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Production and quality assessment of fig wine: A comparative study on Turkish fig varieties

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Abstract: This study aimed to produce technologically viable fig wines from two main Turkish fig varieties (Sarilop and Bursa Siyahi) and to evaluate their quality and acceptability. Fig musts were prepared at two soluble solids concentrations (17 and 24 °Bx) using fresh and sun-dried Sarilop (yellow-coloured) and fresh Bursa Siyahi (dark purple-coloured) figs. Total phenolic content of fig wines ranged from 223.21 to 267.98 mg gallic acid equivalents (GAE)·L^{-1}, while total antioxidant capacity varied from 3.73 to 4.42 μmol Trolox·(100 mL)$^{-1}$ (ABTS) and 35.09 to 69.30 μmol Trolox·(100 mL)$^{-1}$ (DPPH). Wines produced from fresh Bursa Siyahi figs exhibited the highest antioxidant activity. Both fig variety and fruit form (fresh or dried) significantly affected phenolic composition. Epicatechin and chlorogenic acid were predominant in wines produced from fresh Bursa Siyahi figs, whereas rutin was dominant in wines made from fresh Sarilop figs. Wines produced from musts with 24 °Bx showed significantly higher descriptive sensory scores than those produced from musts with 17 °Bx ($P < 0.05$). No significant difference in overall impression was observed between wines made from fresh and dried Sarilop figs.

Keywords: phenolics; antioxidant capacity; sensory properties; Sarilop; Bursa Siyahi

Fermentation, one of the oldest preservation techniques, is an effective method for producing new products with diverse physicochemical and sensory characteristics. The main raw material generally used in wine production is grapes. However, the suitability of different fruits such as apricots, apples, peaches, pears, cherries, and berries for wine production has been investigated (Jagtap and Bapat 2015). Fruit wines are non-distilled alcoholic beverages and typically contain between 5 to 13% (*v/v*) alcohol by volume (Swami et al. 2014). Since different fruits have distinct biochemical properties, it is crucial to identify the appropriate production technique for each type of fruit wine (Andersa 2020). In Türkiye, fruit wines are regulated under the general provisions of the Turkish Food Codex and the applicable legislation on alcoholic beverages. In contrast, in the European Union and many other countries, fermented products obtained from fruits other than grapes are not legally classified under the 'wine' category; these products are addressed under separate legal definitions and technical regulations. According to oenological

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practices and common classifications in the literature, an alcohol content of approximately 14% (*v/v*) is used as a practical technical reference point to distinguish table-type fermented products from products with higher alcohol or sweet characteristics. However, there is no alcohol limit specified in the literature for fruit wines. Products with higher alcohol content are classified as sweet, fortified, or special fermented beverages rather than standard fruit wines (Joshi and Kumar 2011; Kosseva et al. 2016).

Fig is one of the oldest and important fruit species grown in Mediterranean countries. Türkiye is the leading producer of figs worldwide, accounting for 27.3% of global production (Terin 2025). Figs are a good source of nutrients, including sugars, polyphenols, and organic acids, and can provide many health benefits. However, fresh figs have a very short shelf life and can be stored only for 2–3 weeks in cold storage (Şengül-Binat and Kırca-Toklucu 2023). Figs are also potentially good raw materials for the production of fermented alcoholic beverages due to their high sugar and polyphenol contents (Lu et al. 2021; Moisescu and Antoce 2022). Processing figs into value-added products, such as fig wine, is a great way to extend their shelf life, maintain their nutrients and bioactive compounds, and enhance their nutritional and functional properties. In recent years, few studies have investigated fig-based alcoholic beverages with respect to the effects of fig variety (Moisescu and Antoce 2022), yeast strain (Zuo et al. 2013; Liu et al. 2021), thermal processing and drying (Lu et al. 2021), and aging (Ma et al. 2022). However, research addressing the physicochemical and sensory properties of fig wine throughout the production process remains limited.

The production of fig wine represents an innovative way to utilise this valuable fruit. Although grape wine has been extensively studied and commercialised, fig wine remains relatively unexplored. Selection of an appropriate fig variety is critical for wine production, as fresh and dried figs differ in moisture and sugar content, which influences fermentation behaviour and final wine characteristics. This study aimed to evaluate the potential of the two main Turkish fig varieties, Sarilop and Bursa Siyahi, for wine production and to explore their suitability for the development of value-added products. Fig musts were prepared at two soluble solids levels (17 and 24 °Bx) using fresh and dried Sarilop figs (yellow-coloured) and fresh Bursa Siyahi figs (dark purple-coloured). To our knowledge, these varieties have not previously been used for winemaking. Physicochemical and sensory analyses were conducted to assess wine quality and acceptability. In addition, total phenolic content, antioxidant capacity, and individual phenolic compounds were determined to examine their potential functional properties.

MATERIAL AND METHODS

Preparation of fig musts

Fresh Sarilop (Figure 1A), sun-dried Sarilop (Figure 1B), and fresh Bursa Siyahi figs (Figure 1C) were obtained from the Aydın Fig Research Institute orchard. Fresh fruits were harvested at full ripeness in August 2022. Approximately 50 kg of fresh or dried

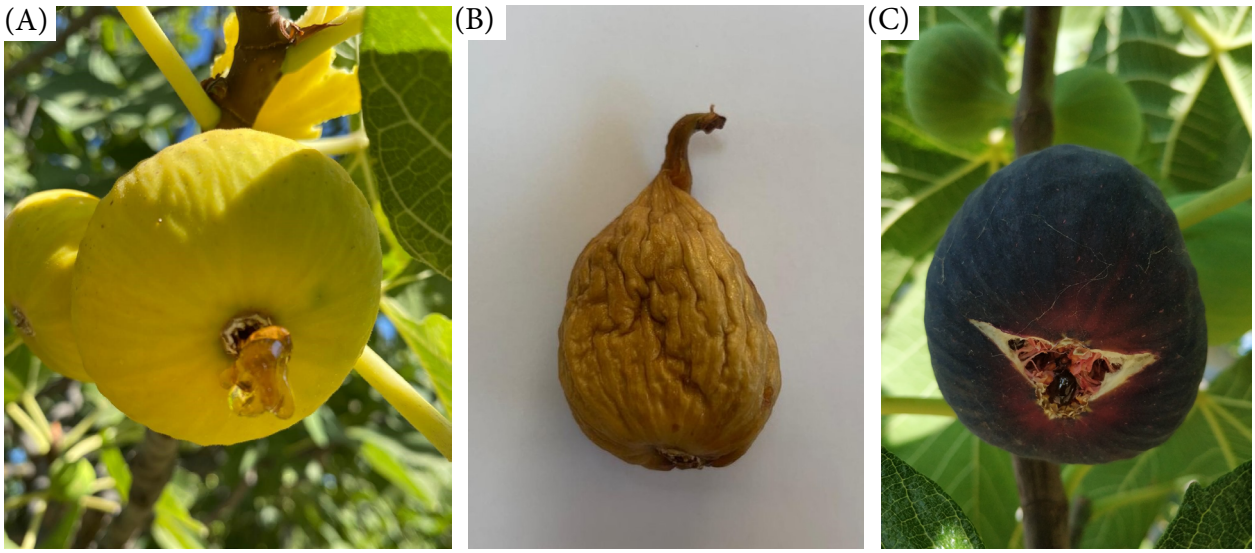

Figure 1. Fig varieties; (A) fresh Sarilop fig, (B) dried Sarilop fig, and (C) fresh Bursa Siyahi fig

