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Fermentation and quality characteristics of peach wine with nectarine addition

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ORIGINAL ARTICLE

Abstract

This study examined how the addition of nectarine affects fermentation, physicochemical properties, and sensory quality of peach wines. White peach wine fermented the slowest, while other peach wines proceeded smoothly. Nectarine peach wine had the highest acidity, which was moderated by blending, with yellow or white peach. White and yellow peach wines showed lower color intensity and higher hue values compared to nectarine peach wine, but these were adjusted to intermediate levels with the addition of nectarine. Nectarine peach, with its high citric acid and tartaric acid contents, had a stronger sourness, which was softened by blending with yellow or white peach wines. The total phenolic compounds were highest in white peach wine, while the total anthocyanin content (TAC) was highest in nectarine peach wine. The addition of yellow or white peach compensated for the lacking functional properties of nectarine peach wine. Sensory evaluation revealed that peach wines added with nectarine softened the sourness of nectarine, enhanced the flavor properties lacking in white peach wine, and reduced the bitterness of yellow peach wine. Overall, blending nectarine with other peach varieties improved the sensory quality and balance of peach wines.

Keywords: antioxidant, blending, fermentation, nectarine addition, peach wine

Introduction

Peach (*Prunus persica* (L.) Batsch) is a sweet, juicy drupe of the Rosaceae family and a prominent stone fruit crop. It is rich in bioactive components such as fiber, phenolic compounds, organic acids, minerals, and vitamins (Di Vaio *et al*., 2015; Liu *et al*., 2015a), which have various health benefits, including antioxidant, antimicrobial, antidiabetic, and anti-inflammatory effects (Bento *et al*., 2022; Nowicka *et al*., 2023). However, despite increasing cultivation and production, the peach industry faces significant post-harvest challenges, particularly rapid softening, browning, and decay (Wang *et al*., 2020). To mitigate these issues, various physical, chemical, and biological approaches have been applied both pre- and post-harvest to improve storability and quality, or to

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process peaches into value-added products such as canned goods, jams, dried fruits, and juices (Lamureanu *et al*., 2015; Rudke *et al*., 2023). Among these strategies, fermentation has emerged as an effective method for processing and preservation. It enhances flavor and aroma (Maicas, 2021), extends shelf life (Sun *et al*., 2022), improves nutritional value (Jagtap and Bapat, 2015), and ensures microbiological safety (Wilkowska *et al*., 2017), while also increasing economic value. Fermented peach products are increasingly favored by consumers because of their potential health benefits associated with bioactive compounds and probiotics (Chugh and Kamal-Eldin, 2020; Diez-Ozaeta and Astiazaran, 2022).

Peaches are broadly classified into fuzzy peaches and nectarines based on the presence or absence of skin fuzz. Fuzzy peaches are further divided into white and yellow varieties based on flesh color (Saidani *et al*., 2017; Zaracho *et al*., 2023). Nectarines, distinguished by their smooth skin and firmer texture, offer a flavor spectrum ranging from sweet to mildly tart (Delgado *et al*., 2013). Yellow peaches possess golden flesh with high sugar and acid content, resulting in a well-balanced tart–sweet flavor, whereas white peaches are characterized by pale flesh, low acidity, and pronounced sweetness (Crisosto *et al*., 2006; Petruccelli *et al*., 2023). These differences in chemical and physical properties influence both the fermentation process and the resulting wine quality, making varietal selection an important consideration in the production of peach wine. A previous study on the production of peach wine (Lee *et al*., 2023b) primarily focused on individual peach varieties, analyzing their sugar content, acidity, and aromatic profiles. However, limited research has investigated how blending different peach varieties might optimize key parameters such as acidity, fermentation kinetics, and flavor profile. While conventional peach wine produced from a single variety may exhibit limitations such as low acidity in white peaches or overly sharp sourness in nectarine peaches (Lee et al., 2023b), blending different varieties offers a practical strategy to harmonize these characteristics, leading to enhanced sensory and broader consumer acceptance in peach wines.

Therefore, this study aimed to evaluate the impact of the addition of nectarine on the fermentation and quality characteristics of peach wine, focusing on how blending different peach varieties can enhance acidity, aroma, and overall wine quality. Specifically, nectarine was blended with white and yellow peaches to offset the limitations of each variety. This approach was expected to optimize fermentation and improve sensory attributes. By analyzing the fermentation performance and quality attributes of these blends, this study sought to support a more sustainable and profitable peach wine industry while offering insights into improved production practices. These findings may help boost the consumption of peach wine, reduce post-harvest losses, and increase the economic value of peaches by transforming them into high-value, fermented products.

Materials and Methods

Materials

Three different peach (*P. persica*) varieties were cultivated following standard agronomic practices at the Cheongdo Peach Research Institute (Iseo-myeon, Chenongdo, Korea) and harvested in August of 2023. The study utilized three peach types: nectarine, yellow peach, and white peach. The nectarine ("Fantasia" variety) is known for its large size, yellow flesh, low acidity, and high sweetness (Kumar *et al*., 2018). The yellow peach ("Baekjungdo" variety) features golden flesh with balanced sweetness and acidity. The white peach ("Cheonjungdo" variety) is characterized by its crisp texture, refreshing taste, and low acidity (Kwon *et al*., 2015; Robertson *et al*., 1990).

