75 ± 0.73b	17.50 ± 0.63b	20.14 ± 0.88a	16.87 ± 0.77b
Trans-Ferulic acid	8.19 ± 0.38e	10.47 ± 0.28d	13.12 ± 0.47c	15.56 ± 0.68b	20.26 ± 0.93a
Coumalic acid	41.86 ± 1.11d	45.70 ± 1.99c	51.27 ± 1.85b	65.00 ± 2.83a	46.13 ± 2.11c
Neochlorogenic acid	0.14 ± 0.01c	0.20 ± 0.01b	0.21 ± 0.01b	0.24 ± 0.01a	nd
Catechin	73.53 ± 1.95c	82.33 ± 3.59b	103.73 ± 3.74a	108.18 ± 4.72a	85.13 ± 3.90b
Syringic acid	1.06 ± 0.05c	2.69 ± 0.12b	9.85 ± 0.36a	nd	nd
Vanillic acid	31.27 ± 1.43c	30.75 ± 1.34c	39.62 ± 1.43b	46.56 ± 2.03a	43.63 ± 2.00a
Chlorogenic acid	6.61 ± 0.30c	22.01 ± 0.58a	4.14 ± 0.15d	11.61 ± 0.31b	11.26 ± 0.52b
Epicatechin	50.54 ± 2.32c	54.21 ± 2.36c	63.86 ± 2.30b	75.75 ± 3.30a	54.97 ± 2.52c
Caffeic acid	9.78 ± 0.35e	10.87 ± 0.29d	13.05 ± 0.47c	16.38 ± 0.43a	15.10 ± 0.40b
Ferulic acid	2.11 ± 0.08d	5.17 ± 0.14b	13.60 ± 0.49a	4.10 ± 0.11c	1.51 ± 0.04e
Benzoic acid	12.60 ± 0.58c	11.76 ± 0.51c	15.33 ± 0.55b	17.57 ± 0.77a	15.29 ± 0.70b
Rutin	49.58 ± 1.79b	70.92 ± 1.88a	68.79 ± 2.48a	71.11 ± 1.88a	67.46 ± 1.78a
Myricetin	6.24 ± 0.23c	6.86 ± 0.18b	8.01 ± 0.29a	1.82 ± 0.05d	2.00 ± 0.05d
Quercetin	0.60 ± 0.02c	0.79 ± 0.02b	0.85 ± 0.03a	0.86 ± 0.02a	0.83 ± 0.02ab
Isorhamnetin	2.78 ± 0.10b	4.75 ± 0.13a	nd	1.45 ± 0.04c	1.17 ± 0.03d
Kaempferol	0.92 ± 0.03c	nd	1.17 ± 0.04a	0.76 ± 0.02d	1.04 ± 0.03b
Salicylic acid	3.01 ± 0.14c	2.86 ± 0.12c	3.21 ± 0.12c	4.61 ± 0.20b	7.48 ± 0.34a
Resveratrol	12.36 ± 0.45e	14.08 ± 0.37d	15.20 ± 0.55c	19.41 ± 0.51b	26.96 ± 0.71a

Notes: Data are expressed as the mean ± standard deviation from replicate analyses ($n = 3$) of three replicate samples. The different lowercase letters in each row indicate significant differences between samples ($p < 0.05$). The "nd" indicates that it is not detected.

3.4. Correlation analysis

The correlation between monomeric phenols and antioxidant activity was analyzed by O2PLS models (Fig. 2). The content of monomeric phenols was used as the independent variable, and the antioxidant activity was used as the dependent variable for multidimensional data analysis. The results showed that the contribution of different monomeric phenolic compounds to antioxidant capacity was different. According to the analysis of VIP map (Fig. 2A), the VIP values of gallic acid, epicatechin, coumaric acid, benzoic acid, caffeic acid, quercetin, catechin, salicylic acid, trans-ferulic acid, resveratrol and vanillic acid neochlorogenic acid were all >1, indicating that they had a strong correlation with antioxidant activity.

Wine is abundant in antioxidants that not only enhance sensory properties and chemical stability, but also offer significant health benefits (Nie et al., 2020). The Pearson correlation coefficient between monomer phenolic compounds and antioxidant activity was shown in Fig. 2B. The results showed that different monomer phenolic compounds had different contributions to different antioxidant capacities (ABTS, DPPH, CUPRAC, and FRAP), and there was a significant correlation between different antioxidant activities. The results showed that gallic acid, epicatechin, coumaric acid, benzoic acid, caffeic acid and catechin were positively correlated with ABTS. Salicylic acid, trans-ferulic acid and resveratrol were positively correlated with DPPH and FRAP, and myricetin and isorhamnetin were negatively correlated with antioxidant activity. This may be caused by the difference in antioxidant mechanisms. It is reported that caffeic acid and epicatechin are through the hydrogen atom transfer mechanism, resveratrol is through the electron-associated proton transfer mechanism, and quercetin is complexed with metal ions (Nie et al., 2020). Therefore, it is not comprehensive to choose a single method to evaluate antioxidant capacity.