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figs were used per trial for fig wine production. Six different musts at 17 and 24 °Bx were prepared from fresh and dried Sarilop figs and fresh Bursa Siyahi figs. Fruits were selected and sorted, and sun-dried figs were screened for aflatoxin under UV light. Fresh fruits were chopped, mashed, and mixed with water at a ratio of 1: 1 (*w/w*) in 20-L glass bottles; dried figs were mixed with water at a ratio of 1: 3 (*w/w*). Sulphur dioxide (50 mg·L^{-1}) was added, and pH of the musts was adjusted to 3.5 by gradual addition of citric acid, monitored using a pH meter. The mash was macerated at 5–7 °C for five days, and 0.2% pectolytic enzyme (Pectinex Ultra AFP, Novozymes, Denmark) was added on the final day. The mash was pressed, and the must was filtered through sieve cloth. Volume of must obtained after pressing was approximately equal to volume of water added, resulting in a soluble solids content of approximately 12 °Bx. Sugar was added to the musts to adjust soluble solids to 17 and 24 °Bx, as measured using a refractometer, and pH was readjusted to 3.5. For each fig type, two independent must preparations were carried out.

Production of fig wines

Wine production was carried out in 15-L glass vessels with airlocks, inoculated with commercial yeast (*Saccharomyces cerevisiae*, Laffort FX10, 20 g·hL^{-1}) and yeast nutrient (Nutricel Start, 30 g·hL^{-1}) in duplicate. Fermentation proceeded at 20 °C, monitored daily for °Bx and temperature (Walker et al. 2021), and was considered complete when reducing sugars fell below 4 g·L^{-1}. Total SO_2 was then measured and adjusted to 50 mg·L^{-1}. Wines were bottled in 750-mL dark amber bottles and stored at 12–13 °C for one month, after which physicochemical and sensory analyses were performed.

Physicochemical analysis

pH was measured using a pH meter (WTW-pH7110, Germany), while total soluble solids (TSS) were determined using a digital refractometer (Hanna, HI96801, USA). Total acidity was determined by titrating 10 mL of diluted samples with 0.1 N NaOH until pH reached 8.1 (Zhang et al. 2022). Results were expressed as grams of citric acid per litre. Reducing sugar content was determined using the Luff–Schoorl method, which measures reduction of copper(II) ions by reducing sugars in the sample under alkaline conditions. Results were evaluated using standard tables, and total reducing sugar content was expressed in g·L^{-1} (Ilieva et al. 2021). Alcohol content was measured using an ebulliometer (Laboratories Dujardin Salleron^{TM}, France). Dry extract and volatile acidity were determined using OIV (2020, OIV-MA-AS2-03A and OIV-MA-AS313-02) methods. For determination of free SO_2, wine samples were acidified with 25% sulphuric acid and then titrated with N/64 iodine solution in the presence of starch indicator. To determine total SO_2, 1 N NaOH solution was added to wine samples, and the same titration procedure was performed after 15 min of hydrolysis (Ulca et al. 2011). Both free and total SO_2 were expressed in mg·L^{-1}. Colour was measured using a Minolta CR-400 (Minolta Co. Ltd., Japan) and expressed in CIELAB coordinates (L^*, a^*, b^*, C^*, h). For each experimental condition, two parallel fermentation batches were prepared, and all analytical determinations were carried out in duplicate, resulting in four independent measurements (n = 4).

Phenolic profile

Major phenolics in fig must and wine were analysed by reversed-phase HPLC (LC20A, Shimadzu, Japan) with a photodiode array detector (SPD-M20A), according to Şengül-Binat and Kırca-Toklucu (2023), with minor modifications. Samples were filtered through 0.45 µm membrane filters and injected onto a Macherey-Nagel C18 column (4.6 × 250 mm, 5 µm). The mobile phase consisted of 2% acetic acid in water (A) and methanol (B), applied under the following gradient conditions: 0 min, 95 : 5; 10 min, 50 : 50; 15 min, 30 : 70; 25 min, 95 : 5, at a flow rate of 0.4 mL·min^{-1}. Chromatograms were recorded at 272, 275, 279, and 356 nm. Quantification was performed using calibration curves of external standards (epicatechin, chlorogenic acid, gallic acid, syringic acid, and rutin) and expressed as mg·L^{-1}.

Total phenolic content (TPC)

TPC was determined using the Folin–Ciocalteu method (Singleton and Rossi 1965) with minor modifications. To 30 µL of sample, 150 µL of 1: 10 diluted Folin–Ciocalteu reagent and 120 µL of 75 g·L^{-1} sodium carbonate were added, vortexed, and incubated in the dark at room temperature for 2 h. Absorbance was measured at 765 nm, and TPC was calculated using a gallic acid standard curve and expressed as mg GA·(100 mL)$^{-1}$.

Total antioxidant activity (TAA)

ABTS assay. ABTS+ radical was prepared by mixing 7 mM ABTS with 2.45 mM potassium persulfate and incubating the mixture in the dark at room tem-

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perature for 12–16 h (Re et al. 1999). The solution was diluted with potassium buffer to an absorbance of 0.700 ± 0.02 at 734 nm. Then, 200 µL of ABTS solution was added to 10 µL of must or wine, and absorbance was recorded every minute for 6 min using a microplate reader (Thermo Scientific, Multiskan Sky, Singapore). Percentage inhibition was calculated and plotted against sample volumes of 10, 20, 30, and 60 µL. Antioxidant activity was determined using a Trolox standard curve and expressed as µmol Trolox·(100 mL)$^{-1}$.

DPPH assay. A 96-well microplate method was used to measure TAA of must and wine samples against the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical (Darvishzadeh et al. 2021). For this purpose, 250 µL of prepared DPPH solution (0.2 mM) was added to 25 µL of must and wine samples in a 96-well microplate. After incubation for 30 min, absorbance was measured at 517 nm using a microplate reader, and results were expressed as µmol Trolox·(100 mL)$^{-1}$.