Sample preparation

Peaches free of mechanical damage and pest infestation were selected, washed with tap water, and manually pitted. The flesh was extracted using a sanitized horizontal masticating juicer (DA282-2, Daesung, Artlon, Paju, Korea), and then filtered through double-layered cheesecloth (0.5 mm mesh) to remove particulates before fermentation. The extracted juices exhibited the following properties: nectarine (9.0 °Brix, pH 3.73, and total acidity 13.81 g/L), yellow peach (10.8 °Brix, pH 4.52, and total acidity 3.37 g/L), and white peach (9.0 °Brix, pH 4.72, and total acidity 3.33 g/L). Five juice formulations were prepared for fermentation: nectarine, yellow peach, white peach, nectarine + yellow peach (1:1), and nectarine + white peach (1:1). Each batch (3.5 L) was transferred into a 5 L fermentation tank. Potassium metabisulfite (200 mg/L, $K_2S_2O_5$; Duksan Pure Chemical Co., LTD, Ansan, Korea) and pectinase (0.5 g/L; DSM Food Specialties, Delft, Netherlands) were added to each batch. After 5 h, dry wine yeast (*Saccharomyces cerevisiae* Fermivin [DSM Food Specialties, Delft, Netherlands]) was inoculated at 0.02% (w/w) based on fruit weight. Fermentation was conducted at 20°C for 13 days. The mixture was stirred twice daily for the first 3 days and once daily thereafter. At the end of fermentation, samples were centrifuged (3,000 × *g*, 15 min) to remove sediments. For physicochemical analysis, all samples were further centrifuged (3,000 × *g*, 10 min) to remove residual particulates. The resulting supernatants were stored at 4°C until further analysis.

Fermentation characteristics

The peach wine samples were subjected to centrifugation (3,000 × *g*, 10 min) for the analysis of fermentation properties. pH was measured using a pH meter (MP 225K, Mettler-Toledo, Schwerzenbach, Switzerland), and the total acidity was determined by titrating filtrates with 0.1 N NaOH (expressed as g/L of tartaric acid) (Hwang and Kim, 2024). Total soluble solids were measured using a refractometer (N-1a, ATAGO Co., Kyoto, Japan), and the reducing sugar content was determined using the 3,5-dinitrosalicylic acid (DNS) reagent method (Miller, 1959). For measuring reducing sugar content, 0.3 mL of the sample was mixed with 1 mL of DNS reagent solution (Sigma-Aldrich, St. Louis, MO, USA) in a test tube and heated in hot water for 5 min. After cooling with tap water, 7 mL of distilled water was added. A blank sample was prepared with 0.3 mL of ultrapure water and 1 mL of DNS reagent solution. The optical density (OD) of the sample was measured against the blank using a UV–Vis spectrophotometer (UV-1601, Shimadzu Co., Kyoto, Japan) at 550 nm. Reducing sugar content (%) in peach wine was determined using a glucose standard curve. Alcohol content was measured using a hydrometer based on the specific gravity of wine distillates (expressed as % v/v) at 15°C (Won *et al*., 2024). The number of viable cells was determined by serially diluting the collected samples in sterile distilled water. The diluted samples were then plated on yeast extract peptone dextrose (YPD) agar plates containing 15 mg/L chloramphenicol (Sigma-Aldrich) and incubated at 30°C for 48 h. The number of yeast colonies formed was expressed as logarithmic colony-forming units per milliliter (log CFU/mL) (Lee *et al*., 2023a).

Wine color

Color analysis was performed using a spectrophotometer (UV-1601, Shimadzu Co.). Hue value was calculated as $A_{420\ nm}/A_{520\ nm}$, and color intensity was calculated as $A_{420\ nm} + A_{520\ nm} + A_{620\ nm}$ (Ortiz *et al*., 2013). Hunter's color values, including L^* (whiteness/darkness), a^* (redness/greenness), b^* (yellowness/blueness), and ΔE (total color difference), were measured using a color meter (CM-3600d, Konica Minolta, Osaka, Japan). The ΔE was calculated as:

$$\Delta E = \sqrt{(L^*initial - L^*changed)^2 + (a^*initial - a^*changed)^2 + (b^*initial - b^*changed)^2}$$

Free sugar and organic acid analysis

Free sugars and organic acids were analyzed via high-performance liquid chromatography (HPLC) (Prominence, Shimadzu Co., Kyoto, Japan). Samples were filtered through a 0.45 μm Millex-HV filter (Millipore, Bedford, USA). Free sugars were analyzed using a Sugar-Pak I column (ID 6.5 × 300 mm, Waters Co., Milford, MA, USA) with deionized water as the mobile phase (0.5 mL/min, 90°C) (Lee *et al*., 2024). Organic acids were analyzed using a PL Hi-Plex H column (ID 7.7 × 300 mm, Agilent Technologies, Santa Clara, CA, USA) with 0.005 M sulfuric acid as the mobile phase (0.6 mL/min, 65°C) (Hong and Park, 2013). A refractive index detector (RID-10A, Shimadzu Co., Kyoto, Japan) was used for detection.