3.5. Effects of postharvest dehydration on volatile compounds in Marselan wines

Aroma is one of the most important indexes to evaluate the sensory characteristics of wine (Qian et al., 2023), which is affected by many factors. Wine made from different varieties or even the same variety of grapes has different characteristics of volatile compounds, and their respective composition and proportion of volatile compounds endow wine with typical aroma. A total of 63 volatile compounds were detected in the five groups of wines (Table 2), including acids, esters, alcohols, ketones, aldehydes, ethers and volatile phenols. Among the volatile compounds, esters are the most abundant, followed by alcohols, which is similar to the previous research results (Urcan et al., 2017), but this study have hardly observed terpenes, considering the differences caused by grape varieties. Principal component analysis was used to further analyze the difference in volatile components in Marselan wine of different dehydration treatments (Fig. 3A). The first two principal components cumulatively explained 68.8% of the total variation (PC1,

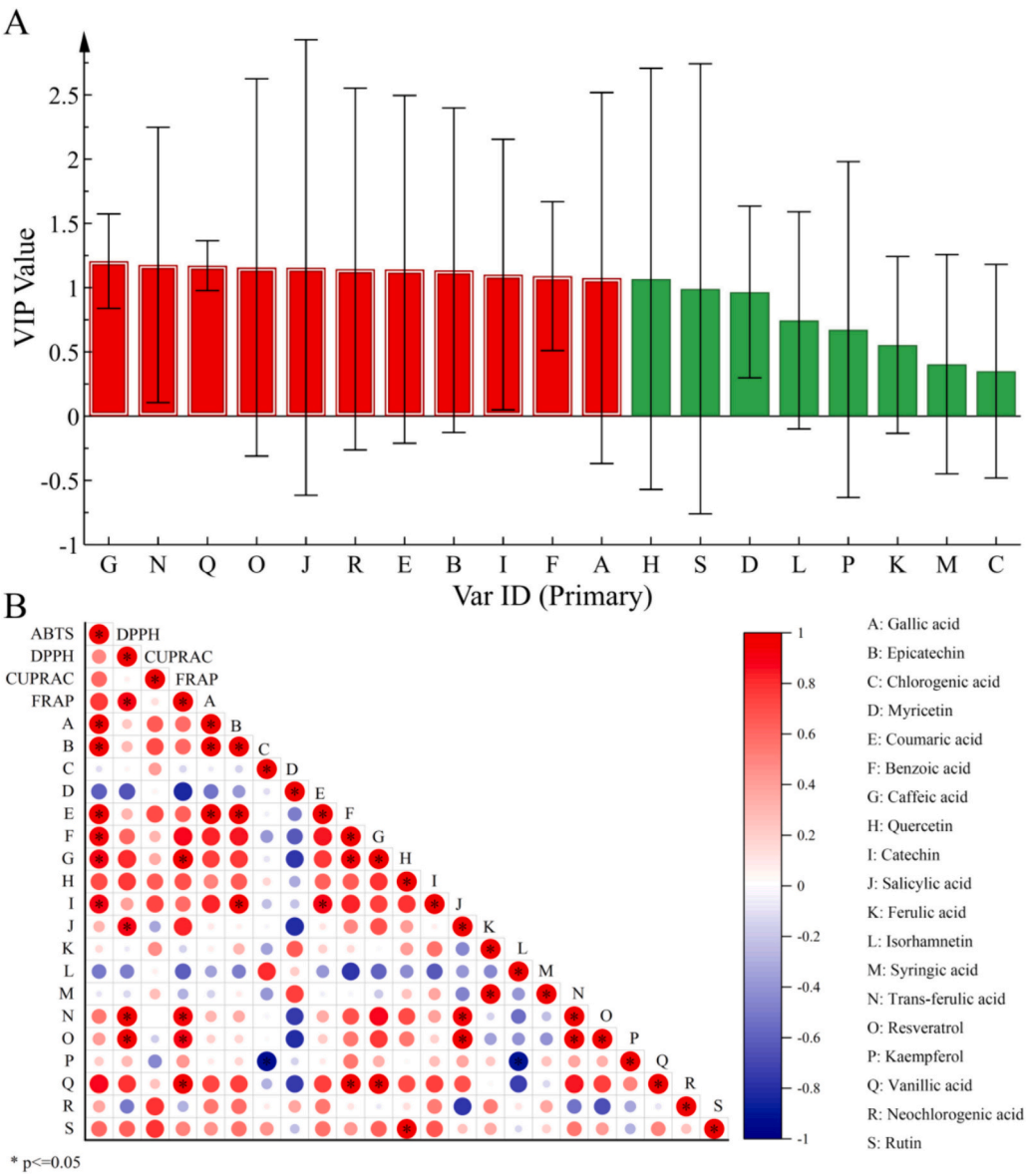

Fig. 2. A: The variable influence on projection in O2PLS models. The variable importance (VIP) value represents relevance. B: The relationship between phenolic compounds and antioxidant activity. The strong correlation and weak correlation are represented by large circles and small circles, respectively. The color of the scale represents the nature of the correlation; 1 represents a completely positive correlation (red), −1 represents a completely negative correlation (blue). The correlation is significant ($p < 0.05$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