Total monomeric anthocyanin (TMA)

TMA of must and wine samples was determined using the pH differential method (Giusti and Wrolstad 2001). For this purpose, two buffer solutions, 0.025 M potassium chloride (pH = 1.0) and 0.4 M sodium acetate (pH = 4.5), were prepared. Extracts were mixed with each buffer solution, and absorbance of the diluted extracts was determined at 511 nm and 700 nm. Total monomeric anthocyanin content was calculated according to the following equation:

$$TMA\left(mg \cdot L^{-1}\right) = \left(A \times MW \times DF \times 1\,000\right) / \left(\varepsilon \times l\right) \quad (1)$$

Where: A – (A511–A700) pH 1.0 – (A511–A700) pH 4.5; MW – molecular weight of cyn-3-glu (449.2 g·mol^{-1}); DF – dilution factor; ε – molar absorptivity of cyn-3-glu (26 900 L·cm^{-1}), l –path length (1 cm).

Sensory evaluation of fig wines

Sensory evaluation of fig wines was assessed after one-month ageing by a trained panel consisting of six panellists (four females and two males, ages 25–45) familiar with wine characteristics from Canakkale Onsekiz Mart University. Panellists underwent 20 h of training over two weeks. Evaluations were conducted with the Spectrum™ descriptive method (Meilgaard et al. 1999). Panellists first defined the best descriptors for the wines. Fourteen descriptive terms were selected for evaluation. Wines were rated using a 0–10 scale (0 = not perceptible; 10 = very high intensity). Visual attributes, including appearance and clarity, were incorporated into overall impression rather than scored as independent attributes. A 25 mL aliquot of each wine was presented in a randomised and balanced order and served at 13–14 °C in tulip-shaped wine-tasting glasses. Wines were aerated for 30 min prior to evaluation. Salt-free crackers were provided to panellists to neutralise the palate between samples.

Ethical approval. The sensory analysis in the study followed the ethical guidelines of the Canakkale Onsekiz Mart University, Science and Engineering Ethics Committee to ensure the protection and rights of all participants. All ingredients and technologies were food-grade, ensuring the products were safe for consumption. All panelists were of legal drinking age and provided informed consent, including the right to withdraw from the study at any time without consequence. No personal or sensitive data was collected without participants' knowledge. The study followed appropriate protocols to protect the rights and privacy of all participants.

Statistical analysis

All analyses were carried out on two parallel samples with duplicate analytical determinations, and results were expressed as mean ± standard deviation (n = 4). Data were analysed using one-way analysis of variance (ANOVA). When significant differences were detected (P < 0.05), means were compared using Duncan's multiple range test. For analysis of TMA in Bursa Siyahi musts (BSM) and corresponding wine samples, a paired t-test was applied. All statistical analyses were performed using SPSS software (version 22.0, SPSS Inc., USA). Relationships between TPC, TMA, and antioxidant capacity were assessed using Pearson correlation analysis.

RESULTS AND DISCUSSION

Physicochemical properties of fig musts. For wine production, six different musts were prepared using Sarilop [fresh (SFM) and dried (SDM)] and fresh Bursa Siyahi (BSM) figs at two soluble solids levels (17 and 24 °Bx). Physicochemical properties of the musts are presented in Table 1. As pH influences alcoholic fermentation, all samples were adjusted to 3.5 using citric acid, which is the predominant organic acid in figs. Total acidity ranged from 7.19 to 9.75 g·L^{-1}, with significant differences among musts (P < 0.05). Musts adjusted to 24 °Bx exhibited lower acidity than those

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Table 1. Physicochemical and antioxidant properties of the fig musts (mean ± SD, n = 4)

	SFM17	SFM24	SDM17	SDM24	BSM17	BSM24
Total acidity ($g \cdot L^{-1}$)*	8.46 ± 0.07^{c}	7.65 ± 0.06^{e}	9.75 ± 0.04^{a}	7.19 ± 0.04^{f}	9.02 ± 0.12^{b}	8.24 ± 0.07^{d}
Dry extract ($g \cdot L^{-1}$)	183.65 ± 0.49^{d}	260.10 ± 0.71^{b}	188.15 ± 0.78^{c}	259.10 ± 0.85^{b}	191.10 ± 0.42^{c}	276.55 ± 3.04^{a}
Reducing sugar ($g \cdot L^{-1}$)	109.49 ± 0.61^{e}	205.40 ± 0.85^{a}	103.44 ± 0.61^{f}	203.00 ± 0.85^{b}	112.08 ± 0.61^{d}	200.60 ± 0.85^{c}
TPC (mg GA$\cdot L^{-1}$)	289.29 ± 3.32^{b}	292.62 ± 14.43^{b}	259.41 ± 19.88^{c}	250.36 ± 96.69^{c}	349.05 ± 7.34^{a}	360.36 ± 9.42^{a}
ABTS [µmol Trolox (100 mL) $^{-1}$]	2.91 ± 0.16^{b}	2.91 ± 0.43^{b}	1.61 ± 0.30^{c}	1.86 ± 0.13^{c}	4.90 ± 0.58^{a}	4.76 ± 0.43^{a}
DPPH [µmol Trolox (100 mL) $^{-1}$]	53.49 ± 2.62^{c}	44.03 ± 4.68^{d}	29.07 ± 4.23^{e}	27.83 ± 1.34^{e}	69.85 ± 1.18^{a}	56.04 ± 2.55^{b}
TMA ($mg \cdot L^{-1}$)	–	–	–	–	5.19 ± 0.23^{a}	4.20 ± 0.37 ^{b}
Epicatechin ($mg \cdot L^{-1}$)	8.19 ± 0.79^{b}	6.51 ± 0.30^{b}	2.58 ± 0.67^{c}	1.82 ± 0.58^{c}	39.17 ± 3.83^{a}	40.79 ± 2.64^{a}
Chlorogenic acid ($mg \cdot L^{-1}$)	3.61 ± 1.78^{c}	1.89 ± 0.68^{c}	1.40 ± 0.64^{c}	1.47 ± 0.24^{c}	26.72 ± 4.89^{b}	31.34 ± 2.37^{a}
Gallic acid ($mg \cdot L^{-1}$)	0.51 ± 0.04^{b}	0.47 ± 0.01^{cd}	0.44 ± 0.01^{d}	0.48 ± 0.03^{bc}	0.61 ± 0.01^{a}	0.59 ± 0.02^{a}
Syringic acid ($mg \cdot L^{-1}$)	9.72 ± 0.87^{a}	8.09 ± 0.17^{b}	5.04 ± 0.16^{c}	4.38 ± 0.24^{cd}	4.45 ± 0.48^{cd}	4.22 ± 0.46^{d}
Rutin ($mg \cdot L^{-1}$)	17.68 ± 0.41^{a}	13.97 ± 0.23^{b}	3.95 ± 0.25^{d}	3.97 ± 0.23^{d}	10.10 ± 0.89^{c}	9.45 ± 0.40^{c}

