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Floral infusions: Elevating the bouquet of non-alcoholic chardonnay wine beverage

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ABSTRACT

This study explores the impact of natural flower extracts from *Prunus persica*, *Rosa chinensis*, and *Lilium bulbiferum* to enhance the aroma of dealcoholized Chardonnay wine, addressing the sensory deficiencies commonly associated with dealcoholized wine beverages (DWBs). The investigation revealed a richer bouquet of aromatic compounds, particularly higher alcohols, esters, and terpenes, which significantly elevated the aromatic profile of treated wines without altering their physicochemical properties. Principal Component Analysis (PCA) showed distinct aroma profiles between control and flower extract-DWBs, with the latter exhibiting enhanced floral and fruity characteristics. Additionally, Partial Least Squares Regression (PLSR) showed a positive correlation between specific volatile classes especially terpenes and esters, sensory attributes of floral and fruity notes, highlighting the crucial role of these compounds in enhancing overall aroma. These findings not only present a promising opportunity to improve the appeal of DWBs, but also suggest a potential for broader applications in the beverage industry.

1. Introduction

Recently, the market for low- and non-alcoholic wines has expanded significantly (FACT4532MR, R, 2022), driven by an increasing consumer preference for healthier beverage options. This trend reflects a growing awareness of the health risks associated with alcohol consumption, as highlighted by the World Health Organization (WHO, 2018). Low-alcohol wines, which have an ethanol content ranging from 0.5 % to 1.2 % *v*/v, and non-alcoholic wines, with alcohol concentrations below 0.5 % v/v, have emerged as popular alternatives (Pickering, 2000; Saliba et al., 2013).

Producing low- and non-alcoholic wines requires strategic interventions at different stages of vinification. These stages include pre-fermentation, fermentation, and post-fermentation, and they are tailored to meet the precise requirements for adjusting alcohol content (Longo et al., 2017; Ma et al., 2023; Sam, Ma, Salifu, et al., 2021). During the pre-fermentation phase, techniques aimed at reducing fermentable sugars are employed. These include dilution of grape juice (Schelezki et al., 2020), juice filtration (Salgado et al., 2017), enzymatic treatment of juice with glucose oxidase (Ruiz et al., 2018), and blending juices from grapes harvested at different maturities (Longo et al., 2018). During fermentation, strategies are mainly focused on limiting ethanol production. This can be achieved through yeast biomass reduction (Fan et al., 2012), halting fermentation prematurely, employing non-Saccharomyces yeast strains with inherently lower ethanol production capabilities (Lemos Junior et al., 2019), and using genetically modified yeast strains designed to produce less alcohol (Puškaš et al., 2020). In the post-fermentation stage, reducing or removing alcohol is commonly done using physical and chemical methods. These methods include thermal techniques like vacuum distillation and spinning cone columns, membrane-based processes such as reverse osmosis, osmotic distillation, and pervaporation, as well as extraction methods using organic solvents, absorbents, and gases (Akyereko et al., 2021; Ma et al., 2023). Each approach is designed to meet the specific requirements for producing wines with lower or minimal alcohol content while aiming to preserve the sensory characteristics and quality of traditional wines.

Within the field of post-fermentation techniques for producing low- and non-alcoholic wines, membrane processes, particularly reverse osmosis (RO) and osmotic distillation (OD), are commonly used due to their minimal impact on the wine's aroma and sensory qualities (Longo et al., 2017; Ma et al., 2023; Sam, Ma, Salifu, et al., 2021). These methods are known for operating at lower temperatures and offering superior separation efficiency, thereby retaining crucial aroma compounds and preserving the organoleptic integrity of the wine. However,

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it has been observed that reducing the alcohol content through RO and OD can cause a degradation in the aroma and sensory profile of the resulting low- and non-alcoholic wines, due to vaporization, diffusion, or adsorption onto the membrane, which potentially negatively affecting consumer acceptance (Corona et al., 2019; Liguori et al., 2019; Motta et al., 2017; Pham et al., 2019; Sam, Ma, Salifu, et al., 2021). To address this challenge, the incorporation of aroma enhancers derived from natural, edible, and approved sources can be explored as a strategy to enhance the aroma profiles of these wines.

Prunus persica (peach), *Rosa chinensis* (Chinese rose), and *Lilium bulbiferum* (fire lily) are known for their distinct and rich aromatic profiles. These flowers contain a variety of volatile compounds, such as terpenoids, glycosides, esters, aldehydes, ketones, and phenolics, which contribute to their characteristic floral and fruity aromas (Du et al., 2019; Johnson et al., 2016; Sun et al., 2019; Zheng et al., 2018; Zhou et al., 2020). Extracting these compounds into an aqueous solution can provide a natural and complex aroma-enhancing agent for dealcoholized wines, potentially enhancing their sensory appeal. Additionally, the aqueous nature of these extracts ensures compatibility with the wine, allowing the integration of aromatic compounds without significantly altering the wine's physicochemical properties (Ma et al., 2022; Sam et al., 2023). This is crucial for maintaining the wine's stability and quality over time. Moreover, incorporating these flower extracts into dealcoholized wines represents an innovative approach that could establish a new industry standard and address the issue of aroma and flavor dilution commonly associated with alcohol removal. This provides a novel solution to enhance the marketability of the product. In addition to their aromatic contributions, extracts from *Prunus persica*, *Rosa chinensis*, and *Lilium bulbiferum* have been reported to have various health-promoting properties, such as antioxidant and anti-inflammatory effects (Zheng et al., 2018). Including them in dealcoholized wines could therefore offer additional health and wellness benefits, aligning with the health-conscious motivations behind the consumption of low- and non-alcoholic beverages.

Considering these precedents, the present study used extracts from rose, peach, and lily flowers to develop non-alcoholic wine beverages from dealcoholized chardonnay wine, with the goal of enhancing the aroma profile. The physicochemical parameters, volatile composition, and sensory attributes of the developed non-alcoholic wine beverages were evaluated and compared to a dealcoholized wine (DW), which served as the control. We hypothesize that the inclusion of extracts will significantly enhance the aroma profile, particularly by increasing the fruity and floral notes of the non-alcoholic wine beverages under investigation. This study could provide a novel solution to enrich the aroma profile of non-alcoholic beverages produced through dealcoholization and enhance their market appeal.

2. Materials and methods

2.1. Reagents and standards

The standards (Table S1) used for quantifying volatile compounds were provided by Sigma-Aldrich (Shanghai, China). All the standards were of gas chromatographic grade and had a purity of ≥90.0 %. Deionized water (<18 MW resistance) was prepared using a Milli-Q purification system (Molecular, Chongqing, China).

2.2. Wine acquisition

Chardonnay white wine (13.4 % *v*/v ethanol, 2019 vintage) was provided by Mogao Winery (Gansu Province, China) and used for the experiment. The wine corresponds to table wines commercialized as a bulk product and was produced using traditional winemaking methods. The chemical parameters of the wine were as follows: alcohol content = 13.4 % v/v, residual sugar = 0.20 g/L, total acidity = .36 g/L, volatile acidity = 0.32 g/L, pH = 3.80, total sulfur dioxide = 54.13 mg/L, and free sulfur dioxide = 24.50 mg/L.

2.3. Source of flowers and extracts preparation

The dried petals of edible *Prunus persica* (peach), *Rosa chinensis* var. spontanea red (Chinese rose), and *Lilium bulbiferum* (fire lily) were obtained from a local market in Lanzhou city, Gansu province, China. They were chosen for this study due to their distinctive and rich aromatic profiles (Sun et al., 2019; Zheng et al., 2018; Zhou et al., 2020), pleasant scent, availability, and their potential for value addition. In China, these flowers are commonly used in cakes, tea, and wine beverages. Petals of *Prunus persica* were harvested in April 2020 at the early opening stage, while those of *Rosa chinensis* and *Lilium bulbiferum* were collected in May 2020 at the early opening and half-opening stages, respectively. Aqueous extracts from the dried petals were prepared as shown in Fig. 1a, following the method described by Ma et al. (2022).