Antioxidant compounds

Antioxidant compounds were measured in terms of total phenolic content (TPC), total flavonoid content (TFC), and total anthocyanin content (TAC. TPC was determined using the Folin–Denis method (Singleton *et al*., 1999). Briefly, 2 mL of 50% Folin–Ciocalteu reagent (Sigma-Aldrich) was added to 2 mL of the sample and left at room temperature (RT) for 3 min. Then, 2 mL of 10% Na_2CO_3 (Sigma-Aldrich) was added, and the mixture was incubated in the dark for 1 h at RT. Subsequently, absorbance was measured at 700 nm using a spectrophotometer (UV-1601, Shimadzu Co.). TPC was expressed as milligrams of gallic acid equivalents (GAE) per liter of sample (mg GAE/L). TFC was quantified using a modified method based on Zhishen *et al*. (1999). Briefly, 70 μL of the sample was mixed with 430 μL of 50% ethanol and 50 μL of 5% $NaNO_2$ (Sigma-Aldrich) and then incubated at RT for 30 min. Subsequently, 50 μL of 10% $Al(NO_3)_3$-$9H_2O$ was added, and the mixture was further incubated at RT for 6 min. Finally, 500 μL of 1 N NaOH was added, and the absorbance was measured at 510 nm using a spectrophotometer (UV-1601, Shimadzu Co.). TFC was expressed as milligrams of catechin equivalents per liter of sample (mg CE/L). TAC was determined using a modified method of Lee *et al*. (2005). Briefly, samples were appropriately diluted in 0.025 M potassium chloride buffer (pH 1.0) and 0.4 M sodium acetate buffer (pH 4.5), then incubated for 30 min in the dark at RT. Absorbance was measured at 520 nm and 700 nm using a spectrophotometer (UV-1601, Shimadzu Co.). TAC was calculated as follows: TAC = (A × MW × DF × 1,000)/(ε × 1), where A = $(A_{520\ nm} - A_{700\ nm})_{pH1.0} - (A_{520\ nm} - A_{700\ nm})_{pH4.5}$, MW = molecular weight of cyanidin-3-glucoside (C3G; 449.2 g/mol), DF = dilution factor, ε = molar extinction coefficient of C3G (26,900 L/[mol.cm]), and 1 = path length (cm). TAC was expressed as milligrams of C3G per liter of sample (mg C3G/L).

Antioxidant activities

The antioxidant capacity of wine was evaluated using 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)

(ABTS) radical scavenging, and ferric reducing antioxidant power (FRAP) assays. For the DPPH radical scavenging assay, 1 µL of sequentially diluted sample was added to a 96-well plate, followed by 199 µL of 0.1 mM DPPH solution (Sigma-Aldrich). The mixture was incubated in the dark at RT for 10 min, and absorbance was measured at 517 nm using a multi-label counter (Victor 3, Perkin Elmer, Waltham, MA, USA). The DPPH radical scavenging activity value was calculated as follows: DPPH (%) = $[(A_{blank} - A_{control})/A_{blank}] \times 100\%$. The ABTS radical scavenging assay was assessed by adding 20 µL of serially diluted sample to a 96-well plate, followed by 180 µL of ABTS solution (Sigma-Aldrich). After incubation in the dark for 7 min at RT, absorbance was measured at 734 nm using a multi-label counter (Fogliano *et al*., 1999). Results were expressed as micromoles of Trolox equivalents per milliliter of sample (µM TE/mL). FRAP activity was determined using a modified method described by Benzie and Strain (1996). Briefly, in a 96-well plate, 25 µL of sequentially diluted samples were added and mixed with 175 µL of freshly prepared FRAP reagent (300 mM acetate buffer, pH 3.6; 10 mM 2,4,6-tripyridyl-s-triazine; and 20 mM ferric chloride in a 10:1:1, v/v/v ratio). The reaction mixture was incubated in the dark at RT for 30 min, and absorbance was measured at 590 nm using a multi-label counter (Victor 3, Perkin Elmer). FRAP values were also expressed as µM TE/mL.

Sensory evaluation

Sensory evaluation was conducted 1 month after bottling using a 7-point hedonic scale. Wines were allowed to settle for 1 h in sealed bottles at RT. Evaluations included assessments of flavor, color, taste, and overall preference using wine glasses. A panel of 20 experienced judges from the Department of Food Science and Technology at Kyungpook National University, all trained in taste discrimination, participated in the study. The panel consisted of 10 males and 10 females in their twenties. To minimize carryover effects, judges rinsed their mouths with distilled water between samples. Wines were presented in a random order to reduce bias. Each wine was assessed with a 3-min interval between samples, during which panelists cleansed their palates with water. Scores were recorded on a 7-point hedonic scale, where 7 represented "like very much," 4 represented "neither like nor dislike," and 1 represented "dislike very much." All participants provided informed consent, and the sensory evaluation was approved by the Institutional Review Board of Kyungpook National University (IRB No. KNU-2024-0249) (Seong *et al*., 2023).

Statistical analysis

All experiments were performed in at least triplicate. Data are presented as mean and standard deviation and were analyzed using the Statistical Package for the Social Sciences version 20.0 (IBM, Armonk, NY, USA). Statistical significance was set at $p < 0.05$ and determined using a one-way analysis of variance (ANOVA), followed by Duncan's multiple range test.

Results and Discussion

Physicochemical properties

The fermentation characteristics of peach wine were investigated based on peach variety and their mixture. Changes in soluble solids, reducing sugars, alcohol content, viable cell count, pH, and total acidity during fermentation are shown in Figure 1. All peach juices were chaptalized to 22 °Brix before fermentation. Soluble solids are a key parameter in fermentation, serving as the primary substrate for yeast metabolism. Reducing sugars, such as glucose and fructose, are directly utilized by yeast and are rapidly consumed in the early stages of fermentation, thereby influencing the fermentation rate (Timmermans *et al*., 2022). In this study, yellow peach wine showed the most rapid consumption of soluble solids, resulting in the lowest final value (6.8 °Brix), while white peach wine exhibited the slowest consumption, ending with the highest value (8.6 °Brix). A similar trend was observed in reducing sugar content, with white peach wine showing the slowest decrease. Nevertheless, the final reducing sugar content in all peach wines was below 1%, indicating successful fermentation. Alcohol production increased rapidly between days 2 and 5, corresponding to the sharp decline in sugar levels, and then progressed slowly until day 13. Yellow peach wine demonstrated the steepest increase, reaching a final alcohol content of 13.2%, indicating efficient fermentation. In contrast, white peach wine reached 12.1%, reflecting slower sugar-to-alcohol conversion. Nectarine and mixed peach wines showed moderate alcohol production rates, with final concentrations ranging from 12.9% to 13.1%. These results suggest that peach variety significantly influences alcohol yield, offering valuable insights for varietal selection in wine production.

