ID: 530

Effect of Needle Micro-Perforation Pretreatment as an Alternative to Alkaline Dipping Solution in Grape Drying on Bioactive Compounds

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Abstract

Grape (*Vitis sp.*) is widely consumed and cultivated globally. In addition to being consumed fresh as wine, juice or dried fruit. It is known for its bioactive compounds, such as flavonoids, polyphenols, anthocyanins, and tannins, which provide health benefits, including antioxidant, anti-inflammatory, and cardioprotective effects. However, grapes are highly susceptible to microbial spoilage due to their high water content, limiting their shelf life. Drying is one of the most common methods used to extend grape shelf life. Pretreatments before drying facilitate moisture removal, accelerating the drying process and preserving nutrients, This study investigates the potential of needle micro-perforation (0.5 mm, 1 mm, and 1.5 mm needle lengths) as an alternative to the widely used dipping method. The total phenolic content, antioxidant capacity (DPPH and CUPRAC), and anthocyanin content of Kavacık grapes (*Vitis vinifera L.* "Alphonse Lavallée" variety) were analyzed. Pretreated grapes were dried using static and convective methods at 60°C, 70°C, and 80°C, and their bioactive compounds were evaluated. Results showed that different pretreatments had varying effects on bioactive compounds. Needle micro-perforation was as effective as the dipping method in preserving total phenolics, antioxidants, and anthocyanins. In static drying, the total phenolic content of samples with needle micro-perforation was approximately 250 mg per 100 g of dry matter higher than that of samples with the dipping treatment. In convective drying, this difference increased to about 400 mg per 100 g of dry matter. Similarly, antioxidant capacity was about 10 µmol Trolox equivalent per gram of dry matter higher in needle micro-perforation samples under static drying and 20 µmol higher under convective drying. In conclusion, needle micro-perforation effectively preserves bioactive compounds and can be considered an alternative to the dipping method.

Key Words: *Kavacık grape, pretreatment, needle micro-perforation, total phenolic content, antioxidant capacity.*

Introduction

Grapes are among the most widely cultivated fruits globally, with an annual production of around 75 million tons (Srivastava et al., 2021). Data from the 2019–2020 period indicates that China leads in grape production, followed by India and Turkey (Sabra et al., 2021; Topalović et al., 2020). According to the Institute of Agricultural Economics and Policy Development, Turkey produced about 3.8 million tons of grapes during the 2023/2024 season, with Manisa being the leading region. Grapes are consumed fresh, used in wine production and processed into products like fruit juice, jam, seed extract, and grape seed oil (Sabra et al., 2021; Srivastava et al., 2021). Approximately 50% of global grape production is allocated to wine, one-third is consumed as fresh fruit, and the remain is used for drying (Srivastava et al., 2021). Grape cultivation depends on climate, disease resistance, fruit color, taste, and whether the variety is seeded or seedless (Sabra et al., 2021). There are between 8,000 and 10,000 *V. vinifera* grape varieties used for commercial purposes (Sabra et al., 2021). Grapes consist of skin, seeds, and pulp. They are rich in bioactive compounds, especially polyphenols, which vary across fruit components (Zhou et al., 2022). These include flavonoids, phenolic acids, and anthocyanins (Kupe et al., 2021). The concentration of these compounds varies by grape variety and is linked to health benefits. Polyphenols in grapes may help prevent cardiovascular diseases, reduce cholesterol, control blood pressure, and protect against several cancers, including breast, skin, lung, colon and prostate (Aubert & Chalot, 2018; Sabra et al., 2021; Topalović et al., 2020). Grapes are also rich in sugars and contain vitamins (A, B1, B3, C) and minerals (iron, potassium, calcium, sodium) (Kirazcı, 2022). Kavacık grapes are grown in Kavacık village in the Karabağlar district of Izmir, Turkey, from the *Vitis vinifera L. 'Alphonse Lavallée'* variety. They are known for their high phenolic content and have received geographical indication as a table grape (Ministry of Culture and Tourism, 2023). Studies confirm the high polyphenol and bioactive compound content of this variety (Aubert & Chalot, 2018). Besides fresh consumption, Kavacık grapes are used to produce molasses and Turkish delight.

Due to their high water content, grapes are susceptible to spoilage from microbial and chemical reactions. Drying is commonly used to extend shelf life by reducing water content and water activity, slowing microbial growth and chemical degradation (Adeyeye et al., 2022). Drying is simple, cost-effective and reduces weight and volume, lowering packaging. Transportation, and storage costs (Ozkan et al., 2022). The drying method affects processing time, energy use and product quality (Ozkan et al., 2022). Hot air drying (HAD) is a faster alternative to sun drying. It offers benefits like reduced drying time, ease of use, low operational costs and better preservation of food safety and quality (Senadeera et al., 2020). Cabinet dryers, commonly used in HAD, prevent microbial spoilage, improving product quality (Yasmin et al., 2022). However, uneven air distribution in these dryers can be addressed by modifying fan placement or using dual fans (Günaydın et al., 2022). Hot air drying of grapes is a widely studied topic in the literature, Hermassi et al. (2017) investigated the drying of seedless Sultani grapes using a hot air dryer at various temperatures, evaluating moisture loss, shrinkage and drying rates through mathematical models. They found that moisture diffusivity increased with temperature, ranging from 3.56×10^{-10} to 12.6×10^{-10} m^2/s, and calculated an activation energy of 57.76 kJ/mol. Similarly, Shafiq et al. (2022) studied seedless grapes using different pretreatments (K_2CO_3 + ethyl oleate, olive oil, hot water and control) and three drying methods (cabinet-type tray dryer, sun tunnel, and open-air drying). The results showed that grapes pretreated with K_2CO_3 + ethyl oleate and dried in a tray dryer had the shortest drying time (26.08 h), with a lighter yellow-green appearance and softer texture.