2.4. Wine dealcoholization and beverage preparation

Sixty liters (60 L) of Chardonnay wine were dealcoholized using an industrial reverse osmosis system (Hangzhou Ruina Membrane Engineering Co., Ltd., Hangzhou, China) following our previously described method (Sam, Ma, Liang, et al., 2021). A schematic diagram illustrating the dealcoholization process is presented in Fig. 1b. An Alfa Laval RO98pHt M20 composite membrane was used, and the process was conducted at a constant pressure of 3.5 MPa and 20 °C. After 180 min, a retentate (0.48 % *v*/v ethanol) was obtained.

Subsequent to dealcoholization, the retentate, referred to as dealcoholized wine (DW, 55 L), was separately reformulated with the extracts to develop dealcoholized wine beverages (DWBs). Following the method of Ma et al. (2022), the dealcoholized wine was divided into four portions (10 L each). Three of these portions were reformulated with natural extracts (NEs) of *Prunus persica*, *Rosa chinensis*, and *Lilium bulbiferum*, and termed PDWB, RDWB, and LDWB, respectively (Fig. S1). Additionally, a control consisting of 10 L of the DW (without any extract addition) was established and compared with DWBs. All samples were stored at 4 °C for 30 days before conducting all analyses.

2.5. Analyzes of physicochemical parameters

The pH, residual sugar, alcohol content, total acidity, volatile acidity, and free and total sulfur dioxide (SO_2) content of the experimental samples were determined using a WineScanTM SO_2 analyzer (FOSS Analytical A/S, Denmark). Color parameters were measured using a spectrophotometer (Genesis 10S UV–vis, Thermo Fisher Scientific, Waltham, MA, USA) following the method outlined in Compendium of International Methods of Wine and Must Analysis (OIV, 2023).

2.6. Determination of volatile compounds

Volatile compounds in wine samples and flower samples were determined using the method of Ivić (Ivić et al., 2021). A gas chromatography–mass spectrometry (GC–MS) system (TRACE 1310- ISQ, Thermo Fisher Scientific, San Jose, CA, USA) connected to a DB-WAX UI capillary column (60 m × 0.25 mm × 0.25 μm film thickness, Agilent Technologies) was used for the analysis. Each wine sample was prepared by adding 5 mL of DW, PDWB, LDWB, or RDWB to a 15 mL glass vial containing 1.5 g sodium chloride (NaCl) and 10 μ L 2-octanol (88.2 mg/L, as an internal standard). 10 g of flower sample was finely ground in liquid nitrogen, a 1.5 g of the flower powder was added in a 15 mL glass vial containing 6 mL of saturated sodium chloride (NaCl) solution and 10 μ L 2-octanol (88.2 mg/L, as an internal standard).

The vial was then sealed with a polytetrafluoroethylene silicone septum. Subsequently, the vial was then equilibrated for 30 min in a water bath at 40 °C with stirring (40 rpm). Headspace solid-phase microextraction (HS-SPME) was then used to extract the volatiles from

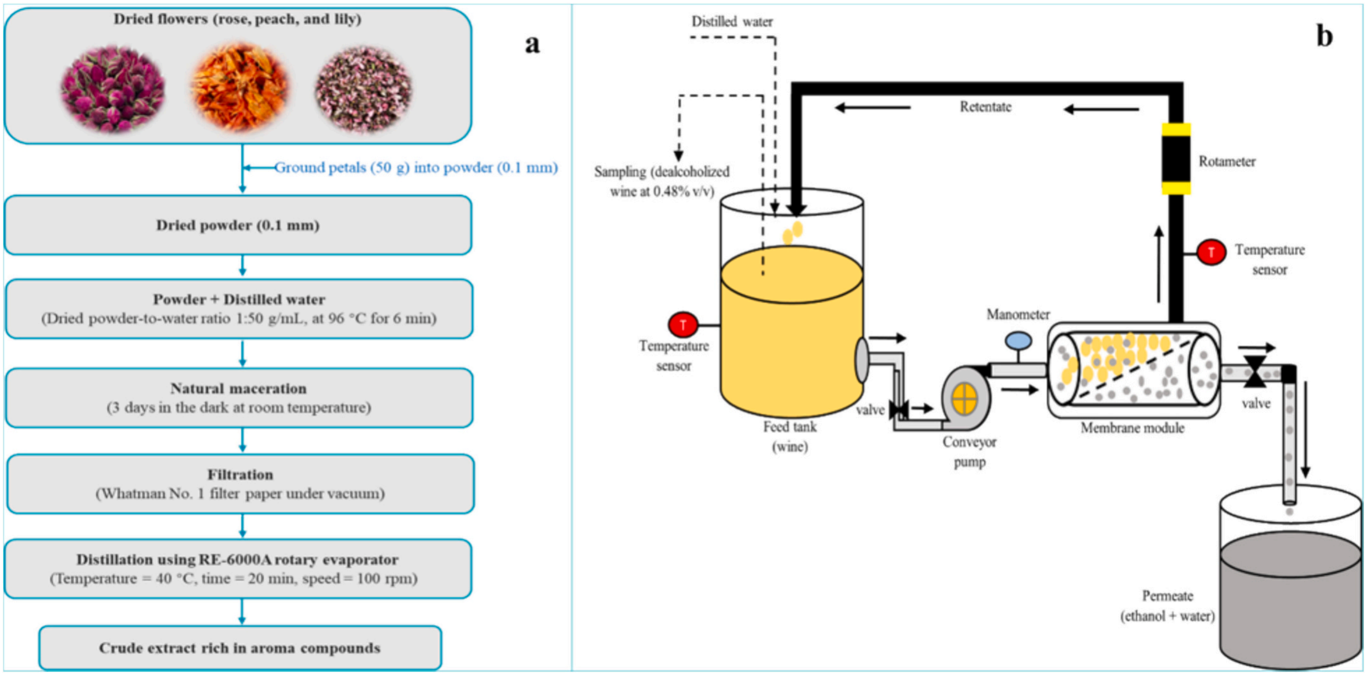

Fig. 1. Fig. 1. Flowchart for (a) preparing aqueous extracts from flowers and (b) dealcoholizing Chardonnay wine using reverse osmosis.

the prepared samples with the aid of using a fiber (DVB/CAR/PDMS, length 1 cm, film thickness 50/30 μm, Supelco, Bellefonte, PA, USA).

The fiber was inserted into the GC–MS system's injector port for desorption and analysis of volatile chemicals at 250 °C in splitless mode for 7 min, using helium (purity 99.9 %) as the carrier gas at a constant flow rate of 1.0 mL/min. The GC oven temperature was initially set to 40 °C for 5 min, then ramped up to 200 °C at a rate of 4 °C/min for 20 min. The MS parameters were configured with a mass range of 50–350 m/z, an ionization voltage of 70 eV, a transfer temperature of 200 °C, and an ion source temperature of 250 °C. Detected volatile compounds were identified by comparing their mass spectra to those in the National Institute of Standards and Technology library (NIST 14, search version 2.0). The identified volatiles were quantified based on their peak areas in the samples against their respective standards (see Section 2.1). Other volatile compounds without standards were quantified using standards of similar volatile compounds.