$^{a–f}$different letters in the same row indicate significant differences for those characteristics ($P < 0.05$); *expressed as citric acid; SFM17 – fresh Sarilop fig must at 17 °Brix; SFM24 – fresh Sarilop fig must at 24 °Brix; SDM17 – dry Sarilop fig must at 17 °Brix; SDM24 – dry Sarilop fig must at 24 °Brix; BSM17 – fresh Bursa Siyahi fig must at 17 °Brix; BSM24 – fresh Bursa Siyahi fig must at 24 °Brix; TPC – total phenolic content; TMA – total monomeric anthocyanins; GA – gallic acid; ABTS – 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); DPPH – 2,2-diphenyl-1-picrylhydrazyl

at 17 °Bx, which is likely attributable to dilution effects associated with higher sugar addition.

TPC of the fig musts varied between 250.36 and 360.36 mg gallic acid (GA)$\cdot L^{-1}$. The highest TPC was found in the musts obtained from fresh Bursa Siyahi figs. These samples also demonstrated the highest antioxidant activity in both ABTS and DPPH assays, most likely due to the presence of anthocyanin pigments in this fig variety. TMA of the BSM was measured as 4.20 and 5.19 $mg \cdot L^{-1}$ for musts at 17 and 24 °Bx, respectively. TPC of the SFM was higher than that of SDM. Additionally, SFM exhibited significantly higher antioxidant activity than SDM ($P < 0.05$). These findings support previous reports indicating that sun-drying reduces TPC and antioxidant activity in figs (Kamiloglu and Capanoglu 2015).

Phenolic compounds of the must samples were analysed using HPLC-PDA, and a total of five phenolic compounds were determined (Table 1). Significant differences were found in the concentrations of epicatechin, chlorogenic acid, gallic acid, syringic acid, and rutin between SDM, SFM and BSM (17–24 °Bx). Fruit form (fresh or dried) and fig variety significantly affected phenolic concentrations in the musts. The lowest concentrations of individual phenolic compounds were found in SDM. Epicatechin (39.17 and 40.79 $mg \cdot L^{-1}$) and chlorogenic acid (26.72 and 31.34 $mg \cdot L^{-1}$) were the most abundant phenolics in BSM, while SFM contained the highest concentrations of rutin (17.68 and 13.97 $mg \cdot L^{-1}$) as the main phenolic compound. Syringic acid was the second most abundant in Sarilop musts (ranging from 9.72 to 4.38 $mg \cdot L^{-1}$), and its concentration in SFM and SDM was higher than in BSM. Gallic acid was the least abundant phenolic compound in all musts, with concentrations ranging from 0.44 to 0.61 $mg \cdot L^{-1}$.

Fermentation process. The fermentation process was monitored by daily measurement of total soluble solids (TSS, °Bx) in the musts, which represents a practical indicator of sugar consumption during fermentation (Moisescu and Antoce 2022). °Bx values of all samples decreased progressively as fermentation advanced (Figure 2), and fermentation was considered complete or stuck when °Bx remained constant.

Final °Bx values differed significantly between musts initially adjusted to 17 °Bx (6.03–6.40) and those adjusted to 24 °Bx (8.18–8.70). Fermentation lasted longer in musts adjusted to 24 °Bx (11–15 days) than in those at 17 °Bx (5–9 days). The longest fermentation period was observed in SDM24. In agreement with Lu et al. (2021), slower sugar degradation in dried-fig wines was associated with lower must acidity. Accordingly, SDM24 exhibited the lowest acidity (7.19 $g \cdot L^{-1}$) among all musts.

Physicochemical properties of fig wines. Physicochemical properties of the wines are given in Table 2.

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Table 2. Physicochemical properties of the fig wines (mean ± SD, n = 4)

	SFW17	SFW24	SDW17	SDW24	BSW17	BSW24
pH	3.51 ± 0.01^{c}	3.60 ± 0.01^{a}	3.38 ± 0.01^{d}	3.60 ± 0.01^{a}	3.49 ± 0.01^{c}	3.57 ± 0.01^{b}
Total acidity (g·L^{-1})*	10.58 ± 0.21^{b}	9.77 ± 0.08^{e}	11.65 ± 0.32^{a}	10.03 ± 0.23^{de}	10.19 ± 0.29^{cd}	10.49 ± 0.11^{bc}
Dry extract (g·L^{-1})	27.35 ± 0.55^{b}	30.85 ± 0.62^{a}	28.42 ± 1.00^{b}	31.83 ± 1.03^{a}	28.71 ± 1.77^{b}	31.95 ± 0.53^{a}
Reducing sugar (g·L^{-1})	3.12 ± 0.07^{d}	3.30 ± 0.06^{c}	2.74 ± 0.06^{e}	3.78 ± 0.06^{a}	3.38 ± 0.04^{c}	3.60 ± 0.04^{b}
Free SO_2 (mg·L^{-1})	8.50 ± 0.58^{c}	16.50 ± 0.58^{a}	7.00 ± 0.00^{d}	9.25 ± 0.50^{bc}	10.00 ± 0.82^{b}	16.25 ± 0.50^{a}
Total SO_2 (mg·L^{-1})	24.00 ± 0.82^{e}	49.50 ± 0.58^{a}	44.75 ± 0.50^{b}	44.00 ± 0.82^{b}	25.50 ± 0.58^{d}	33.50 ± 1.29^{c}
Density (g·mL^{-1})	0.999 ± 0.00^{a}	0.993 ± 0.00^{c}	0.998 ± 0.00^{a}	0.993 ± 0.00^{c}	0.994 ± 0.00^{b}	0.990 ± 0.00^{d}
Alcohol (*v/v*)	8.40 ± 0.16^{d}	15.30 ± 0.16^{b}	7.98 ± 0.39^{d}	15.90 ± 0.12^{a}	8.90 ± 0.48^{c}	15.65 ± 0.31^{ab}
Volatile acid (g·L^{-1})	0.21 ± 0.05^{c}	0.24 ± 0.00^{bc}	0.27 ± 0.03^{b}	0.33 ± 0.03^{a}	0.21 ± 0.03^{c}	0.29 ± 0.03^{ab}