Microbial growth during fermentation is critical, as it affects both fermentation efficiency and the production of key metabolites, including organic acids. Therefore, pH and total acidity are vital factors influencing wine quality and post-fermentation stability. A low initial pH prolongs the yeast lag phase, inhibits yeast growth, and reduces sugar consumption rate, thereby increasing acetic acid and glycerol contents while decreasing ethanol and succinic acid levels (Liu *et al*., 2015b). Total acidity, which reflects the overall concentration of organic acids, plays a crucial role in balancing flavor, enhancing stability, and ensuring the microbial safety of wine (Chidi *et al*., 2018).

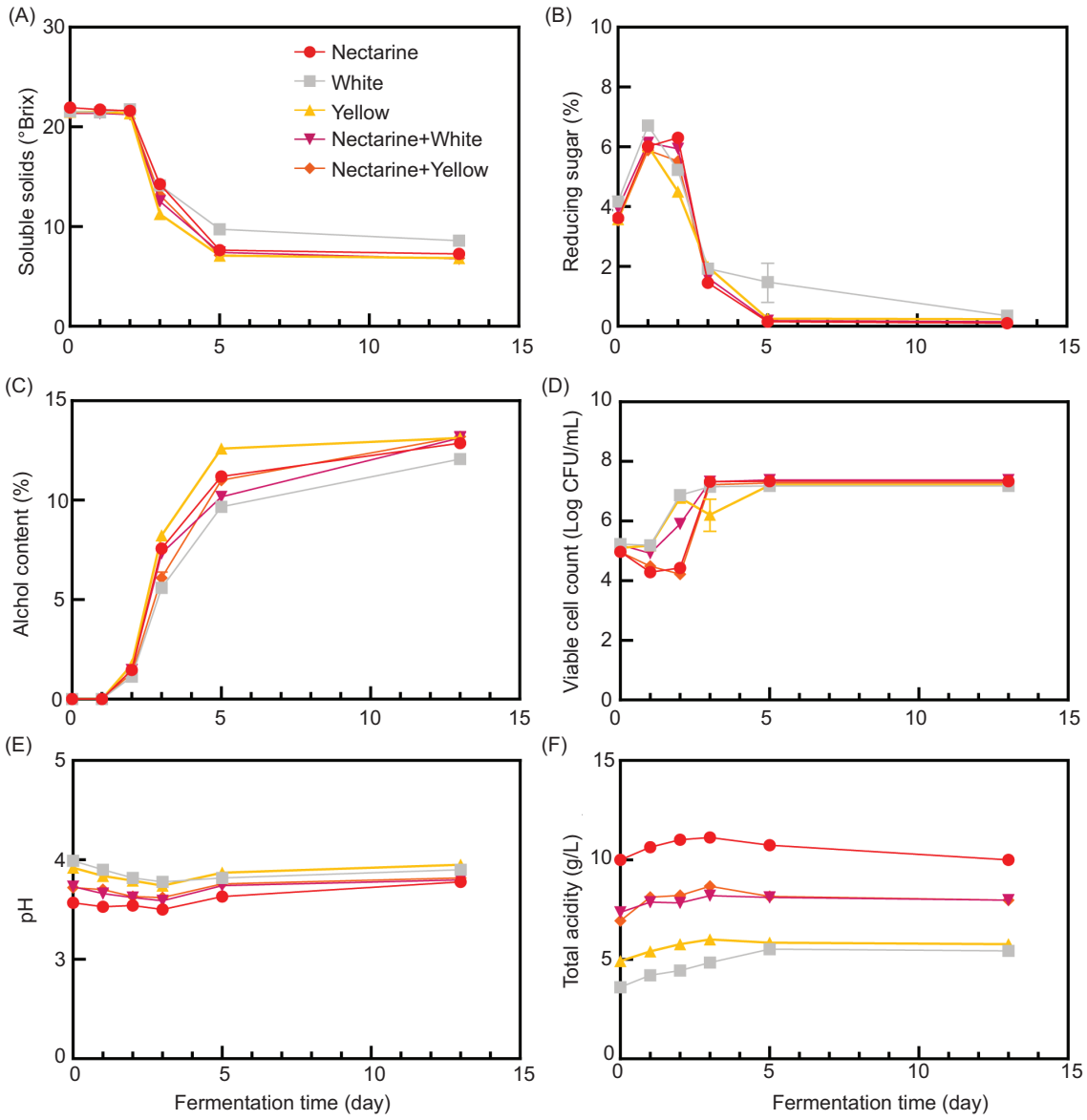

Figure 1. Physicochemical properties of different peach wines during fermentation. (A) Soluble solids; (B) Reducing sugars; (C) Alcohol content; (D) Viable cell count; (E) pH; (F) Total acidity.