2.7. Sensory evaluation

A panel of 13 experienced wine tasters conducted a sensory evaluation of DW and DWBs, as described in a previous study (Liguori et al., 2019). All participants were informed that their participation in the experiment was voluntary, and their formal consent was obtained. The Research Ethics Committee of Gansu Agricultural University (reference number GSAU-Eth-VMC-2023-038) granted ethical approval for human subjects to participate in the current study. The judges assessed the samples at room temperature and rated them on various attributes such as bitterness, acidity, sweetness, wine body, color intensity, floral note, fruity note, aroma intensity, and overall acceptability using a 10-point scale (Sam, Ma, Liang, et al., 2021), with 1 representing extremely low and 10 representing extremely high. The final rating for each wine was calculated by adding together the average scores.

2.8. Statistical analyzes

The data on physicochemical parameters and volatile compounds were analyzed using analysis of variance (ANOVA) and multiple comparison analysis (Tukey test; $p < 0.05$) in XLSTAT (version 2019, Addinsoft, New York, USA). Orthogonal partial least squares discrimination analysis (OPLS-DA) was performed using Simca 14.1(Umetrics, Sweden). Mean values of sensory data were compared using the Kruskal-Wallis non-parametric test. Principal component analysis (PCA) was also used to determine the association between sensory characteristics and volatile compounds in the samples. Additionally, partial least squares regression (PLSR) was used to assess how volatile categories influenced the perceived aromas of the samples. The PLSR analysis was performed with Unscrambler 9.7 (Camo, Trondheim, Norway), using cross-validation and standardization of the variables. A PCA biplot was obtained from the statistical output, while the sensory spider plot was generated using Origin 2021 software (Origin Lab, Northampton, USA).

3. Results and discussion

3.1. Effect of extracts on the chemical parameters of experimental samples

Table 1 presents the findings from the analysis of the chemical composition of dealcoholized wine beverages, focusing on the effects of different flower extracts. The data show that there were no significant differences in residual sugar, alcohol content, total and volatile acidity, pH, total and free sulfur dioxide, color intensity, and hue between the control dealcoholized Chardonnay wine (DW) and those containing *Rosa chinensis* (RDWB), *Prunus persica* (PDWB), and *Lilium bulbiferum* (LDWB) extracts. This suggests that the addition of these flower extracts does not significantly alter the basic physicochemical properties of the dealcoholized wines.

When comparing these findings with previous studies, it is evident that using natural extracts in modifying dealcoholized wines has been shown to have minimal impact on the wine's basic chemical composition while potentially enhancing sensory attributes. In a study by Liguori et al. (2019), it was found that adding floral wine flavors like 2-phenylethanol, ethyl decanoate, and geraniol could improve the sensory profile of dealcoholized wines without significantly altering their chemical composition. Similarly, Rodríguez-Bencomo et al. (2013) discovered that glycosidic aroma precursors could enhance wine aromas without substantially affecting core wine parameters. Recent research by Sam

Table 1
Chemical composition of dealcoholized wine beverages.

Physicochemical parameter	DW	LDWB	PDWB	RDWB	P-value
Residual sugar (g/L)	1.02 ± 0.01a	1.02 ± 0.02a	1.02 ± 0.01a	1.01 ± 0.03a	0.803
Alcohol (% v/v)	0.48 ± 0.00a	0.47 ± 0.00a	0.48 ± 0.00a	0.47 ± 0.00a	0.409
Total acidity (tartaric acid g/L)	6.43 ± 0.01a	6.33 ± 0.25a	6.30 ± 0.17a	6.50 ± 0.27a	0.727
Volatile acidity (g/L)	0.20 ± 0.01a	0.19 ± 0.25a	0.19 ± 0.01a	0.20 ± 0.26a	0.250
pH	3.55 ± 0.01a	3.55 ± 0.01a	3.54 ± 0.01a	3.54 ± 0.02a	0.460
Total SO_2 (mg/L)	51.91 ± 0.02a	50.40 ± 0.53a	50.57 ± 0.61a	50.67 ± 0.38a	0.131
Free SO_2 (mg/L)	21.90 ± 0.20a	21.30 ± 1.13a	20.93 ± 1.19a	21.27 ± 0.95a	0.670
Color intensity	0.45 ± 0.04a	0.45 ± 0.04a	0.44 ± 0.03a	0.45 ± 0.04a	0.999
Hue	1.37 ± 0.33a	1.31 ± 0.22a	1.39 ± 0.31a	1.35 ± 0.33a	0.991

Data are expressed as the means of three samples ± standard deviations. Different letters within each row are significantly different (Tukey test; $P < 0.05$). SO2; sulfur dioxide, DW; dealcoholized Chardonnay wine (control), RDWB; dealcoholized wine beverage containing *Rosa chinensis* extract, PDWB; dealcoholized wine beverage containing *Prunus persica* extract, and LDWB; dealcoholized wine beverage containing *Lilium bulbiferum* extract.

et al. (2023) and Ma et al. (2022) investigated the impact of peach, rose, and lily extracts on enhancing the sensory qualities of dealcoholized red wine and rosé wine. The research found no influence on the chemical parameters. These findings are promising for the wine industry as they indicate that adding flower extracts can preserve the quality of dealcoholized wine and potentially introduce new aroma profiles that appeal to consumers seeking natural beverage options.

3.2. Volatile compounds detected in flower samples

A total of 107 volatile compounds were detected in the flower samples (Table S2), including 25 esters (E1-E25), 10 higher alcohols (H1−H10), 23 aldehydes (A1-A23), 9 ketones (K1-K9), 12 fatty acids (F1-F12), 16 terpenes (T1-T16), 8 volatile phenols(V1-V8), and 4 lactones(L1-L4). A reliable OPLS-DA was performed for these individual compounds and plotted in Fig.2, the biomarkers with relatively variable importance in projection (VIP) >1.0 are shown with labels in the loading plot, and a total of 52 volatile compounds are marked. The lily and peach flower were located on the right side and left side of pq(corr)[1], respectively, and rose flower were located on the positive side of pq (corr)[2]. The lily flower had higher concentration of esters, aldehydes, and lactones, while the peach flower had higher concentration of esters, fatty acids, and terpenes, moreover, the rose flower showed higher concentration of higher alcohols and volatile phenols. The top five volatile compounds with the highest VIP values were valeric acid, ethyl benzoate, β-lonone, 3,5-dimethoxytoluene, Ethyl acetate, D-camphor, methyl phenylacetate, α-terpineol, caryophyllene oxide, and methyl benzoate, these compounds may be important indicators to distinguish the difference between flowers. Due to the huge difference in the thresholds of volatile compounds, the effect of the flower extract on aroma profile of dealcoholized wine beverages could be complicated.

3.3. Volatile compounds detected in the experimental samples

Fifty-eight (58) aroma compounds were detected and quantified in the samples (Table 2). The main types of aroma compounds detected in all samples were higher alcohols (55.3 %), esters (39.7 %), aldehydes and ketones (2.7 %), fatty acids (1.7 %), and terpenes (0.5 %). Among the experimental samples, a higher percentage of all types of aroma compounds was found in RDWB (29.6 %), followed by LDWB (28.2 %), PDWB (25.5 %), and DW (16.7 %). The higher percentage of aroma compounds observed in RDWB, LDWB, and PDWB compared to DW can be attributed to the unique chemical composition of aqueous extracts from *Rosa chinensis*, *Lilium bulbiferum*, and *Prunus persica*, which include a diverse array of volatile compounds not typically present in wine. These extracts provide a rich source of aroma-active compounds such as esters, terpenes, and phenolics (Sun et al., 2019; Zheng et al., 2018; Zhou et al., 2020), which can synergistically interact with the wine matrix to enhance aroma perception (Yang et al., 2023). Additionally, the concentration levels of these compounds in the flower extracts may have surpassed those naturally occurring in Chardonnay wine, resulting in a more pronounced aromatic profile.