$^{a–e}$different letters in the same row indicate significant differences for those characteristics (P < 0.05); *expressed as citric acid; SFM17 – fresh Sarilop fig must at 17 °Brix; SFM24 – fresh Sarilop fig must at 24 °Brix; SDM17 – dry Sarilop fig must at 17 °Brix; SDM24 – dry Sarilop fig must at 24 °Brix; BSM17 – fresh Bursa Siyahi fig must at 17 °Brix; BSM24 – fresh Bursa Siyahi fig must at 24 °Brix

pH and total acidity are critical parameters influencing sensory characteristics as well as microbiological and biochemical stability of wines (Payan et al. 2023). pH of fig wines ranged from 3.38 to 3.60, and total acidity ranged from 9.77 to 11.65 g·L^{-1}, with significant differences among samples (P < 0.05). Wines produced from musts adjusted to 24 °Bx exhibited higher pH values. The highest total acidity was observed in wine produced from dried Sarilop must at 17 °Bx, whereas the lowest was observed in wine from fresh Sarilop must at 24 °Bx. Alcohol content increased with initial soluble solids, ranging from 7.98–8.90% (*v/v*) in wines adjusted to 17 °Bx to 15.30–15.90% (*v/v*) in those adjusted to 24 °Bx. Alcohol levels approaching 16% (*v/v*) exceed the typical range reported for conventional fruit wines; therefore, these products may be classified as specialty or dessert-style fruit wines. All samples contained < 4 g·L^{-1} residual sugar, confirming complete fermentation and classification as dry wines. Moisescu and Antoce (2022) reported alcohol levels of 17.5–18.0% (*v/v*) in beverages produced from fresh figs by adjusting musts to 29 °Bx; however, those products were classified as semi-sweet due to residual sugar levels of 12.59–26.98 g·L^{-1}. These findings underscore the importance of optimising sugar concentration and acidity prior to fermentation. Acceptable volatile acidity was observed in all fig wines, with values ranging from 0.21 to 0.33 g·L^{-1}. Wines produced from musts adjusted to 24 °Bx exhibited higher volatile acidity than those at 17 °Bx, with the highest value recorded in SDW24. Volatile acids at concentrations of 0.2 –0.7 g·L^{-1} may contribute positively to wine complexity through interactions with other flavour compounds (Liang et al. 2022). Total SO_2 levels in all fig wines remained below the regulatory limit of 200 mg·L^{-1}.

Total phenolics, total monomeric anthocyanins, and antioxidant capacities of fig wines. TPC, TMA, and TAA of the fig wines are shown in Table 3. Significant differences in TPC, TAA, and TMA were observed between the wine samples (P < 0.05). TPC of the fig wines ranged from 223.21 to 267.98 mg·L^{-1}. Unlike the must samples, TPC values of SFW were higher

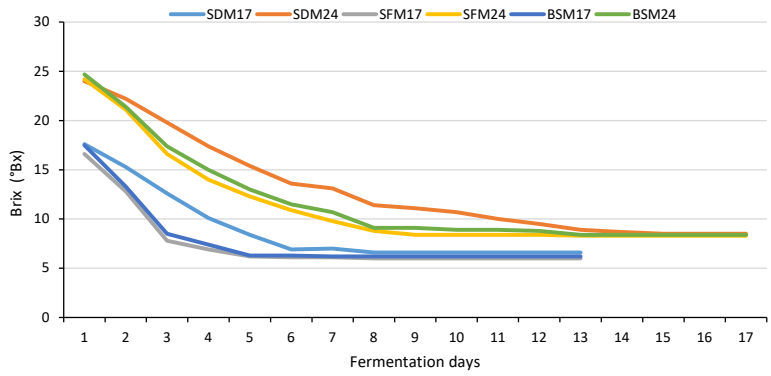

Figure 2. Changes in the Brix levels during alcoholic fermentation

SFM17 – fresh Sarilop fig must (17 °Brix); SFM24 – fresh Sarilop fig must (24 °Brix); SDM17 – dry Sarilop fig must (17 °Brix); SDM24 – dry Sarilop fig must (24 °Brix); BSM17 – fresh Bursa Siyahi fig must (17 °Brix); BSM24 – fresh Bursa Siyahi fig must (24 °Brix)

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Table 3. Total phenolic content (TPC), total monomeric anthocyanins (TMA), and antioxidant capacities (ABTS and DPPH) of the fig wines (mean ± SD, n = 4)

	SFW17	SFW24	SDW17	SDW24	BSW17	BSW24
TPC (mg GA·L^{-1})	227.26 ± 14.05^{c}	254.04 ± 5.40^{ab}	223.21 ± 14.28^{c}	236.79 ± 5.0^{c}	252.98 ± 2.73^{b}	267.98 ± 9.20^{a}
ABTS [μmol Trolox·(100 mL)$^{-1}$]	3.95 ± 0.15^{bc}	4.35 ± 0.17^{ab}	3.73 ± 0.26^{c}	3.97 ± 0.26^{bc}	4.25 ± 0.32^{ab}	4.42 ± 0.16^{a}
DPPH [μmol Trolox·(100 mL)$^{-1}$]	46.40 ± 1.39^{b}	49.55 ± 2.02^{b}	35.09 ± 5.39^{c}	35.18 ± 4.95^{c}	69.30 ± 6.63^{a}	66.45 ± 0.94^{a}
TMA (mg·L^{-1})	–	–	–	–	2.79 ± 0.14^{a}	2.40 ± 0.17^{b}

$^{a–c}$different letters in the same row indicate significant differences for those characteristics (P < 0.05); SFW17 – fig wine from fresh Sarilop must at 17 °Brix, SFW24 – fig wine from fresh Sarilop must at 24 °Brix; SDW17 – fig wine from dry Sarilop fig must at 17 °Brix; SDW24 – fig wine from dry Sarilop fig must at 24 °Brix; BSW17 – fig wine from fresh Bursa Siyahi fig must at 17 °Brix; BSW24 – fig wine from fresh Bursa Siyahi fig must at 24 °Brix; GA – gallic acid; ABTS – 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); DPPH – 2,2-diphenyl-1-picrylhydrazyl

than those of SDW. However, Lu et al. (2021) found no significant differences in total polyphenols between fresh (679 mg·L^{-1}) and dried Brown Türkiye fig (reddish-brown skin) wines (731 mg·L^{-1}).

We observed that alcoholic fermentation resulted in a slight decrease in TPCs, with a range of 5.4–21.44% in SFW-SDW and 25.64–27.52% in BSW. During fermentation, the amount of free phenolic compounds may decrease due to binding with other molecules in the food matrix, degradation by microbial enzymes, and hydrolysis by specific microbial strains (Hu et al. 2023). Budak et al. (2022) also found higher TPC before fermentation than after, aligning with the findings of our study. On the other hand, Liu et al. (2021) reported that the levels of phenolic compounds and antioxidant activity in fig wine made from fresh red-skinned figs were significantly higher than those of their corresponding must.