43.9%; PC2, 24.9%), and there was a clear separation between wine samples of different dehydration treatments. According to the loading plot of PCA (Fig. 3B), the aromatic compounds were identified and labeled. The change process of volatile compounds in the post-harvest dehydration process can be identified by the cluster heatmap (Fig. 3C). The volatile compounds with similar rules were divided into 5 clusters. Group 1 increased significantly at MSL10, and then showed a relatively stable trend. Cluster 2 was characterized by the highest concentration in the control group or mild dehydration period. Cluster 3 fluctuated slightly before MSL20 and reached the highest concentration during MSL20. Cluster 4 peaked in the MSL15 period. Cluster 6 showed greater volatility between samples and increased overall compared with the control group.

3.5.1. *Alcohol compounds*

Higher alcohols are secondary products of yeast metabolism. Isobutanol, isoamyl alcohol and phenylethyl alcohol are the main alcohols in Marselan dehydration wine. Isobutanol has the unique stimulating smell of wine, which endows wine with light sweet and mellow characteristics. The content of isoamyl alcohol is the highest, and it accumulates significantly with the degree of dehydration, reaching a peak at the MSL25 period. It was reported that isoamyl alcohol can be produced by the leucine-Ehrlich pathway and *de novo* synthesis pathway (Roman, Rubio-Breton, Perez-Alvarez, & Garde-Cerdan, 2020), with fruit, bitter almonds and other fragrances. Phenylethanol is produced by phenylalanine metabolism (Wang et al., 2023) and has a rose fragrance. Compared with CK, the alcohols in the dehydrated Marselan wine had higher content and greater richness. For example, 2,3-butanediol is significantly increased in dehydrated wines, giving the wine a creamy aroma. Of note, one of the reactions associated with dehydration metabolism is that with the action of lipoxygenase (LOX) activity and alcohol dehydrogenase (ADH) activity, cell metabolism is converted from aerobic to anaerobic, resulting in the formation of some C6 volatiles, providing herbaceous odors for grapes and wines (Costantini, Bellincontro, De Santis, Botondi, & Mencarelli, 2006).

Table 2
Content of aroma components in Marselan wines (μg/L).