However, excessive acidity may negatively impact consumer preference, with 5–8 g/L being the preferred range for grape wines (Tian *et al.*, 2024). Among the samples, nectarine peach wine had the lowest initial pH and highest total acidity, whereas white peach wine showed the highest initial pH and lowest acidity. Yellow peach wine displayed moderately low acidity and high pH, while mixed peach wines presented balanced values for both parameters. Following fermentation, the total acidity of white and yellow peach wines increased slightly, while that of nectarine and mixed peach wines remained relatively stable. In terms of pH, nectarine peach wine exhibited a modest increase, whereas the other peach wines retained pH levels similar to their initial values. Notably, the viable cell count in nectarine peach wine rose more slowly during the early stages of fermentation, likely because of the inhibitory effects of its higher acidity and lower pH on microbial growth. Despite this initial delay, all peach wines reached viable cell counts exceeding 7 log CFU/mL from day 5 onward, indicating robust and consistent fermentation across all samples.

Color characteristics

Color is one of the most immediately noticeable attributes of fruit wine and plays a key role in shaping the consumer's first impression. Beyond visual appeal, wine

color also reflects its chemical composition and can offer an insight into its flavor profile (Veríssimo *et al*., 2021). In winemaking, pigments such as anthocyanins, carotenoids, and tannins—extracted from the fruit during fermentation—are primarily responsible for color (Wen *et al*., 2023). Managing these pigments is essential for achieving the desired appearance and quality in the final product. In this study, changes in the color of peach wine were assessed using several parameters: L^*, a^*, b^*, ΔE, color intensity, and hue value (Figure 2). Initially, L^* values for all peach wines ranged from 61.51 to 62.55 but decreased to 58.39–61.07 by the end of fermentation, indicating a general darkening of the wines. This trend is commonly observed in fruit wines and is attributed to the formation of complex pigments and the reduction in lightness caused by phenolic compound interactions (Basalekou *et al*., 2023). The initial a^* values for all peach wines ranged from −0.46 to 0.60, indicating a slight shift from green toward red. Notably, nectarine peach wine had the highest initial a^* value, demonstrating a tendency toward more redness. By the end of fermentation, the a^* values of nectarine + white peach wine and nectarine + yellow peach wine increased significantly to 3.15 and 3.20, respectively. This indicates that the addition of nectarine enhances the redness of the wine, primarily because of the extraction of anthocyanins and other red pigments from the fruit during fermentation (Claus, 2019; Wu *et al*., 2022). Similarly, Wang *et al*. (2024) reported that fermenting pressed apple juice without pectinase pretreatment resulted in the loss of red pigments and a significant decrease in a^* values, whereas other pretreatments maintained pigment stability, highlighting the influence of processing methods on pigment retention. In terms of b^* values, nectarine-added peach wines showed an increase compared to initial values, while wines made solely from white or yellow peaches exhibited a decrease. The b^* value, which reflects yellowness, is influenced by the fruit type and fermentation conditions. Carotenoids such as β-carotene, lutein, zeaxanthin, α-carotene, and β-cryptoxanthin contribute to yellowness (Zhao *et al*., 2022) and can be affected by fermentation conditions, such as temperature and pH (Claus and Mojsov, 2018; Saini *et al*., 2022). The overall color difference (ΔE) between the initial and final states was 0.59 for white peach wine, 1.91 for yellow peach wine, and 3.21 for nectarine peach wine, indicating that the most substantial color change occurred in nectarine peach wine. This underscores the significant impact of nectarine addition on color development during fermentation. Notably, decoloration is common during fermentation and aging, primarily because of pigment degradation and oxidation, making ΔE a key metric for monitoring color stability (Wu *et al*., 2022). In nectarine-added peach wines, particularly during the early stages of fermentation, all color values changed markedly. This may be attributed to the lower pH of nectarine peach wines, which slows microbial activity and prolongs the lag phase—allowing greater pigment extraction and transformation (Mendes Ferreira and Mendes-Faia, 2020).

Color intensity decreased slightly in white and yellow peach wines but increased from 0.08 to 0.12 in peach wines added with nectarine, suggesting an enhancement in color depth because of the addition of nectarine. Color intensity is an important sensory attribute linked to consumer preference, as it often correlates with perceived flavor richness (Fan *et al*., 2023). Moreover, hue values were decreased in all samples, with a more pronounced reduction in peach wines added with nectarine, indicating that addition of nectarine had a stronger influence on hue shifts, which are typically associated with pigment stability (Rivero *et al*., 2019). A lower hue value suggests a shift toward a more stable and desirable color profile for long-term storage and visual appeal (Zhang *et al*., 2023). Overall, this study demonstrated that the color of peach wine undergoes various changes during fermentation, with the addition of nectarine significantly influencing several color parameters. These color changes not only affect consumer perception but also serve as critical indicators of wine quality and storage stability, underscoring the importance of color management in fruit wine production.

Free sugar and organic acid contents

The free sugar and organic acid contents of peach wines from different varieties showed significant differences (Table 1). In the free sugar analysis, white peach wine, which exhibited a slower fermentation rate, had notably higher levels of glucose (2.04 g/L), sucrose (0.65 g/L), and fructose (4.25 g/L) compared to the other peach wines, while the remaining peach wines had consumed most of their free sugars. In the organic acid analysis, nectarine peach wine contained significantly higher concentrations of citric acid (8.19 g/L) and tartaric acid (6.64 g/L) than both white and yellow peach wines. On the other hand, white peach wine had significantly higher malic acid content (4.91 g/L) compared to nectarine and yellow peach wines. In peach wines added with nectarine, citric acid, tartaric acid, and malic acid were detected at intermediate levels, in contrast to the wines made from single peach cultivars. No significant differences were found in succinic acid and acetic acid levels across the studied peach wines.