Seven terpenes (T1-T7) were identified and quantified in the samples, with concentrations ranging from 0.004 mg/L (in DW) to 0.059 mg/L (in RDWB). The total relative concentration of terpenes was, on average, 14 % higher in the latter. Among the terpenes, α-terpineol had DWBs compared to DW. The terpene with the highest concentration was α-terpineol, followed by citronellol (both in RDWB). The addition of NEs significantly affected the number and concentration of individual terpenes in DWBs compared to the control (DW). It was observed that the concentration of all terpenes in DWBs (except linalool) was significantly higher compared to DW, while the concentration of β-damascenone remained almost unchanged. Notably, α-terpineol increased from 0.051 mg/L in DW to 0.059 mg/L in RDW, representing a fold change of approximately 1.16. In contrast, the concentration of linalool decreased from 0.020 mg/L in DW to 0.017 mg/L in RDW, indicating a 15 % reduction. Extracts from *R. chinensis*, *L. bulbiferum*, and *P. persica* offer a rich source of aroma-active compounds, including terpenes (Du et al., 2019; Inna & Olena, 2020; Johnson et al., 2016; Mohammed et al., 2021; Niu et al., 2021), which can synergistically interact with the wine matrix to enhance the concentration of terpenes (Yang et al., 2023). Specifically, linalool in DWBs may have undergone molecular rearrangement to form citronellol, geraniol, geranyl acetone, and α-terpineol through processes such as hydrogenation, isomerization, cyclization, or nucleophile 1,3 transfer (Yang et al., 2023). This results in a decreased concentration of linalool and an increase in the concentrations of the aforementioned volatiles in DWBs compared to DW. Consistent with our previous studies (Ma et al., 2022; Sam et al., 2023), the concentrations of citronellol, geraniol, geranyl acetone, and α-terpineol increased after adding extracts from these flowers to dealcoholized Pinot Noir rosé and Merlot red wines. However, nerol was not detected in DW but showed detectable concentrations of 0.002 mg/L and 0.003 mg/L in LDWB and RDWB, respectively. Nevertheless, its concentration in these samples was very low compared to other terpenes.

The concentrations of most esters in DWBs increased with the addition of NEs compared to DW. Ethyl octanoate, isoamyl acetate, and ethyl hexanoate had the highest concentrations of 4.817 mg/L (in LDWB), 1.933 mg/L (in RDWB), and 1.703 mg/L (in LDWB), respectively. Compared with DW, the concentrations of these esters increased significantly by 1.7-fold, 1.1-fold, and 2.7-fold in LDWB, RDWB, and LDWB, respectively. These esters can impart wines with fruity and floral aromas (Guth, 1997). Additionally, the concentrations of some esters, including ethyl acetate, isoamyl hexanoate, isoamyl octanoate, and ethyl hexadecanoate, increased in DWBs after adding NEs. However, their increase was not significant compared with DW. Similarly, a higher concentration of these esters was observed in a dealcoholized white wine reconstituted with glycosidic aroma precursors isolated from grapes (Rodríguez-Bencomo et al., 2013). Remarkably, some esters, including ethyl propanoate, ethyl isovalerate, ethyl crotonate, and isoamyl isobutanoate, which were absent due to dealcoholization, were detected in DWBs, suggesting that *R. chinensis*, *L. bulbiferum*, and *P. persica* contained these esters (Du et al., 2018; Johnson et al., 2016; Mohammed et al., 2021; Sun et al., 2019; Zhou et al., 2020;). Particularly, ethyl crotonate was newly introduced in DWBs, while ethyl propanoate, ethyl isovalerate, and isoamyl isobutanoate were newly

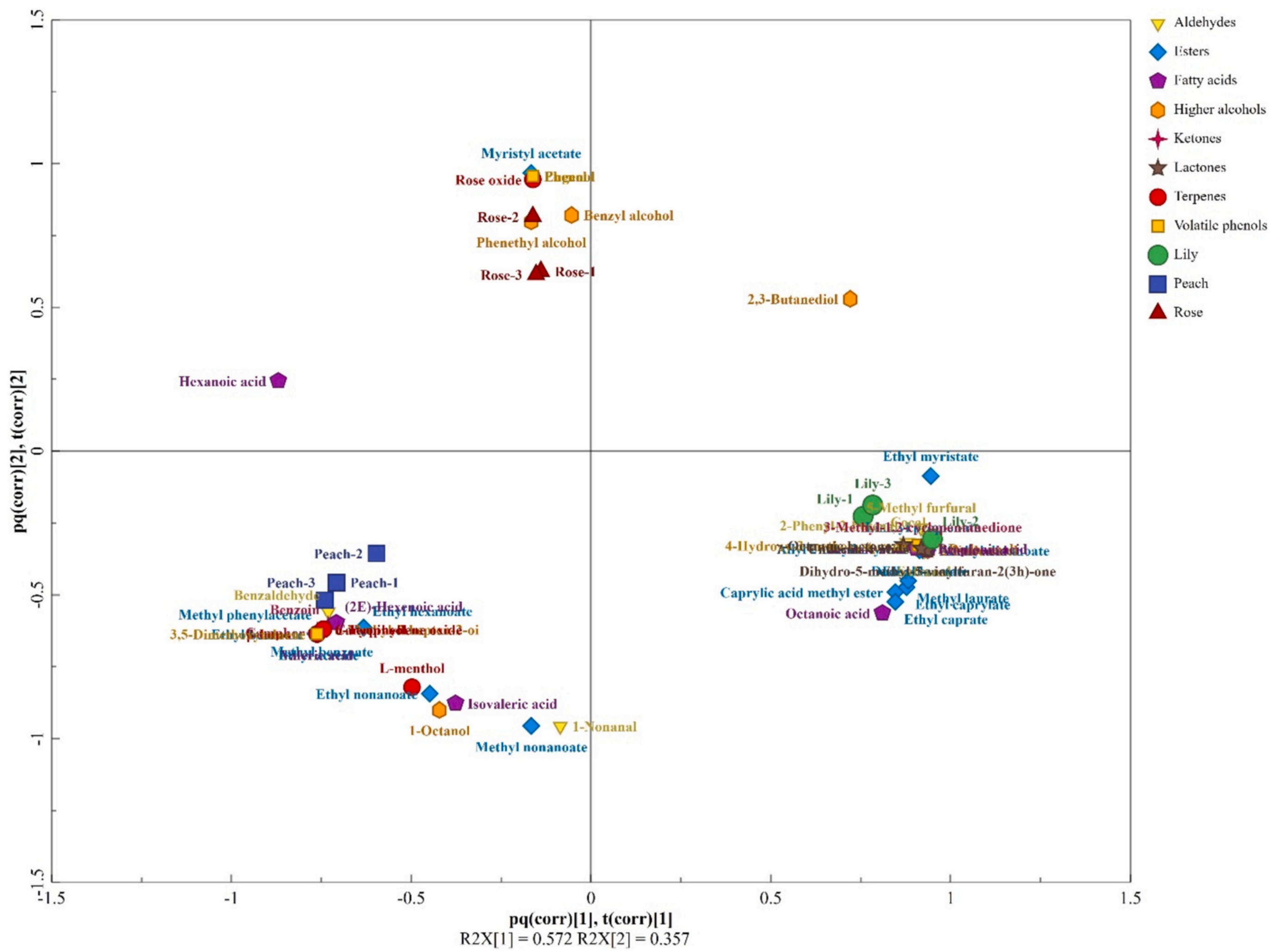

Fig. 2. Orthogonal partial least squares discrimination analysis (OPLS-DA) based on volatile compound concentration in different flower samples. The 52 volatile compounds with VIP values >1.0 were marked with labels, and others were hidden.

formed only in RDWB, PDWB, and LDWB, respectively. These newly identified esters are rich sources of fruity and floral aromas (Guth, 1997) and may contribute to the aroma profile of DWBs. It is worth mentioning that the decrease or complete loss of some esters observed in DW may not be solely due to dealcoholization by RO. The removal of alcohol may have also influenced the ester equilibrium through esterification and hydrolysis reactions. As a result, the esters could have undergone degradation, releasing alcohols and their analogous acids (Pham et al., 2019).