Compounds		RI	CK	AD10	AD15	AD20	AD25
Acids							
A1	Malonic acid	1774	nd	0.87 ± 0.04b	nd	4.12 ± 0.11a	nd
A2	Acetic acid	1463	nd	nd	169.14 ± 6.1a	nd	83.51 ± 2.21b
A3	Isobutyric acid	1102	4.63 ± 0.12c	8.17 ± 0.37b	8.49 ± 0.31b	8.94 ± 0.24a	2.26 ± 0.06d
A4	Lactic acid	1138	26.14 ± 0.69a	2.98 ± 0.14b	nd	nd	nd
A5	Butyric Acid	1636	0.28 ± 0.01d	2.7 ± 0.12b	1.19 ± 0.04c	1.33 ± 0.04c	8.02 ± 0.21a
A6	2-Methylhexanoic acid	1757	13.38 ± 0.35c	14.98 ± 0.26b	18.69 ± 0.67a	3.95 ± 0.1d	1.05 ± 0.03e
A7	1-Hexanoic acid	1836	32.82 ± 0.87b	34.79 ± 0.6a	33.13 ± 1.19b	28.49 ± 0.75c	10.85 ± 0.29d
A8	Octanoic acid	2060	73.01 ± 1.93a	48.55 ± 0.84b	30.92 ± 1.11d	34.82 ± 0.92c	nd
Esters							
B1	Ethyl acetate	888	334.84 ± 5.8e	649.83 ± 11.26d	1134.41 ± 40.9b	1936.99 ± 51.25a	950.02 ± 25.14c
B2	Isobutyl acetate	1015	nd	nd	nd	1.15 ± 0.03	nd
B3	Ethyl butanoate	1037	66.34 ± 1.15b	3.28 ± 0.06d	72.72 ± 2.62a	9.88 ± 0.26c	0.42 ± 0.01e
B4	Isoamyl acetate	1119	419.49 ± 7.27c	415.76 ± 7.2c	955.93 ± 34.47b	2122.63 ± 56.16a	87.91 ± 2.33d
B5	Isoamyl benzoate	1206	nd	nd	0.09 ± 0.02b	nd	0.34 ± 0.01a
B6	Ethyl hexanoate	1230	456.96 ± 7.91c	260.88 ± 4.52d	678.69 ± 24.47a	553.81 ± 14.65b	90.04 ± 2.38e
B7	Hexyl acetate	1272	6.47 ± 0.11d	8.81 ± 0.15c	12.56 ± 0.45b	13.37 ± 0.35a	nd
B8	Ethyl heptanoate	1329	19.49 ± 0.34b	21.52 ± 0.37a	12.54 ± 0.45c	nd	nd
B9	Pentyl acetate	1176	7.45 ± 0.13a	3.28 ± 0.07b	2.79 ± 0.1c	1.3 ± 0.03d	nd
B10	Methyl octylate	1551	1.36 ± 0.02c	1.06 ± 0.02d	2.68 ± 0.1b	nd	5.52 ± 0.15a
B11	Ethyl caprylate	1437	1096.68 ± 19a	639.99 ± 12.8c	955.9 ± 34.47b	360.84 ± 9.55d	192.64 ± 5.1e
B12	7-Octenoic acid ethyl ester	1478	12.59 ± 0.22a	3.43 ± 0.07b	nd	nd	nd
B13	Linalyl butyrate	1681	3.12 ± 0.05	nd	nd	nd	nd
B14	Octanoic acid,2-methylpropyl ester	1551	1.04 ± 0.02	nd	nd	nd	nd
B15	Formic acid, octylester	1557	22.26 ± 0.97a	9.8 ± 0.2b	4.07 ± 0.18d	9.15 ± 0.24b	6.78 ± 0.18c
B16	Methyl Caprate	1591	4.54 ± 0.2	nd	nd	nd	nd
B17	Methyl benzoate	1612	2.2 ± 0.1a	nd	1.62 ± 0.07b	nd	nd
B18	Ethyl caprate	1645	290.21 ± 12.65a	265.13 ± 5.3b	156.97 ± 6.84c	109.73 ± 2.9d	51.2 ± 1.35e
B19	3-Methylbutyl octanoate	1659	nd	1.74 ± 0.03c	1.86 ± 0.08b	2.56 ± 0.07a	nd
B20	Ethyl trans-4-Decenoate	1680	123.64 ± 2.14a	64.93 ± 1.3b	19.28 ± 0.84d	29.22 ± 0.77c	5.6 ± 0.15e
B21	Methyl salicylate	1753	0.59 ± 0.01d	4.09 ± 0.08b	4.95 ± 0.22a	1.99 ± 0.05c	nd
B22	Ethyl phenylacetate	1783	4.29 ± 0.07a	3.02 ± 0.06c	3.42 ± 0.15b	nd	nd
B23	Ethyl isovalerate	1064	9.57 ± 0.17b	18.6 ± 0.37a	nd	nd	nd