TMA of BSW17 and BSW24 were determined as 2.79 and 2.40 mg·L^{-1}. TMA in Bursa Siyahi fig must was 1.8 times higher than that in fig wines, indicating that anthocyanin pigments were degraded during fermentation and one month of storage. Similarly, severe reductions in TMA of red wines were reported at the end of alcoholic fermentation and storage (Uzkuç et al. 2022). The degradation of anthocyanins is closely associated with the activity of β-glycosidase; therefore, the structure of anthocyanins and the presence of β-glucosidase should be considered in fruit wine production (Yuan et al. 2024). Studies have also suggested that β-glucosidase produced by yeast is one of the causes of anthocyanin degradation during fruit wine fermentation (Tofalo et al. 2021).

The antioxidant capacities of the fig wines were determined using both ABTS and DPPH assays. Interestingly, DPPH values were found to be approximately ten times higher than those obtained from the ABTS assay (Table 3). This variation may be attributed to differences in radical chemistry and reaction mechanisms, resulting in method-dependent responses of phenolic compounds in wines (Lachman et al. 2009). There was a significant difference in the DPPH of fig wines, ranging from 35.09 to 69.30 μmol Trolox·(100 mL)$^{-1}$. The highest DPPH was observed in BSW17 and BSW24. It was also reported TAA was highly correlated with the presence of phenolic compounds and anthocyanins in fig wines (Liu et al. 2021). SDW17 and SDW24 exhibited significantly lower DPPH and ABTS radical scavenging activities compared with the other wines. This is likely due to the reduction of TPCs and TAA in figs caused by sun drying, as indicated by Kamiloglu and Capanoglu (2015). However, Lu et al. (2021) reported that drying figs before the fermentation process did not have a significant effect on the DPPH and oxygen radical scavenging capacities of fig wines, although fresh wines had higher capacities than dried ones. After fermentation, it was observed that ABTS radical scavenging activities of all Sarilop musts increased (1.4–2.3 times), while ABTS radical scavenging activities of BSM decreased slightly. The DPPH of Sarilop musts also increased except SFM17. In a study conducted by Tarko et al. (2020), apple cider showed higher TAA than must, while blackcurrant wine exhibited lower TAA compared to their corresponding musts.

We observed an average relationship between the two antioxidant assays, as indicated by a correlation coefficient (R) of 0.506 (Table 4), consistent with those previously reported by other researchers (Hosu et al. 2014, Alañón et al. 2011). A moderate to strong positive correlation was observed between TPC and both ABTS (R = 0.620) and DPPH (R = 0.724) radical scavenging activities, indicating an association rather than a caus-

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Table 4. Correlation between total phenolic content (TPC), total monomeric anthocyanins (TMA) and antioxidant capacities (ABTS and DPPH)

		TPC	ABTS	DPPH	TMA
TPC	Pearson *R*	1.000	0.620**	0.724**	–0.575
	P	–	0.001	0.000	0.136
ABTS	Pearson *R*	0.620**	1.000	0.506*	–0.081
	P	0.001	–	0.012	0.848
DPPH	Pearson *R*	0.724**	0.506*	1.000	0.372
	P	0.000	0.012	–	0.364
TMA	Pearson *R*	–0.575	–0.081	0.372	1.000
	P	0.136	0.848	0.364	–

* and **significance levels at 0.05 and 0.01, respectively (2-tailed)

al relationship. Similarly, a strong positive correlation was reported between TPC and TAA in fruit wines (Davidovic et al. 2013, Zuo et al. 2013). On the other hand, there was a statistically insignificant and weak correlation (R = 0.372) between the DPPH assay and TMA. A similar relation was also found by some researchers (Kallithraka et al. 2005; Orak 2007; Li et al. 2009). Although anthocyanins may contribute to antioxidant capacity, the weak and statistically insignificant correlation observed between total monomeric anthocyanins and DPPH activity suggests that antioxidant capacity in fig wines is likely associated with total phenolic content rather than anthocyanins alone.

Phenolic compounds of fig wines. Five phenolic compounds, including epicatechin, chlorogenic acid, gallic acid, syringic acid, and rutin, were identified, and their concentrations were determined in each fig wine. The concentrations of these phenolic compounds are presented in Table 5. The selected phenolic compounds represent major and commonly reported phenolics in fig and fig-derived products rather than a comprehensive phenolic profile (Veberic et al. 2008; Şengül-Binat and Kırca-Toklucu 2023). The results indicated that the alcohol content had little effect on the differences in these values. However, the type of fruit (fresh or dried) and the fig variety significantly affected the phenolic concentrations in wines. Among the samples, SDW had the lowest individual phenolic concentrations (ranging from 0.38 to 2.96 mg·L^{-1}). SFW contained ten times more rutin than SDW, while the contents of syringic and epicatechin were about 1.5 and 2 times higher, respectively. However, Lu et al. (2021) found that fig wines obtained from dried Brown Türkiye figs had much higher amounts of individual phenolic compounds than those obtained from fresh figs. They also found that catechin was the highest phenolic compound in fresh Brown Türkiye fig wines, while rutin was predominant in wines made from dried figs.

Phenolic concentrations of the fig wines made from fresh Sarilop figs ranged from 0.40 to 11.63 mg·L^{-1}. Rutin had the highest concentration (9.87 and 11.63 mg·L^{-1}) among the identified phenolics in SFW17 and SFW24. Syringic acid was the second-highest phenolic compound detected (4.49 and 4.04 mg·L^{-1}), while epicatechin ranked third (1.98 and 2.36 mg·L^{-1}) in fresh Sarilop wines. In BSW17 and BSW24, epicatechin (23.09 and 25.04 mg·L^{-1}) and chlorogenic acid (19.88 and 26.37 mg·L^{-1}) were the most abundant phenolic

Table 5. Phenolic compounds of the fig wines (mean ± SD, n = 4)

Phenolic compounds	SFW17	SFW24	SDW17	SDW24	BSW17	BSW24
Epicatechin (mg·L^{-1})	1.98 ± 0.51^{c}	2.36 ± 0.14^{c}	1.05 ± 0.07^{d}	1.03 ± 0.03^{d}	23.09 ± 0.65^{b}	25.04 ± 0.04^{a}
Chlorogenic acid (mg·L^{-1})	0.47 ± 0.28^{c}	0.40 ± 0.09^{c}	0.40 ± 0.12^{c}	0.38 ± 0.02^{c}	19.88 ± 0.18^{b}	26.37 ± 0.79^{a}
Gallic acid (mg·L^{-1})	0.50 ± 0.03^{bc}	0.54 ± 0.04^{a}	0.44 ± 0.01^{e}	0.48 ± 0.01^{d}	0.56 ± 0.01^{a}	0.53 ± 0.01^{ab}
Syringic acid (mg·L^{-1})	4.49 ± 0.23^{a}	4.04 ± 0.13^{b}	2.96 ± 0.08^{d}	2.84 ± 0.01^{d}	3.52 ± 0.13^{c}	3.44 ± 0.11^{c}
Rutin (mg·L^{-1})	11.63 ± 0.86^{a}	9.87 ± 0.07^{b}	1.10 ± 0.16^{d}	0.94 ± 0.06^{d}	5.17 ± 0.06^{c}	5.60 ± 0.07^{c}