The results presented in Table 2 show that the concentrations of higher alcohols (H1-H18) were higher in the samples in the following order: RDWB > LDBW > PDWB > DW. Among the higher alcohols, isoamyl alcohol had the highest concentration (4.857 mg/L in RDWB), followed by 1-butanol (4.405 mg/L in LDWB), and 1-hexanol (2.255 mg/L in DW). Adding NEs significantly increased the concentration of certain alcohols in DWBs compared to DW, especially 1-butanol, 1-nonanol, 1-undecanol, and 1-octen-3-ol. This suggests that the NEs contributed to these volatile compounds in DWBs or influenced their formation through synergistic interactions. Additionally, alcohols such as 1-propanol and isoamyl alcohol were only found in DWBs. Consistent with similar studies conducted on Merlot red wine and Pinot Noir semi-sweet wine (Ma et al., 2022; Sam et al., 2023), 1-propanol was reported to be absent in these wines after dealcoholization at 0.7 % by RO.

Fatty acids in DW were found to be higher than those in DWBs. By comparison, the total content of fatty acids in LDWB, PDWB, and RDWB decreased by −55.7 %, −64.3 %, and − 63.9 % respectively. Hexanoic acid, which is known to impart wine with a rancid and fatty smell, had the highest concentration in DW compared with DWBs (Table 2). However, it can also enhance the freshness and fruity aroma of wine (Etievant, 1991). After adding the NEs, no significant differences were observed between DW and DWBs. This finding is consistent with our previous study (Sam et al., 2023). However, in contrast, a higher concentration of hexanoic, octanoic, and decanoic acids was found in a dealcoholized white wine spiked with glycosidic aroma precursors (Robinson et al., 2014) compared to the control. Fatty acids in wine are known to undergo various transformations, including esterification, hydrolysis, and interactions with other wine constituents, leading to changes in their concentrations (Fan et al., 2012; Kong et al., 2021, 2022; Makhotkina & Kilmartin, 2012). The observed decrease in certain fatty acids following the addition of natural extracts could be due to the formation of esters, as fatty acids are precursors to ester formation. The presence of esters is supported by the increased concentration of these compounds in the DWBs compared to the control. Additionally, the introduction of new aroma-active compounds from the flower extracts may have altered the equilibrium of fatty acids in the wine matrix, leading to their reduced concentration. Other factors such as the type and level of dealcoholization, the type and vintage of wine used, the specific aroma enhancer employed, or the addition level and aging time could also account for these disparities.

Seven aldehydes and ketones (C1-C7) were detected. Their total

Table 2
Concentrations (mg/L) of the main volatile compounds present in the dealcoholized wine and dealcoholized wine beverages.