B24	Phenethyl acetate	1812	95.55 ± 1.66a	75.2 ± 1.5c	8.18 ± 3.67b	56.68 ± 2.04d	58.57 ± 1.55d
B25	Ethyl laurate	1841	25.37 ± 0.44b	36.1 ± 0.72a	17.9 ± 0.78c	15.68 ± 0.57d	1.54 ± 0.04e
B26	Isoamyl decanoate	1866	0.95 ± 0.02b	1.32 ± 0.03a	nd	nd	nd
B27	Ethyl 3-phenylpropanoate	1892	1.56 ± 0.03	nd	nd	nd	nd
Alcohols							
C1	3-Methyl-2-butanol	1099	1.86 ± 0.04c	2.49 ± 0.07b	7.57 ± 0.33a	1.08 ± 0.04d	0.76 ± 0.02e
C2	Isobutanol	1102	321.05 ± 7.41d	238.36 ± 6.31e	476.53 ± 20.77c	957.89 ± 34.54a	814.91 ± 21.56b
C3	Butanol	1135	16.69 ± 0.39c	nd	nd	86.93 ± 3.13a	58.66 ± 1.55b
C4	3-Methyl-1-butanol	1201	3915.11 ± 90.42e	6078.98 ± 160.83d	11,863.32 ± 517.11b	13,639.93 ± 491.79a	6813.78 ± 180.28c
C5	2-Ethyl-1-butanol	1307	1.28 ± 0.03b	5.12 ± 0.14a	nd	nd	nd
C6	4-Methyl-1-pentanol	1318	4.9 ± 0.11c	7.86 ± 0.21b	14.65 ± 0.64a	4.21 ± 0.15d	3.62 ± 0.1e
C7	(*S*)-(+)-2-Heptanol	1339	nd	0.61 ± 0.02b	1.77 ± 0.08a	nd	nd
C8	1-Hexanol	1351	nd	198.74 ± 5.26b	313.36 ± 13.66a	nd	170.8 ± 4.52c
C9	1,4-Pentanediol	1402	nd	3.26 ± 0.09	nd	nd	nd
C10	Heptan-1-ol	1452	139.23 ± 3.22c	181.28 ± 4.8b	0.79 ± 0.03d	244.2 ± 8.8a	nd
C11	butane-2,3-diol	1545	5.4 ± 0.12d	190.16 ± 5.03a	142.9 ± 6.23b	44.39 ± 1.6c	139.42 ± 3.69b
C12	1-Nonanol	1658	13.58 ± 0.31a	6.97 ± 0.18b	0.82 ± 0.04e	3.09 ± 0.11d	5.52 ± 0.15c
C13	Methionol	1711	4.22 ± 0.19c	3.52 ± 0.09d	11.47 ± 0.5a	6.31 ± 0.23b	2.51 ± 0.07e
C14	Benzyl alcohol	1877	4.52 ± 0.21d	8.88 ± 0.24c	10.21 ± 0.44b	14.96 ± 0.54a	3.55 ± 0.09e
C15	Phenethyl alcohol	1906	997.97 ± 45.73e	1091.69 ± 28.88d	2294.13 ± 99.99a	1561.64 ± 56.31b	1349.8 ± 35.71c
Others							
D1	Capriphenone	1903	nd	Nd	3.78 ± 0.1b	4.24 ± 0.15a	4.1 ± 0.11a
D2	Acetoin	1284	nd	23.94 ± 0.63c	3.35 ± 0.09d	676.36 ± 24.39b	714.72 ± 18.91a
D3	Propiophenone	1712	nd	2.84 ± 0.08b	nd	nd	5.67 ± 0.15a
D4	2,5-Heptanedione	1759	nd	nd	nd	2.68 ± 0.1	nd
D5	Geranylacetone	1858	5.2 ± 0.19	nd	nd	nd	nd
E1	Melonal	1366	4.49 ± 0.16b	2.2 ± 0.06d	4.38 ± 0.12b	9.79 ± 0.35a	3.02 ± 0.08c
E2	Nonanal	1391	nd	3.24 ± 0.09	nd	nd	nd
E3	Decanal	1499	8.31 ± 0.3a	5.33 ± 0.14b	2.41 ± 0.06c	nd	nd
F1	Hexyl Ether	1367	0.51 ± 0.02	nd	nd	nd	nd
F2	15-Crown-5	2431	0.86 ± 0.03a	0.19 ± 0.01c	0.86 ± 0.02a	0.29 ± 0.01b	0.32 ± 0.01b
F3	12-Crown-4	2450	0.64 ± 0.02c	0.15 ± 0.01e	1.45 ± 0.04a	0.29 ± 0.01d	1.04 ± 0.03b
F4	2,4-Di-t-butylphenol	2309	89 ± 3.21a	42.63 ± 1.13c	42.53 ± 1.13c	77.43 ± 2.79b	79.54 ± 2.1b
F5	Gamma-Butyrolactone	1632	nd	1.05 ± 0.02	nd	nd	nd