Amerine *et al*. (1965) proposed that the perceived intensity of sourness from organic acids follows the order malic acid > tartaric acid > citric acid > lactic acid, when present in equal concentrations. A study by Lee *et al*. (2023b) reported that *Sunfre*, a variety of nectarine, had much higher citric acid contents than both white and yellow peach varieties, along with higher total acidity, indicating

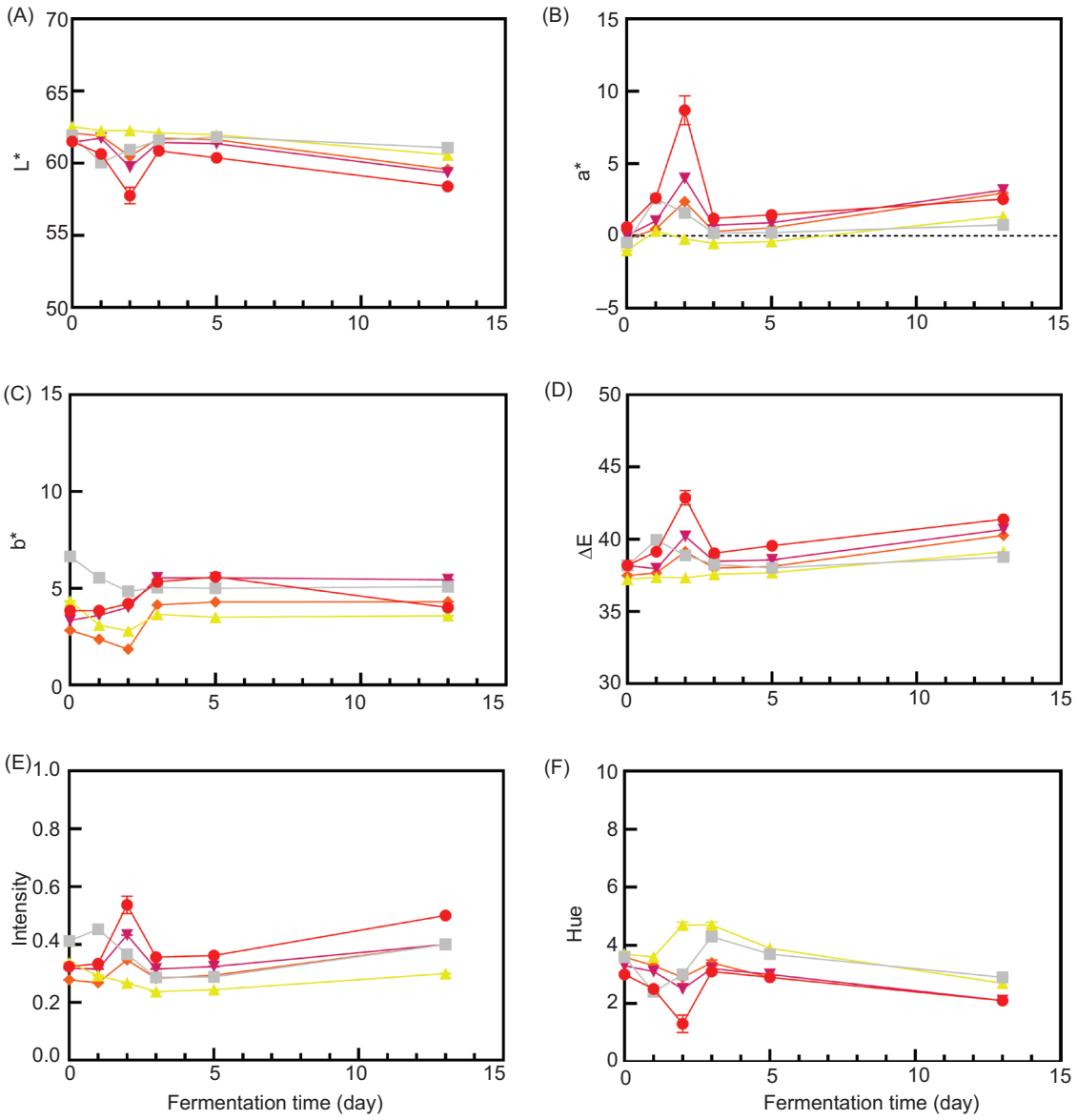

Figure 2. Color characteristics of different peach wines during fermentation. (A) L* value; (B) a* value; (C) b* value; (D) ΔE value; (E) Color intensity; (F) Hue value.

a relatively stronger sourness. In line with this, our study found that although the content of malic acid was the highest in white peach wine, the total content of citric acid and tartaric acid in nectarine peach wine was significantly higher, suggesting that nectarine peach wine would have the strongest sourness. Therefore, while wine made solely from the nectarine peach variety has a strong sourness that could reduce consumer preference, blending with yellow or white peach cultivars could mitigate this drawback.

Antioxidant capacities

The antioxidant capacities of the peach wines, assessed through DPPH, ABTS, and FRAP assays—key indicators of the wines' health-promoting potential—are summarized in Table 2. The DPPH assay revealed that white peach wine exhibited the highest antioxidant activity (77.4 ± 0.4%), followed by yellow peach wine (76.4 ± 0.4%), with nectarine peach wine showing the lowest activity (73.5 ± 0.9%). In the ABTS assay, nectarine and nectarine + yellow peach wines demonstrated the highest antioxidant capacities (0.61 ± 0.01 and 0.61 ± 0.02 μM TE/mL, respectively), whereas nectarine + white wine showed the lowest value (0.56 ± 0.00 μM TE/mL). FRAP assay results indicated that nectarine peach wine had the strongest reducing power (0.21 ± 0.00 μM TE/mL), followed by nectarine + yellow peach wine (0.19 ± 0.00 μM TE/mL). Overall, nectarine peach wine exhibited significantly higher antioxidant activity

Table 1. Free sugar and organic acid contents (g/L) of peach wines produced from different varieties.