$^{a–d}$different letters in the same row indicate significant differences for those characteristics (P < 0.05); SFW17 – fig wine from fresh Sarilop must at 17 °Brix, SFW24 – fig wine from fresh Sarilop must at 24 °Brix; SDW17 – fig wine from dry Sarilop fig must at 17 °Brix; SDW24 – fig wine from dry Sarilop fig must at 24 °Brix; BSW17 – fig wine from fresh Bursa Siyahi fig must at 17 °Brix; BSW24 – fig wine from fresh Bursa Siyahi fig must at 24 °Brix

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compounds. Similarly, a study by Liu et al. (2021) reported that chlorogenic acid, epicatechin, and catechin were the predominant phenolics in fig wine made from fresh red-skinned figs in China.

Individual phenolic compounds are significantly affected by alcoholic fermentation in fruit wines. Some of them increase due to enhanced extraction, while others decrease due to degradation or transformation during fermentation. In our study, all fig wines showed lower levels of epicatechin, chlorogenic acid, syringic acid, and rutin compared to their corresponding musts. On the other hand, gallic acid content was not affected by the fermentation process. Zhang et al. (2022) reported that some phenolics, including gallic acid, *p*-coumaric acid, and quercetin, increased, while syringic acid, ferulic acid, and cinnamic acid decreased in fermented blueberry wine. The specific changes in phenolics may depend on the fruit, yeast strains, and fermentation conditions.

Colour properties of fig wines. The colour of wine is an important parameter in assessing its quality, age, type, and composition. The colour characteristics of the fig wines were evaluated using CIELAB parameters (L^*, a^*, b^*, C^*, and h), and the results are presented in Table 6. Colour attributes differed significantly ($P < 0.05$) among fig wines, depending on variety (Bursa Siyahi vs. Sarilop) and fruit form (fresh vs. dried). As expected, BSW17 and BSW24 had significantly lower L^* ($P < 0.05$) and higher a^* ($P < 0.05$) compared to the wines made from yellow-coloured Sarilop figs. Kumar et al. (2022) also reported that wines with high TMA exhibited lower L^*, resulting in darker colouration, which aligns with our findings. In addition to fig variety, the fresh or dried form of the figs also affected the colour of the fig wines. SDW17 and SDW24 had significantly higher b^* ($P < 0.05$), indicating enhanced yellowness, and lower a^* ($P < 0.05$) compared to the other wines. The parameter h, known as the hue angle, represents the qualitative aspect of colour and is used to describe the overall impression of a colour, such as red (h = 0°), yellow (h = 90°), or green (h = 180°). Wines made from dried Sarilop figs had the highest (SDW17: 76.53°; SDW24: 76.45°), indicating yellowish hues. On the other hand, wines made from fresh figs exhibited hue lower than 60°, which represent reddishness. This clearly reflects the effects of the drying process. The lowest hue values (25.39° and 25.52°) were observed in BSW17 and BSW24 wines, which were produced from purple-coloured fresh figs. C^*, referred to as chroma, represents colour saturation or intensity. Higher chroma indicates more concentrated, vivid, and saturated colour (Fan et al. 2023). The C^* of the wine samples ranged from 10.37 (SFW24) to 18.41 (BSW24), with BSW17 and BSW24 exhibiting the highest and statistically significant values. These results showed that Bursa Siyahi wines were more vividly coloured. However, regardless of fresh or dried form, no statistically significant variations were observed in C^* of Sarilop wines, which showed moderate values, indicating a less saturated colour.

Sensory evaluations of fig wines. The mean scores of the sensory evaluation of the fig wines based on a 10-point scale are shown in Table 7. Significant differences were observed between fig wines produced from fresh and dried figs, as well as between musts of varying °Bx (17 and 24). All wine samples were visually clear and free from noticeable turbidity or sediment during the sensory evaluation, which contributed to a positive overall sensory perception.

Fig wines had prominent sourness (3.13–6.92) and sweetness (2.00–4.08). SFW17 had the highest scores for sour taste and the lowest score for sweetness (2.00). Sarilop wines were generally evaluated as more sour and less sweet than Bursa Siyahi wines. SFW had higher scores for sourness and lower scores for sweetness compared to their dried counterparts. Bitterness was rated as low (0.42–2.54) across all fig wines. BSW

Table 6. Colour properties of the fig wines (mean ± SD, n = 4)

	SFW17	SFW24	SDW17	SDW24	BSW17	BSW24
L^*	18.84 ± 0.89^{b}	24.03 ± 0.20^{a}	24.02 ± 1.23^{a}	23.02 ± 0.18^{a}	12.71 ± 1.15^{d}	14.26 ± 1.24^{c}
a^*	7.94 ± 0.33^{b}	5.66 ± 0.10^{b}	2.56 ± 0.08^{c}	2.44 ± 0.04^{c}	15.15 ± 2.84^{a}	16.62 ± 3.18^{a}
b^*	7.51 ± 0.60^{bc}	8.69 ± 0.14^{b}	10.70 ± 0.42^{a}	10.12 ± 0.07^{a}	7.15 ± 1.06^{c}	7.92 ± 1.45^{bc}
C^*	10.93 ± 0.65^{b}	10.37 ± 0.08^{b}	11.00 ± 0.43^{b}	10.41 ± 0.06^{b}	16.76 ± 3.02^{a}	18.41 ± 3.49^{a}
h	43.35 ± 1.20^{c}	56.93 ± 0.86^{b}	76.53 ± 0.24^{a}	76.45 ± 0.28^{a}	25.39 ± 0.89^{d}	25.52 ± 0.55^{d}

$^{a–d}$different letters in the same row indicate significant differences for those characteristics ($P < 0.05$); SFW17 – fig wine from fresh Sarilop must at 17 °Brix, SFW24 – fig wine from fresh Sarilop must at 24 °Brix; SDW17 – fig wine from dry Sarilop fig must at 17 °Brix; SDW24 – fig wine from dry Sarilop fig must at 24 °Brix; BSW17 – fig wine from fresh Bursa Siyahi fig must at 17 °Brix; BSW24 – fig wine from fresh Bursa Siyahi fig must at 24 °Brix