Notes: Data are expressed as the mean ± standard deviation from replicate analyses (n = 3) of three replicate samples. CK represents control, MSL10, MSL15, MSL20, MSL25 represent postharvest dehydration at 10%, 15%, and 20%, 25%berry weight loss, respectively.The different lowercase letters in each row indicate significant differences between samples ($p < 0.05$). The "nd" indicates that it is not detected. The substances represented by A1-F5 correspond to Fig. 3b.

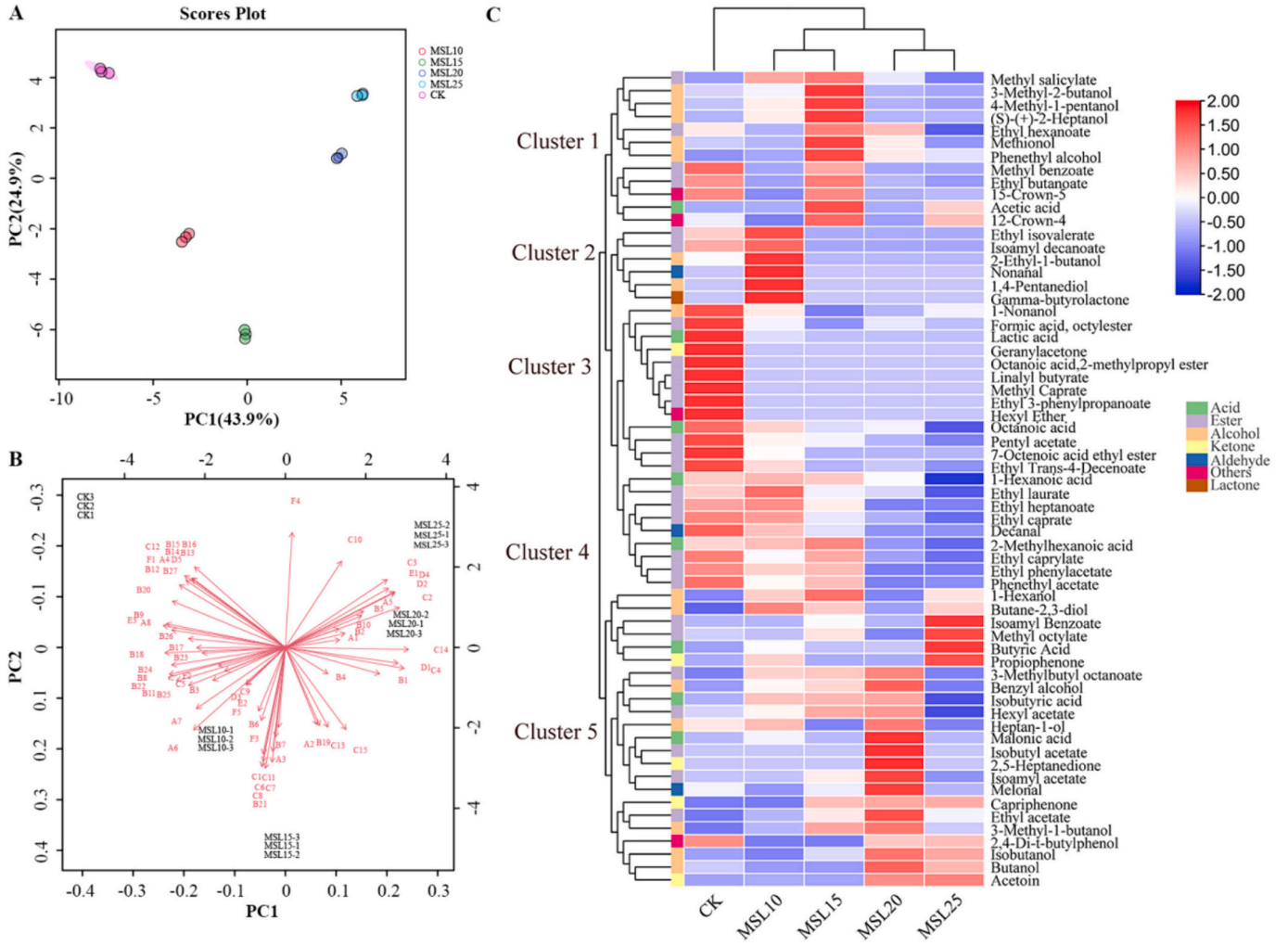

Fig. 3. Principal component analysis (PCA) score plot (A) and loading plot (B) based on the concentrations of volatile compounds in Marselan wines, and heatmap analysis (C) based on the concentrations of maker volatile compounds identified by PCA analysis. Each serial number in Fig. B represented one compound listed in Table 2.

3.5.2. *Acid compounds*

Volatile acid is a kind of organic acid in wine, which mainly comes from the grape itself and the microbial metabolism in the winemaking process. Moderate amount of volatile acid not only increases the complexity and interest of wine, but also helps to maintain good stability and shelf life of wine. A total of 8 volatile acids were detected in this study. The volatile acids of Marselan dehydration wine were mainly acetic acid, hexanoic acid and octanoic acid. Acetic acid is an important indicator to control whether the wine production process is contaminated by bacteria and whether it is spoiled during storage. In this study, acetic acid was detected in MSL15 and MSL25, which may be the result of microbial oxidation of ethanol during fermentation of these two groups of wines. Hexanoic acid provided the taste of grass and fruit for wine, and octanoic acid provided the taste of dairy products. They had the highest content in CK, which were 32.82 μg/L and 73.01 μg/L, respectively. With the advancement of dehydration, the content of octanoic acid and hexanoic acid showed a downward trend, and octanoic acid was not even detected in MSL25. It was worth noting that hexanoic acid and octanoic acid were C6-C10 fatty acids, it had been reported that although the presence of C6-C10 fatty acids was usually associated with the appearance of negative odors (Tufariello, Capone, & Siciliano, 2012), they were very important for the aromatic balance in wine because they oppose the hydrolysis of the corresponding esters. Shinohara (2014) reported that the concentration of 4–10 mg/L C6-C10 fatty acids provideed a mild and pleasant aroma for wine, while higher than 20 mg/L will have a negative impact on the senses, in our study, only the content of MSL25 was lower than this level. In summary, the postharvest dehydration treatment caused a loss of volatile acid in wine, but this trend may be beneficial to the quality of wine.

3.5.3. *Ester compounds*

Volatile esters were the main aroma substances of Marselan dehydration wine, which were significantly affected by the dehydration process and were produced in large quantities during the fermentation process. A total of 27 esters were detected in ‘Marselan’ dehydration grapes. Among them, ethyl acetate, isoamyl acetate, ethyl butyrate and other substances were significantly accumulated, which was similar to previous results (Lopez de Lerma, Moreno, & Peinado, 2014). Due to the differences in dehydration rate and grape varieties, ethyl butyrate, amyl acetate, ethyl octanoate, ethyl decanoate, phenethyl acetate and ethyl laurate in this study observed a clear opposite trend. Ethyl esters were mainly synthesised during yeast fermentation by enzymatic grape precursors and by ethanolysis of acyl-CoA that is formed during fatty acid synthesis or degradation (Tufariello et al., 2012). Acetates were of great importance in the aroma of the whole wine, leaving a positive contribution of sweet taste, fruit taste and grape smell through unique sensory characteristics. It was worth noting that our study found methyl salicylate in all the periods before MSL20, which is a signaling molecule that

plays a key role in regulating the biosynthesis of terpenes in fruit tissues (Sanmartin et al., 2021).