Item	Nectarine	White	Yellow	Nectarine + White	Nectarine + Yellow
Free sugars (g/L)					
Glucose	0.20 ± 0.02^{c}	2.04 ± 0.02^{a}	0.14 ± 0.01^{d}	0.25 ± 0.01^{b}	0.19 ± 0.01^{c}
Sucrose	0.13 ± 0.01^{b}	0.65 ± 0.01^{a}	0.02 ± 0.00^{e}	0.08 ± 0.01^{c}	0.04 ± 0.00^{d}
Fructose	1.49 ± 0.01^{c}	4.25 ± 0.13^{a}	1.52 ± 0.02^{c}	1.76 ± 0.03^{b}	1.52 ± 0.01^{c}
Organic acids (g/L)					
Citric acid	8.19 ± 0.17^{a}	2.46 ± 0.02^{e}	2.77 ± 0.02^{d}	5.28 ± 0.01^{b}	5.13 ± 0.02^{c}
Tartaric acid	6.64 ± 0.01^{a}	5.68 ± 0.01^{e}	6.29 ± 0.01^{d}	6.59 ± 0.01^{b}	6.41 ± 0.01^{c}
Malic acid	4.14 ± 0.01^{c}	4.91 ± 0.04^{a}	4.17 ± 0.01^{c}	4.49 ± 0.01^{b}	4.03 ± 0.02^{d}
Succinic acid	1.12 ± 0.01^{c}	0.69 ± 0.01^{e}	1.35 ± 0.00^{a}	1.11 ± 0.01^{d}	1.18 ± 0.00^{b}
Acetic acid	0.09 ± 0.00^{a}	0.08 ± 0.00^{b}	0.08 ± 0.00^{b}	0.08 ± 0.00^{b}	0.07 ± 0.00^{b}

Different superscript letters in a row indicate significant differences ($p < 0.05$).

Table 2. Antioxidant capacities and related compound contents of peach wines produced from different varieties.

Item	Nectarine	White	Yellow	Nectarine + White	Nectarine + Yellow
Antioxidant activities					
DPPH inhibition (%)	73.5 ± 0.9^{c}	77.4 ± 0.4^{a}	76.4 ± 0.4^{a}	74.3 ± 0.5^{bc}	74.6 ± 0.5^{b}
ABTS (μM TE/mL)	0.61 ± 0.01^{a}	0.57 ± 0.00^{bc}	0.58 ± 0.01^{b}	0.56 ± 0.00^{c}	0.61 ± 0.02^{a}
FRAP (μM TE/mL)	0.21 ± 0.00^{a}	0.16 ± 0.00^{d}	0.17 ± 0.00^{c}	0.17 ± 0.00^{c}	0.19 ± 0.00^{b}
Antioxidant compounds					
Total phenolic content (mg GAE/L)	493.3 ± 2.1^{e}	586.0 ± 3.8^{a}	521.1 ± 3.5^{c}	532.2 ± 2.7^{b}	503.9 ± 3.7^{d}
Total flavonoid content (mg CE/L)	137.4 ± 0.1^{a}	136.8 ± 0.1^{c}	137.1 ± 0.1^{b}	136.9 ± 0.0^{c}	137.0 ± 0.0^{b}
Total anthocyanin content (mg C3G/L)	77.9 ± 19.3^{a}	27.8 ± 9.6^{b}	33.4 ± 16.7^{b}	39.0 ± 19.3^{b}	44.5 ± 9.6^{b}

Different superscript letters in a row indicate significant differences ($p < 0.05$).

in the ABTS and FRAP assays ($p < 0.05$) compared to most other peach wines, except for the nectarine + yellow peach blend in the ABTS assay. The antioxidant compound contents, including TPC, TFC, and TAC, are presented in Table 2. The highest TPC (586.0 ± 3.8 mg GAE/L) was observed in white peach wine, while nectarine peach wine had the lowest (493.3 ± 2.1 mg GAE/L). This relatively low TPC in nectarine peach wine was effectively improved through blending, resulting in significantly higher TPC values in the mixed wines. Nectarine peach wine had the highest TFC, though the difference was not statistically significant when compared with other wines. For TAC, nectarine peach wine again had the highest value (77.9 ± 19.3 mg C3G/L), while white peach wine had the lowest (27.8 ± 9.6 mg C3G/L), likely reflecting variations in red pigment concentrations among the cultivars. Importantly, blending nectarine with white or yellow peaches enhanced the TAC levels of those wines, thereby improving their overall anthocyanin content.

Peaches are rich in phytochemicals such as phenolic acids and flavonoids, which are linked to various health benefits (Li *et al*., 2023). The concentration of these compounds is influenced by factors such as genotype, cultivation practices, growing region, maturity stage, and cultivar type (Andreotti *et al*., 2008; Gil *et al*., 2002). A strong positive correlation between TPC and antioxidant capacity has also been reported in fruit wines (Liang *et al*., 2022). Notably, the peel of peaches, nectarines, and plums contains higher levels of phenolics, anthocyanins, and flavonols than their flesh (Gil *et al*., 2002). According to Reig *et al*. (2013), the content of anthocyanin in the skin of nectarine cultivars (9.92–11.43 mg/kg) was substantially higher than that in the skin of yellow peach cultivars (0.70–0.94 mg/kg). Consistent with this, our study found the highest TPC in white peach wine, while nectarine peach wine exhibited the highest anthocyanin content, highlighting cultivar-based differences in phytochemical composition. The complementary nature of these phytochemicals across different types of peach

supports the conclusion that blending cultivars can enhance the functional properties of peach wines.