Compound	RI	DW	LDWB	PDWB	RDWB	*P*-value	Odor Descriptor	Code
Terpenes								
Linalool	1540	0.020 ± 0.123a	0.019 ± 0.001b	0.018 ± 0.003b	0.017 ± 0.002b	0.0001	Floral	T1
α-Terpineol	1689	0.051 ± 0.007b	0.057 ± 0.016a	0.058 ± 0.002a	0.059 ± 0.004a	<0.0001	Floral	T2
Citronellol	1762	0.019 ± 0.001b	0.022 ± 0.027a	0.021 ± 0.002b	0.023 ± 0.001a	<0.0001	Rose, green	T3
Nerol	1791	ND	0.002 ± 0.001b	ND	0.003 ± 0.005a	<0.0001	Citrus, floral	T4
β-damascenone	1810	0.010 ± 1.828a	0.012 ± 0.003a	0.013 ± 0.007a	0.014 ± 0.005a	0.058	Floral, fruity	T5
Geraniol	1836	0.011 ± 0.005b	0.013 ± 0.101a	0.013 ± 0.021a	0.015 ± 0.003a	<0.0001	Fruity, floral	T6
Geranyl acetone	1846	0.004 ± 0.462b	0.005 ± 0.062a	0.005 ± 0.071a	0.005 ± 0.105a	0.001	Floral, green	T7
Esters								
Ethyl acetate	882	0.241 ± 0.005a	0.245 ± 0.015a	0.258 ± 0.005a	0.262 ± 0.001a	0.058	Fruity, balsamic	E1
Ethyl propanoate	949	ND	ND	ND	0.120 ± 0.005	–	Fruity, balsamic	E2
Isobutyl acetate	1004	0.180 ± 0.001c	0.124 ± 0.005a	0.122 ± 0.001ab	0.120 ± 0.002b	<0.0001	Banana	E3
Ethyl butanoate	1032	0.389 ± 0.001c	0.418 ± 0.001b	0.465 ± 0.013a	0.475 ± 0.005a	0.001	Fruity, floral, fatty	E4
Ethyl isovalerate	1065	ND	ND	0.205 ± 0.001	ND	–	Fruity	E5
Isoamyl acetate	1116	1.784 ± 0.021c	1.872 ± 0.001b	1.812 ± 0.007b	1.933 ± 0.01a	0.001	Fruity	E6
Ethyl crotonate	1153	ND	0.124 ± 0.001b	0.120 ± 0.001b	0.129 ± 0.002a	<0.0001	Tropical fruit	E7
Isoamyl isobutanoate	1186	ND	0.120 ± 0.085	ND	ND	–	Fruity, green	E8
Ethyl hexanoate	1229	0.629 ± 0.028b	1.703 ± 0.011a	1.398 ± 0.001a	1.434 ± 0.001a	<0.0001	Fruity, fatty	E9
Hexyl acetate	1267	0.136 ± 0.002a	0.140 ± 0.001a	0.136 ± 0.002a	0.137 ± 0.001a	0.077	Fruity, green, herb	E10
Ethyl (Z)hex-3-enoate	1298	0.120 ± 0.001a	0.121 ± 0.002a	0.120 ± 0.001a	0.120 ± 0.001a	0.267	–	E11
Ethyl 2-hexenoate	1353	0.007 ± 0.001b	0.031 ± 0.010a	0.023 ± 0.011a	0.015 ± 0.002ab	0.043	–	E12
Ethyl octanoate	1431	2.773 ± 0.106d	4.817 ± 0.003a	4.504 ± 0.009b	3.524 ± 0.001c	< 0.0001	Floral, fruity, green	E13
Isoamyl hexanoate	1456	0.121 ± 0.002a	0.126 ± 0.001a	0.126 ± 0.001a	0.121 ± 0.003a	0.281	Fruit, buttery, spicy	E14
Ethyl leucate	1522	0.119 ± 0.001a	0.122 ± 0.003a	0.118 ± 0.001a	0.121 ± 0.003a	0.164	Fruity	E15
Ethyl 3-hydroxybutyrate	1525	0.120 ± 0.012a	0.121 ± 0.001a	0.120 ± 0.002a	0.123 ± 0.021a	0.792	Fruity	E16
Ethyl decanoate	1632	0.135 ± 0.001a	0.134 ± 0.001a	0.133 ± 0.002a	0.146 ± 0.014a	0.367	Fruity	E17
Ethyl benzoate	1648	0.120 ± 0.001c	0.122 ± 0.002b	0.124 ± 0.001a	0.121 ± 0.002c	0.001	Floral, fruity, fatty	E18
Isoamyl octanoate	1659	0.187 ± 0.001a	0.194 ± 0.012a	0.195 ± 0.011a	0.196 ± 0.012a	0.783	Fruity	E19
Diethyl succinate	1674	0.046 ± 0.013b	0.103 ± 0.003a	0.096 ± 0.001a	0.111 ± 0.004a	0.002	Fruity, floral, cream	E20
Phenethyl acetate	1815	0.104 ± 0.003d	0.126 ± 0.001b	0.124 ± 0.002c	0.129 ± 0.005a	< 0.0001	Fruity, floral	E21
Ethyl hexadecanoate	2250	0.038 ± 0.005a	0.037 ± 0.004a	0.038 ± 0.005a	0.039 ± 0.005a	0.984	Fruity, waxy	E22
Higher alcohols								
1-Propanol	1038	ND	0.047 ± 0.001a	0.032 ± 0.010b	0.059 ± 0.001a	0.001	Fruity, pungent	H1
Isobutanol	1095	0.104 ± 0.002b	0.104 ± 0.002b	0.087 ± 0.006c	0.117 ± 0.001a	0.004	Solvent, raw green	H2
1-Butanol	1144	1.359 ± 0.011d	4.405 ± 0.001a	2.586 ± 0.020b	2.509 ± 0.023c	<0.0001	Medicinal, resinous	H3
Isoamyl alcohol	1208	ND	4.386 ± 0.011b	3.932 ± 0.021c	4.857 ± 0.0120a	<0.0001	Bitter almond	H4
3-Methyl-1-pentanol	1316	0.086 ± 0.010a	0.079 ± 0.001a	0.070 ± 0.011a	0.093 ± 0.001a	0.136	Fatty, green, pungent	H5
1-Hexanol	1348	2.255 ± 0.826a	1.303 ± 0.071b	1.173 ± 0.090b	1.432 ± 0.001b	<0.0001	grass	H6
3-Ethoxy-1-propanol	1365	0.217 ± 0.088a	0.212 ± 0.052a	0.179 ± 0.004a	0.250 ± 0.058a	0.539	Fruity	H7
cis-3-Hexen-1-ol	1368	0.131 ± 0.130a	0.158 ± 0.001a	0.161 ± 0.002a	0.183 ± 0.003a	0.089	Fruity, fatty, herb	H8
1-Octen-3-ol	1445	0.005 ± 0.013c	0.096 ± 0.001b	0.094 ± 0.003b	0.114 ± 0.001a	<0.0001	Floral, fatty, herb, earthy	H9
Ethylhexanol	1490	0.051 ± 0.006a	0.077 ± 0.001a	0.059 ± 0.020a	0.085 ± 0.001a	0.234	Rose, citrus, oily, green	H10
2,3-Butanediol	1552	0.114 ± 0.064a	0.113 ± 0.005a	0.134 ± 0.004a	0.122 ± 0.001a	0.118	Fruity, floral, cream, herb	H11
1-Octanol	1554	0.728 ± 0.118a	0.796 ± 0.001a	0.774 ± 0.020a	0.722 ± 0.001a	0.858	Floral, fatty	H12
1-Nonanol	1658	0.012 ± 0.009b	0.016 ± 0.001b	0.025 ± 0.005a	0.019 ± 0.001ab	0.031	Fruity, floral, fatty, green	H13
1-Decanol	1756	0.962 ± 0.020a	0.986 ± 0.001a	0.989 ± 0.003a	0.986 ± 0.001a	0.340	Floral, fatty	H14
1-Undecanol	1850	0.036 ± 0.001b	0.038 ± 0.003b	0.125 ± 0.005a	0.037 ± 0.007b	< 0.0001	Fruity, mandarin, waxy	H15
Benzyl alcohol	1865	1.024 ± 0.007a	1.012 ± 0.038a	1.032 ± 0.054a	0.911 ± 0.001a	0.062	Fruity, floral, pungent	H16
2-Phenylethanol	1907	0.376 ± 0.002a	0.439 ± 0.001a	0.409 ± 0.024a	5.481 ± 7.122a	0.474	Floral, fruity	H17
Dodecanol	1965	0.219 ± 0.005a	0.212 ± 0.001a	0.212 ± 0.001a	0.212 ± 0.001a	0.085	Fatty	H18
Acids								
2-Methylhexanoic acid	1661	0.117 ± 0.010a	0.125 ± 0.001a	0.132 ± 0.002a	0.127 ± 0.005a	0.193	Cheese, rancid, sour	A1
Hexanoic acid	1840	0.441 ± 0.047a	0.191 ± 0.068b	0.121 ± 0.093c	0.129 ± 0.233bc	0.001	Rancid, fatty	A2
Octanoic acid	2054	0.100 ± 0.013a	0.007 ± 0.008b	0.008 ± 0.007b	0.007 ± 0.003b	<0.0001	Rancid, grass, dust	A3
Decanoic acid	2272	0.104 ± 0.094a	0.014 ± 0.095a	0.011 ± 0.091a	0.012 ± 0.061a	0.269	Sour, vinegar	A4
Aldehydes and ketones								
2-Heptanone	1178	0.003 ± 0.001a	0.006 ± 0.003a	0.004 ± 0.002a	0.005 ± 0.006a	0.450	Fatty, cinnamon, green	C1
6-Methyl-5-hepten-2-one	1338	0.003 ± 0.001a	0.001 ± 0.005a	0.003 ± 0.002a	0.002 ± 0.004a	0.540	Fruity, herb, pungent	C2
2-Nonanone	1374	ND	ND	ND	0.010 ± 0.004	–	Fruity, green	C3
Nonanal	1389	0.004 ± 0.004b	0.008 ± 0.001ab	0.009 ± 0.001ab	0.011 ± 0.001a	0.042	Fruity, fatty, green, spicy	C4
Citronellal	1477	0.002 ± 0.007a	0.003 ± 0.005a	0.002 ± 0.001a	0.003 ± 0.002a	0.114	Cherry; lemon; green; rose;	C5
Decanal	1491	0.011 ± 0.004b	0.016 ± 0.007a	0.017 ± 0.002a	0.011 ± 0.001b	0.001	Fruity, flora, grassy	C6
Benzaldehyde	1517	0.006 ± 0.001c	0.948 ± 0.018b	1.420 ± 0.191a	0.038 ± 0.002c	<0.0001	Almond, cherry, pungent	C7

Data are means ± SD ($n = 3$). Different letters in the same row indicate statistical differences at 0.05 according to the Tukey test. RI means calculated Retention Index. “ND” means not detected. DW; dealcoholized Chardonnay wine (control), RDWB; dealcoholized wine beverage containing *Rosa chinensis* extract, PDWB; dealcoholized wine beverage containing *Prunus persica* extract, and LDWB; dealcoholized wine beverage containing *Lilium bulbiferum* extract. Odor descriptors for the volatile compounds were obtained from Volatile Compounds in Food (https://www.vcf-online.nl/VcfCompoundSearch.cfm, accessed on 15 December 2023) and Flavornet database (http://www.flavornet.org, accessed on 15 December 2023).

relative concentration ranged from 0.029 mg/L to 1.455 mg/L, with the lowest concentration in DW and the highest concentration in PDWB. Among the carbonyl compounds, the most significant increase was observed in benzaldehyde in the case of PDWB (Table 2). Consistent with the findings of our previous study (Ma et al., 2022), benzaldehyde had the highest concentration in a dealcoholized semi-sweet rose wine spiked with *P. persica* extract, compared to other samples. This suggests that the *P. persica* extract contained a substantial amount of benzaldehyde (Mohammed et al., 2021) or the benzaldehyde was derived from the Strecker degradation of amino acids in the extract through the Maillard reaction (Santos et al., 2015), which, in both cases, exhibited a unique compatibility with the wine matrix, resulting in a significant enhancement of benzaldehyde. 2-Nonanone was only found in RDWB, but its concentration was low.