3.5.4. Others

Other important volatile organic compounds are also significantly affected by the water loss rate. The aldehydes in the wine aroma are derived from unsaturated fatty acids, such as linoleic acid and linolenic acid, or they are products catalyzed by lipoxygenase (Tufariello et al., 2012). Our research only observed three aldehydes (melon aldehyde, nonanal, decanal) in Marselan wines, probably because they were easily reduced to the corresponding alcohols in the fermentation stage. It was worth noting that 3-hydroxy-2-butanone was detected in all wine samples except the CK, which provided sweetness, dairy flavor and greasy smell of fat for wine.

3.6. Analysis of key aroma compounds

Since the aroma performance of volatile compounds was highly correlated with their olfactory thresholds, the relative OAVs of volatile compounds in Marselan dehydration wine were introduced in the subsequent analysis. Compounds with OAVs >1 (exceeding the olfactory threshold) may directly affect the aroma of wine. In addition, volatile compounds with OAVs >0.1 have an important effect on the overall aroma of wine. In this study, a total of 13 aroma substances with OAVs >1 were detected (Table S2), and the effects of dehydration on these substances in Marselan wine were studied by principal component analysis (Fig. 4A). PC1 explained 46.4% of the total variance, and PC2 explained 32.5% of the total variance. According to the PCA diagram, different samples were completely separated, indicating that there were significant differences in volatile compounds among the five samples. According to the load diagram (Fig. 4B), the samples with different