Sensory evaluation

The sensory evaluation of different peach wines revealed notable differences across various characteristics, as shown in Figure 3. Nectarine + yellow and nectarine + white peach wines received the highest ratings for color (6.63), while nectarine peach wine scored the lowest (4.63). For flavor, nectarine + white peach wine garnered the highest score (5.79), closely followed by nectarine + yellow peach wine (5.68), with white peach wine receiving the lowest score (4.89). In terms of sweetness, white peach wine scored the highest (5.63), while nectarine + white peach wine had the lowest score (3.42). Regarding sourness, nectarine peach wine exhibited the highest rating (6.89), while yellow peach wine had the lowest rating (4.63). Yellow peach wine was rated the most bitter (5.21), while white peach wine was the least bitter (3.95). The overall preference was the highest for white peach wine (6.05) and the lowest for yellow peach wine (4.21). These sensory characteristics reflect the inherent properties of the peach varieties used (Liu *et al*., 2022; Petruccelli *et al*., 2023). White peach is known for its high natural sweetness and low bitterness, which likely contributed to its high sweetness rating and low bitterness score. In contrast, yellow peach typically has more pronounced sourness and bitterness, which is evident in its higher sourness and bitterness ratings. Blending nectarine with white and yellow peach varieties results in wines with more balanced sensory attributes, improving overall palatability. When blended, white peach wine, with its high sweetness and low bitterness, benefits from enhanced aroma, while yellow peach wine exhibits reduced bitterness (Medeiros *et al*., 2022). These combinations create diverse peach wines that cater to various consumer preferences, with white peach wine emerging as the most preferred overall because of its balanced sweetness, low sourness, and low bitterness. These findings underscore the potential of mixed peach wines to satisfy a broad range of consumer tastes and preferences.

Conclusions

This study investigated the fermentation characteristics, physicochemical properties, and sensory profiles of peach wines from different varieties, including white, yellow, and nectarine peaches. To improve the flavor and functional quality of these wines, we blended nectarine peaches with white or yellow peach varieties. Nectarine peach wine exhibited higher total acidity, primarily because of its elevated citric and tartaric acid content, resulting in a notably sour taste compared to wines from

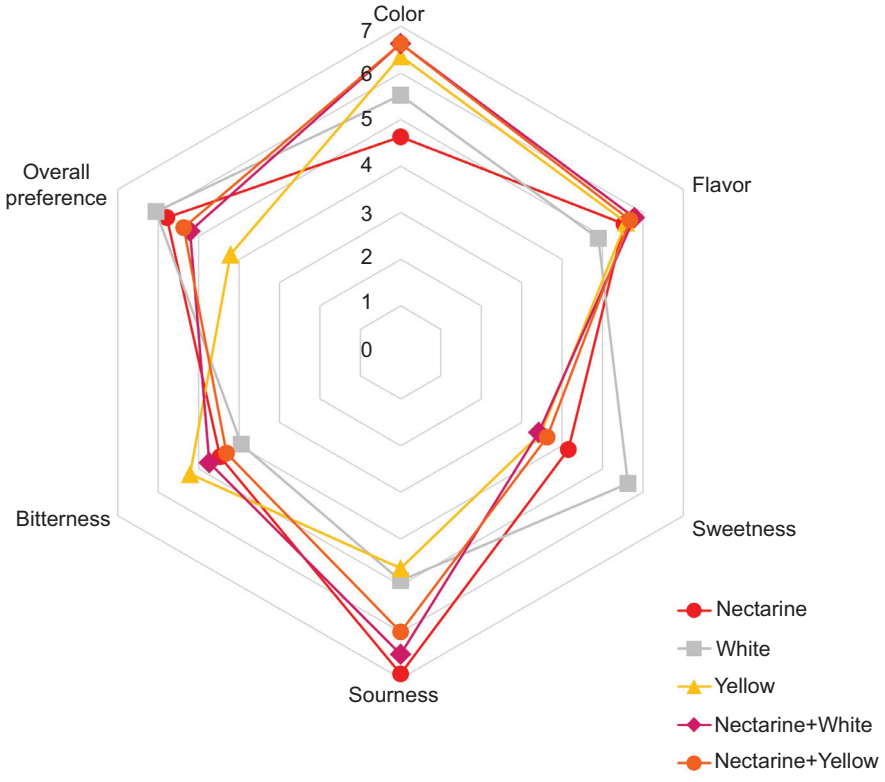

Figure 3. Sensory evaluation scores of wines produced using different peach varieties.

other peach varieties. However, blending nectarine with white or yellow peaches helped improve these characteristics. Although nectarine peach wine had a higher anthocyanin content (derived from its peel) compared to other peach wines, it contained lower levels of TPC, leading to a relatively lower DPPH value and antioxidant capacity. This deficiency can be balanced by blending with yellow or white peaches. Sensory evaluation showed that yellow peach wine, with its mild sourness and sweetness, received a lower overall preference. However, the addition of nectarine improved its sensory profile. Overall, this study demonstrated that adding nectarine to other peach varieties can address the shortcomings of single-variety peach wines, providing valuable insights for the future development of the peach wine industry.

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Author Contributions

All authors contributed equally to this article.

Conflicts of Interest

The author's declare no conflicts.

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