3.4. Effect of extracts on the sensory attributes of experimental samples

The results of the sensory evaluation for dealcoholized wines (DW) and dealcoholized wines with natural aromatic extracts (DWBs) are presented in Fig. 3. The process of dealcoholization and reformulation with natural aromatic extracts has an impact on the sensory profiles of wines (Liguori et al., 2019; Rodríguez-Bencomo et al., 2013). In terms of appearance, all samples scored between 7.0 and 7.5, with no significant differences. Compared to DW (4.6), LDWB, PDWB, and RDWB received significantly higher ratings of 6.8, 7.3, and 7.3, respectively, for the fruity attribute. A similar trend was observed for the floral attribute, with RDWB, PDWB, and LDWB scoring higher (7.0, 7.2, and 7.2, respectively) compared to DW (4.5). Regarding sweetness perception, all samples had low ratings (between 3.8 and 4.0) with no significant differences among them. DW received a moderately high rating (7.0) for acidity, while LDWB received a rating neither high nor low (< 6). PDWB and RDWB were both rated high, with scores of 6.6 and 6.05 respectively. Bitterness was perceived to be higher in DWBs than in DW, although the ratings were below 4, indicating a moderately low perception. This may be due to phenolic substances such as flavonoids, polyphenols, and flavanols in edible flower extracts. On the other hand, hotness perception was similar across samples and rated moderately low. Except for DW (5.65), the DWBs had higher body scores ranging from 6.25 to 6.6, with LDWB being the highest. The acceptability of all samples was high, particularly for DWBs. A similar observation was made in rose and red wines (Ma et al., 2022; Sam et al., 2023). The preference order was as follows: LDWB > RDWB > PDWB > DW. The higher number and concentration of aroma compounds (Table 2), the higher body rating, and the stronger perception of fruity and floral aromas in DWBs can best explain the higher acceptability of DWBs over DW. In summary, the addition of NEs, especially L. *bulbiferum* and *R. chinensis*, substantially enhances the aroma compounds in DWBs, resulting in a more complex and satisfying aromatic experience compared to DW.

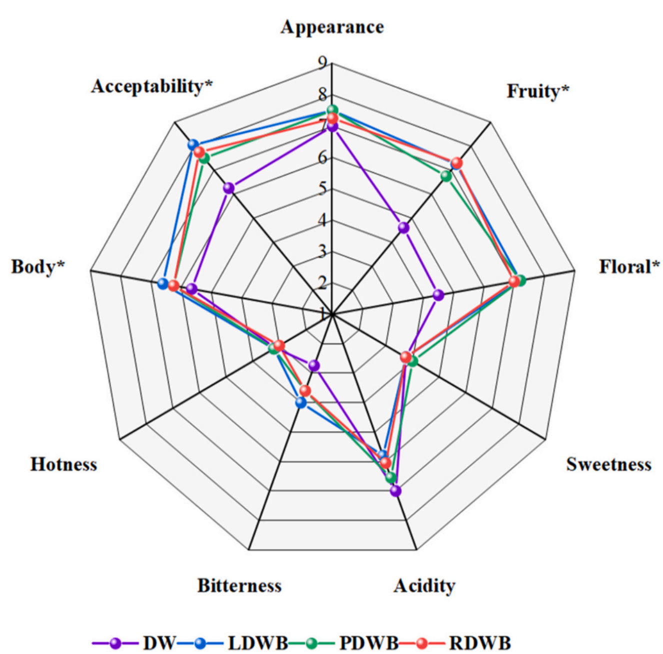

Fig. 3. Sensory diagram of experimental samples. DW; dealcoholized Chardonnay wine (control), RDWB; dealcoholized wine beverage containing *Rosa chinensis* extract, PDWB; dealcoholized wine beverage containing *Prunus persica* extract, and LDWB; dealcoholized wine beverage containing *Lilium bulbiferum* extract.

3.5. Principal component analysis

The PCA biplot (Fig. 4) illustrates the associations and separations between the volatile compounds, samples, and sensory attributes. Samples were differentiated based on their different aroma compositions, with DW positioned in the upper left quadrant on the PCA plot (PC2), far away from RDWB, which was positioned in the upper right quadrant on the plot (PC1). Meanwhile, LDWB and PDWB were located in the lower right quadrant of the plot (PC1).

Volatiles such as hexanoic acid (A2), octanoic acid (A3), decanoic acid (A4), 6-methyl-5-hepten-2-one (C2), 3-methyl-1-pentanol (H5), 1-hexanol (H6), benzyl alcohol (H16), dodecanol (H18), and linalool (T1) were strongly and positively correlated with PC2, and the concentrations of these compounds were high in DW. However, no olfactory attribute was positively associated with DW, indicating an adverse effect of dealcoholization. RDWB was also strongly and positively correlated with ethyl acetate (E1), ethyl propanoate (E2), ethyl butanoate (E4), isoamyl acetate (E6), isoamyl isobutanoate (E8), ethyl leucate (E15), ethyl 3-hydroxybutyrate (E16), ethyl decanoate (E17), diethyl succinate (E20), phenethyl acetate (E21), ethyl hexadecanoate (E22), 2-nonanone (C3), nonanal (C4), citronellal (C5), 1-propanol (H1), isobutanol (H2), 3-ethoxy-1-propanol (H7), *cis*-3-hexen-1-ol (H8), ethylhexanol (H10), 2-phenylethanol (H17), α-terpineol (T2), citronellol (T3), nerol (T4), *β*-damascenone (T5), and geraniol (T6). These volatiles, known for their fruity odors (Guth, 1997), primarily contributed to the fruity aromas of RDWB, resulting in a strong positive correlation between the two on PC1. On the other hand, 2-heptanone (C1), decanal (C6), benzaldehyde (C7), isobutyl acetate (E3), ethyl isovalerate (E5), ethyl crotonate (E7), ethyl hexanoate (E9), hexyl acetate (E10), ethyl (Z)hex-3-enoate (E11), ethyl 2-hexenoate (E12), ethyl octanoate (E13), isoamyl hexanoate (E14), ethyl benzoate (E18), isoamyl octanoate (E19), 1-butanol (H3), isoamyl alcohol (H4), 1-octen-3-ol (H9), 2,3-butanediol (H11), 1-octanol (H12), 1-nonanol (H13), 1-decanol (H14), 1-undecanol (H15), 2-methylhexanoic acid (A1), and geranyl acetone (T7) were strongly and positively correlated with PDWB and LDWB. These volatiles, known for their floral scents (Contador et al., 2015; Guth, 1997) also characterized PDWB and LDWB with floral olfactory attributes. In terms of gustatory attributes, DW was mainly characterized by acidity and hotness on PC2, while DWBs were characterized by appearance, bitterness, sweetness, body, and overall impression (acceptability) on PC2. These findings align with those of the volatile composition and sensory results presented in Table 2 and Fig. 2, respectively. Previous studies have also associated dealcoholized wine with high acidity (Corona et al., 2019; García et al., 2021; Liguori et al., 2019; Lisanti et al., 2013), whereas dealcoholized wines reconstituted with natural extracts have been linked to enhanced floral and fruity aromas (Liguori et al., 2019; Ma et al., 2022; Rodríguez-Bencomo et al., 2013; Sam et al., 2023). The findings of our study, as well as those reported in similar studies, support our hypothesis that *P. persica*, *R. chinensis*, and L. *bulbiferum* extracts can significantly enhance the aroma profile of dealcoholized Chardonnay wine.