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Table 7. Descriptive sensory evaluation scores of the fig wines (10-point scale, mean ± SD, n = 6)

	BSW17	BSW24	SFW17	SFW24	SDW17	SDW24
Sour	5.38 ± 0.7^{b}	3.13 ± 0.3^{e}	6.92 ± 0.5^{a}	5.25 ± 0.6^{b}	4.54 ± 0.5^{c}	3.67 ± 0.9^{d}
Sweet	3.88 ± 0.6^{ab}	3.54 ± 0.6^{ab}	2.00 ± 0.9^{d}	2.71 ± 1.3^{cd}	3.17 ± 1.1^{bc}	4.08 ± 0.9^{a}
Bitterness	1.88 ± 0.6^{b}	2.54 ± 0.5^{a}	0.42 ± 0.7^{d}	1.21 ± 0.7^{c}	0.54 ± 0.5^{d}	0.79 ± 0.9^{cd}
Astringency	2.33 ± 0.4^{ab}	2.21 ± 0.5^{b}	2.46 ± 0.3^{ab}	2.71 ± 0.8^{a}	1.58 ± 0.5^{c}	1.67 ± 0.6^{c}
Fruity	2.54 ± 0.4^{d}	3.75 ± 0.3^{c}	6.67 ± 0.8^{a}	5.58 ± 1.6^{b}	4.38 ± 0.6^{c}	3.88 ± 0.6^{c}
Ripe fruit	1.83 ± 0.6^{ab}	1.38 ± 0.6^{bc}	1.75 ± 0.3^{ab}	2.21 ± 0.9^{a}	1.21 ± 0.4^{c}	1.17 ± 0.3^{c}
Floral	1.42 ± 0.4^{b}	2.00 ± 0.5^{a}	1.71 ± 0.4^{ab}	1.92 ± 0.4^{a}	1.58 ± 0.4^{ab}	2.00 ± 0.8^{a}
Alcohol	5.25 ± 0.5^{c}	8.71 ± 0.5^{a}	5.13 ± 0.4^{c}	8.08 ± 0.4^{b}	5.13 ± 0.4^{c}	8.42 ± 0.4^{ab}
Fermented	2.96 ± 0.8^{a}	2.00 ± 0.4^{b}	2.92 ± 0.4^{a}	2.00 ± 0.6^{b}	1.67 ± 0.4^{b}	1.04 ± 0.1^{c}
Sulphurous	1.04 ± 0.5^{a}	0.63 ± 0.3^{a}	0.75 ± 0.5^{a}	0.63 ± 0.8^{a}	1.04 ± 0.1^{a}	0.83 ± 0.4^{a}
Mineral	1.67 ± 0.8^{b}	1.50 ± 0.5^{b}	2.63 ± 0.7^{a}	2.50 ± 0.4^{a}	1.79 ± 0.4^{b}	1.88 ± 0.5^{b}
Body	5.46 ± 0.7^{e}	8.00 ± 0.7^{b}	6.58 ± 0.6^{d}	7.92 ± 0.6^{bc}	7.46 ± 0.4^{c}	8.79 ± 0.4^{a}
Finish	6.08 ± 0.7^{d}	7.83 ± 0.6^{b}	6.67 ± 0.7^{c}	7.88 ± 0.5^{b}	7.63 ± 0.3^{b}	8.75 ± 0.3^{a}
Overall impression	6.79 ± 0.6^{c}	8.58 ± 0.6^{a}	7.67 ± 0.3^{b}	8.83 ± 0.3^{a}	8.04 ± 0.3^{b}	8.63 ± 0.5^{a}

$^{a–d}$different letters in the same row indicate significant differences for those characteristics (P<0.05); SFW17 – fig wine from fresh Sarilop must at 17 °Brix, SFW24 – fig wine from fresh Sarilop must at 24 °Brix; SDW17 – fig wine from dry Sarilop fig must at 17 °Brix; SDW24 – fig wine from dry Sarilop fig must at 24 °Brix; BSW17 – fig wine from fresh Bursa Siyahi fig must at 17 °Brix; BSW24 – fig wine from fresh Bursa Siyahi fig must at 24 °Brix

showed the highest bitterness scores, likely due to the varietal characteristics of these figs. Astringency scores ranged from 1.58 to 2.71, and SDW showed the lowest scores compared to fresh ones. This may be associated with the low tannin of figs (Liu et al. 2021). All wines also received low scores (1.50–2.63) for mineral characteristics. SFW exhibited higher fruit aromas than SDW. In contrast, fruit aroma remained at low intensities in BSW.

As expected, fig wines produced from musts adjusted to 24 °Bx exhibited a pronounced alcohol aroma. Alcohol content in these wines ranged from 15.3 to 15.9% (v/v), which is notably higher than that typically reported for most commercial fruit wines. Although elevated alcohol levels may dominate the sensory profile, these wines also received higher scores for body and finish. SDW24 achieved the highest scores for finish (8.75) and body (8.79), suggesting greater structural intensity and persistence. Moreover, wines produced from 24 °Bx musts received the highest overall scores (SFW24: 8.83; SDW24: 8.63; BSW24: 8.58), with no significant differences among them. Among wines adjusted to 17 °Bx, SDW17 received the highest scores for body (7.46), finish (7.63), and overall (8.04).

These findings indicate that both raw material selection (fresh versus dried figs) and must concentration are important factors influencing the final sensory quality of fig wine. Although the present data provide insight into the effects of different must treatments, they should be interpreted as preliminary observations regarding sensory characteristics rather than definitive evidence of consumer preference. Further studies involving a larger consumer panel are necessary to assess the market potential of these high-alcohol fig wines.

CONCLUSION

This study examined the quality characteristics of fig wines made from two main Turkish fig varieties. The results demonstrate that fig variety, fruit form (fresh or dried), and must concentration are critical determinants of fig wine quality. Wines made from fresh Bursa Siyahi figs had the highest level of total phenolic compounds, as well as antioxidant activity. BSW were significantly redder, darker, and more saturated in colour, while Sarilop wines exhibited yellower, lighter, and less saturated colour properties. For optimal technological preparation, a fruit-to-water ratio of 1 : 1 (*w/w*) for fresh figs and 1 : 3 (*w/w*) for dried figs is recommended. These ratios, combined with an initial soluble solid adjustment to 24 °Bx, provide a balanced must for producing high-alcohol fig wines with desirable sensory attributes. The results highlight that 24 °Bx musts are technically superior for producing high-quality wines, characterised by enhanced body, finish, and overall sensory intensity compared

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to 17 °Bx musts. Based on their alcohol content (approaching 16% *v/v*), these products may be classified as specialty or dessert-style fruit wines. Overall, these findings confirm the feasibility of producing specialty wines from Turkish fig varieties.

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