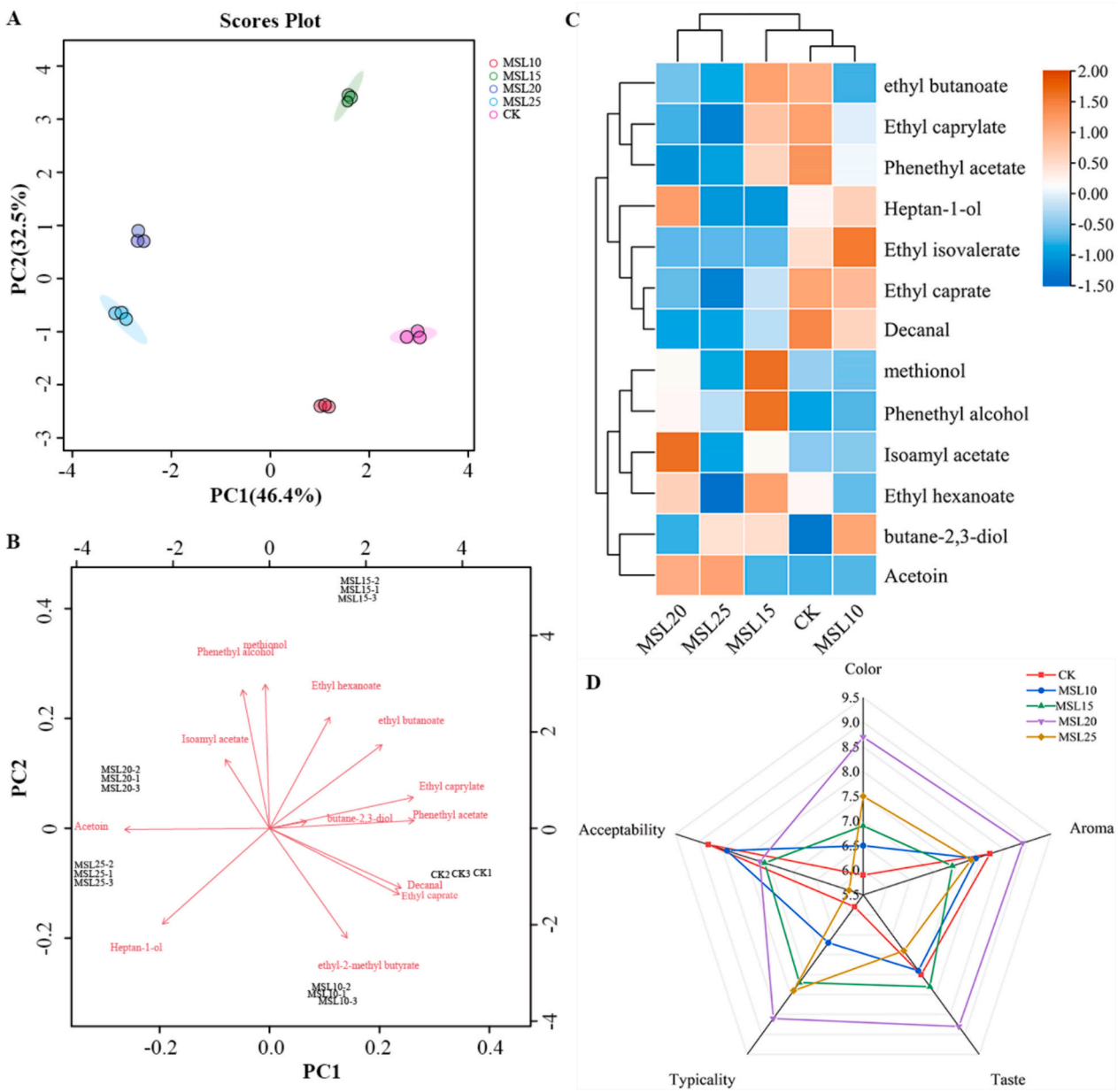

Fig. 4. Principal component analysis based on the concentrations of the volatile compounds with relative OAVs higher than 1 (A), and partial least squares-discriminant analysis loading plot showing the volatile compounds with the VIP higher than 1 (B), Heatmap analysis (C) based on the concentrations of the volatile compounds with relative odor activity values (OAVs) higher than 1, Radar chart of sensory characteristics of Marselan wines (D).

dehydration degrees were located in different quadrants. CK had a strong correlation with decanal and ethyl decanoate, which rendered the wine obvious fat and fruity attributes, respectively. Ethyl 2-methylbutyrate was the characteristic aroma compound of MSL10, with green fruit aroma. The most important contributors to MSL25 were n-heptanol and 3-hydroxy-2-butanone, which endowed the wine with lemon flavor, sweet and milk flavor. The characteristic aroma compound of MSL20 was isoamyl acetate, and the characteristic flavor was banana and pear. According to the clustering results and trend heat maps (Fig. 4C) of flavor compounds, decanal, phenethyl acetate and ethyl caprylate contributed the most to CK. With the increase of dehydration degree, ethyl isovalerate accumulated significantly in MSL10 period, while phenethyl alcohol and methionol contributed the most to MSL15. After the MSL20 period, the aroma substances began to decrease significantly, which was caused by the high degree of dehydration.

3.7. Sensory evaluation

Sensory evaluation was performed according to color, aroma, taste, typicality and acceptance (Fig. 4D). The results showed that there were significant differences in sensory characteristics of Marselan wines with different dehydration degrees. CK scored higher in taste, acceptability and aroma, which may be related to the strong fruit aroma and long commercialization time of CK. As a representative of mild dehydration degree, MSL10 and MSL15 showed great differences in sensory characteristics. Considering that during the MSL10 period, close to common dry red wine, the color and typicality were not prominent, but the acceptability was high. By contrast, MSL15 was just the opposite, and the typicality and taste were improved. The MSL20 scores were generally high, indicating that the dehydration treatment produced many substances (alcohols and esters) that improved the characteristics of the wine. The acceptable significant decline in wine during MSL25 may be due to excessive alcohol caused by excessive dehydration and the concentration effect reaching a critical value, resulting in the production of bad odors and metabolites. In general, moderate dehydration treatment can improve the sensory quality of Marselan wines.

4. Conclusions

This study investigated the impacts of different postharvest dehydration levels on the basic physical and chemical properties, phenolic compounds, antioxidant activities, aroma compounds, and sensory characteristics of Marselan wines. Postharvest dehydration increased the alcohol content, residual sugar and titratable acid of wine. The contents of total phenols and total flavonoids in wine reached the highest content when the grape weight was reduced by 20%, while the contents of total anthocyanins and total tannins were significantly higher than those of CK. The monomeric phenols and antioxidant activities were generally improved and significantly correlated. Postharvest dehydration increased the contents of isobutanol, isoamyl alcohol, phenethyl alcohol, ethyl acetate, isoamyl acetate and ethyl butyrate in Marselan wine, rendering floral, fruity and sweet taste of Marselan wine. This study showed that the postharvest dehydration treatment of grape berries mainly increased the content of phenolic substances in wine, changed the aroma and sensory characteristics of wine, and considered that the wine products produced with a dehydration degree of about 20% had the best comprehensive quality. This study is the first time to combine Xinjiang high-quality 'Marselan' grapes with post-harvest dehydration technology, which verifies the effectiveness of post-harvest dehydration technology in improving wine quality, provides new ideas for the development of wine industry in Xinjiang, and provides theoretical basis for Marselan dehydration wine. It is of great significance to promote the healthy and sustainable development of the wine industry in Xinjiang. The change trend of physical and chemical properties of wine caused by different degrees of dehydration is similar, but it is necessary to further study the degree of dehydration and dehydration methods to better explain the impact on wine quality.

Institutional review board statement

"Not application" for studies not involving humans or animals.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

CRediT authorship contribution statement

Chenxu Xi: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Junbo Zhang:** Investigation, Formal analysis. **Fengming Zhang:** Methodology, Data curation. **Dong Liu:** Software, Investigation. **Weidong Cheng:** Project administration, Conceptualization. **Feifei Gao:** Writing – review & editing. **Ping Wang:** 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.

Acknowledgments

We were thankful to Chateau Changyu Baron Balboa Wine Co., Ltd. for providing the wine of this work. This work was supported by the High-level Talent Research Project of Shihezi University (No. RCZK2021B36) and the Xinjiang Production and Construction Corps Shihezi City Financial Project (No. 2023NY02-1).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2024.101503.

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