3.6. Volatiles and the correlation with gustatory attributes

There were significant differences in the quantified values of floral and fruity olfactory notes among the samples, with higher perception in DWBs. To clarify the mathematical relationship between these aromas and volatiles, PLSR models of the sensory traits were built, grouping the volatiles into various classes: terpenes, esters, higher alcohols, fatty acids, and aldehydes and ketones. The relationship was determined by

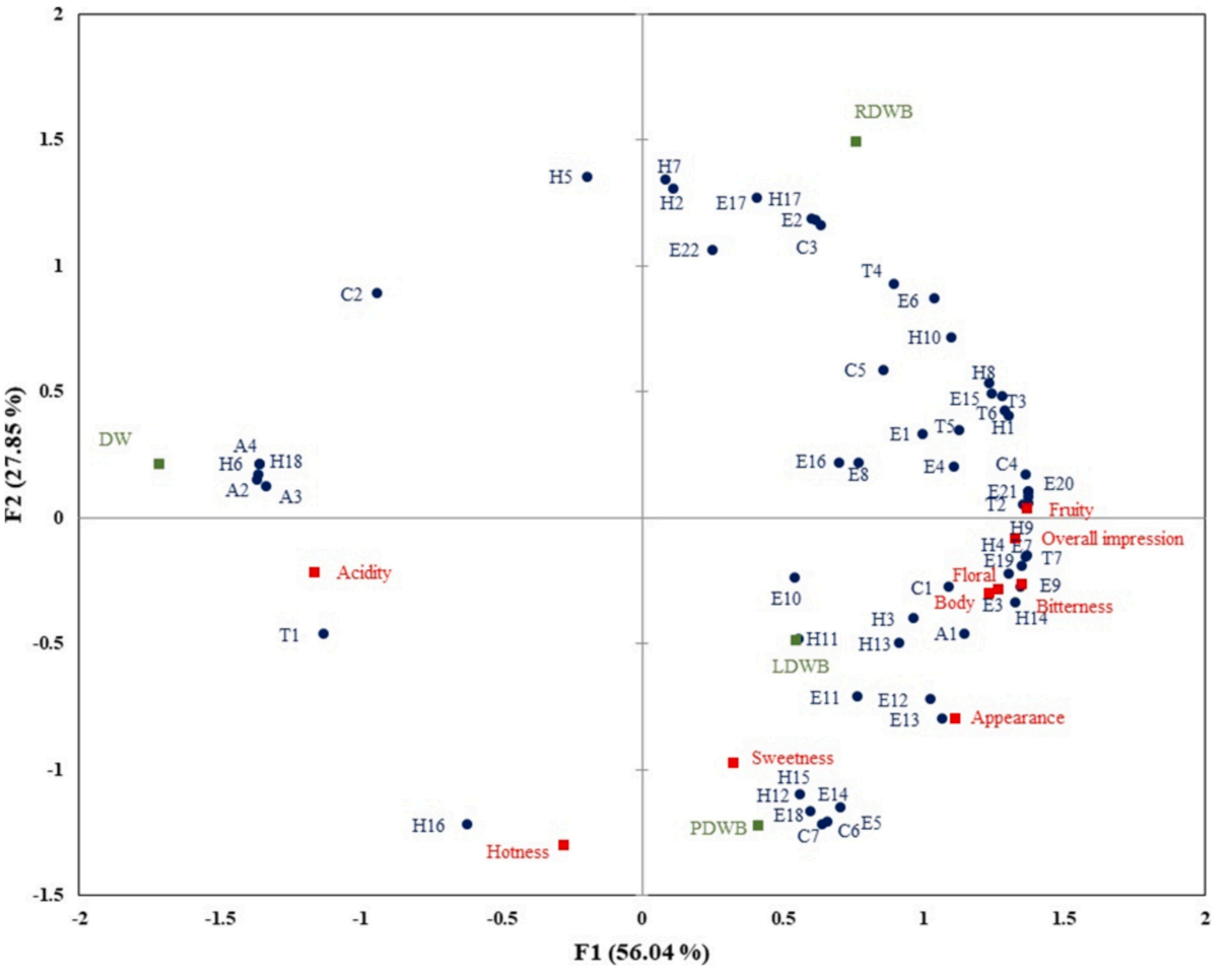

Fig. 4. Principal component analysis (PCA) biplot of volatile compounds and sensory attributes of samples. DW; dealcoholized Chardonnay wine (control), RDWB; dealcoholized wine beverage containing *Rosa chinensis* extract, PDWB; dealcoholized wine beverage containing *Prunus persica* extract, and LDWB; dealcoholized wine beverage containing *Lilium bulbiferum* extract. For the meaning of A1-A4, C1-C7, E1-E22, H1-H18, and T1–7, refer to Table 2.

the standardized correlation coefficients of the models. The regression coefficients (Table 3) showed both positive and negative contributions, suggesting that fruity and floral characteristics were formed with different contributions from the volatile compounds. All classes of volatiles, except fatty acids, had a positive impact on the fruity and floral attributes of the samples. Terpenes had the greatest impact compared to other classes, possibly due to the NEs. Terpenes and esters significantly contributed to fruity and floral attributes, with high regression coefficients (> 0.27), while higher alcohols and aldehydes and ketones made a slight contribution, with correlation coefficients >0.14 but <0.2 (Table 3). The positive impact of higher alcohols on sensory attributes, specifically floral and fruity notes, appears to contradict their typical characteristics. This may be attributed to the involvement of higher alcohols in the formation of esters (Wang et al., 2017), which are significant contributors to fruity and floral characteristics. On the other hand, fatty acids had a negative contribution to fruity and floral notes, with coefficients <0.1 on the sensory characteristics. Thus, NEs from *P. persica*, *R. chinensis*, and *L. bulbiferum* played an important role in improving terpenes and esters production and enhancing the aroma of DWBs.

Table 3
Standardized regression coefficients of volatile classes and olfactory attributes.

Variable	Fruity	Floral
Terpenes	0.296	0.300
Esters	0.278	0.282
Higher alcohols	0.142	0.144
Fatty acids	−0.310	−0.315
Aldehydes and ketones	0.171	0.174
R^2 (calibration/ validation)	0.966/0.898	0.996/0.982
RMSE	0.749	0.159

4. Conclusions

In conclusion, this study demonstrates that incorporating natural flower extracts from *Prunus persica*, *Rosa chinensis*, and *Lilium bulbiferum* significantly enriches the aroma profile of dealcoholized Chardonnay wine, thereby overcoming important sensory limitations commonly associated with non-alcoholic wines. The analysis of volatile compounds, supported by PCA and PLSR findings, not only validates the improvement of key aromatic notes but also establishes a scientific basis for the observed sensory enhancements. These extracts, with their complex blend of floral and fruity aromas, present a promising opportunity for the innovation of non-alcoholic wine beverages, aligning with the increasing consumer demand for healthier and more sensory-rich alternatives. However, the study acknowledges certain limitations, such as the limited range of flower extracts and the absence of long-term analysis concerning aroma stability. Further research is needed to address these limitations, including investigations into other flowers like jasmine, lavender, and Hibiscus, which are known for their rich aromatic profiles, in order to broaden the range of extracts. Additionally, future research should explore the long-term stability and aging potential of these enhanced wines, conduct comprehensive consumer acceptance studies, assess the scalability of these methods for commercial production, and evaluate the market viability of these beverages in the non-alcoholic wine sector. This could pave the way for the development of a wider range of innovative non-alcoholic beverages that cater to diverse consumer preferences. Overall, this study establishes a foundation for future research in the field, potentially expanding the scope of strategies for enhancing non-alcoholic wines and making a significant contribution to the evolution of the beverage industry towards inclusivity and diversity in product offerings.

CRediT authorship contribution statement

Tengzhen Ma: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Faisal Eudes Sam:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as spotential competing interests: Tengzhen Ma reports article publishing charges was provided by Lanzhou City Science and Technology Bureau. Tengzhen Ma reports article publishing charges and equipment, drugs, or supplies were provided by Gansu Education Department. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2024.102015.

Data availability

Data will be made available on request.

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