Drying is energy-intensive and time-consuming, leading to the use of pretreatments to enhance drying efficiency, reduce energy costs and preserve food quality (Gavahian et al., 2024). Pretreatments can be physical (thermal and non-thermal) or chemical (Bassey et al., 2021; Deng et al., 2019). Chemical pretreatments involve immersing the product in solutions or exposing it to gases (Deng et al., 2019). Alkaline dipping in a potash solution is a common chemical pretreatment for grape drying, typically containing 5% potassium carbonate and 1–2% olive oil (Çoban & Abuşka, 2024). Potassium carbonate removes the waxy layer on the grape skin, facilitating moisture loss and shortening drying time (Carranza-Concha et al., 2012). This method preserves color and reduces drying time in seedless and black grapes (Doymaz, 2006; Shafiq et al., 2022). However, concerns about chemicals in food and water safety have increased interest in sustainable, chemical-free methods (Deng et al., 2019). Physical pretreatments, such as ultrasonic field, microwave, pulsed electic field enhance drying efficiency without chemicals (Bassey et al., 2021; Deng et al., 2019). Needle micro-perforation, which is a physical pretratment, creates small pores in the fruit peel, increasing diffusion and accelerating moisture removal. This method is more effective than some chemical methods in reducing drying time (Jazini & Hatamipour, 2010; Mabellini et al., 2013). Olives, plums, and cherries benefit from this technique, as the waxy layer on their skin acts as a barrier to moisture removal (Mabellini et al., 2012). In a study on olives, different pretreatments such as perforation with a metal brush, blanching, a combination of perforation and blanching and perforation followed by immersion in brine were applied before hot air drying. It was found that perforation had a positive effect on the drying process, enhancing moisture loss and improving overall drying efficiency (Gambella, 2000).

In this study, Kavacık grapes were dried at 60, 70, and 80°C using static and convective dryers. Needle micro-perforation and alkaline dipping pretreatments were applied, with needle lengths of 0.5, 1.0, and 1.5 mm tested. The aim of this study is to determine and evaluate the effects of needle micro-perforation pretreatment on bioactive compounds of Kavacık grapes by comparing with alkaline dipping pretreatment.

Materials and Methods

Materials

Kavacık village (Karabağlar, Izmir) sourced *Alphonse Lavallée (Vitis vinifera L.)* grapes were harvested at optimum ripeness. To reduce fungal contamination, grapes were immersed in 5% vinegar for 15 minutes, rinsed with water, air-dried, and stored in 500 g polyethylene bags at 4 °C for up to 15 days. Average berry diameter and length were 25.23 ± 3.80 mm and 25.99 ± 4.92 mm. Respectively, with a mean weight of 8.90 ± 0.48 g. Initial moisture content was 4.04 ± 0.02 kg water/kg dry matter (AOAC method, 100 °C). Grapes were divided into two pretreatment groups as alkaline dipping (control) and needle micro-perforation.

Pretreatments

In this study, needle pretreatment was compared with the industry-standard alkaline dipping method, which is widely used for grape drying. Accordingly, the control group (DG) was prepared for drying by immersion in an alkaline solution containing 5% (v/v) potassium carbonate (K_2CO_3) and 1% (v/v) extra virgin olive oil at 25 °C for 2 minutes, following the method described by Doymaz and Altıner (2012). Needle micro-perforated grapes (MG0.5, MG1.0, and MG1.5) were punctured using micro-perforators with the same number of needles but varying needle lengths: 0.5 mm for MG0.5, 1.0 mm for MG1.0 and 1.5 mm for MG1.5. These lengths were selected to be shorter than, equal to or longer than the average skin thickness of the grapes.

Drying Process

Grape samples (approximately 25 g per group), including the needle micro-perforated (MG0.5, MG1.0, MG1.5) samples and the alkaline-dipped control group (DG), were dried at 60, 70, and 80 °C using a static cabinet dryer and a convective hot air dryer. Both systems featured temperature control to ensure consistent thermal conditions throughout the drying process. The airflow velocity in the convective dryer was measured as approximately 2.5 m/s using a mini anemometer (UT363, Uni-T, China). The drying process continued until the sample weights reached a final moisture content of 0.24 kg water/kg dry matter.

Bioctive Compound Analysis

Total Phenolic Content (TPC)

The total phenolic content was determined using a modified version of the method outlined by Akbaş et al. (2017). For this analysis, extracts were prepared from both dried and fresh grape samples. For the dried grape extracts, approximately 2–3 grams of dried grapes were weighed and immersed in a sealed container with a solvent at a ratio of 1:10 (dried grape:solvent). The solvent comprised 80% methanol, 19.9% distilled water and 0.1% hydrochloric acid (HCl). The samples were incubated at +4 °C for 24 hours. Similarly, for the fresh grape extracts, approximately 10 grams of fresh grapes were weighed and combined with the same solvent at a 1:10 ratio. Following extraction, the grapes were ground in a mortar and filtered. Similarly, for the fresh grape extracts, approximately 10 grams of fresh grapes were weighed and combined with the same solvent at a 1:10 ratio.

For the phenolic content analysis, 0.5 ml of the extract was mixed with 2.5 ml of 0.2 N Folin–Ciocalteu reagent, vortexed, and allowed to incubate in the dark for 3 minutes. Following this, 2 ml of 7.5% sodium carbonate solution was added and, the mixture was vortexed again and incubated for 30 minutes. After the incubation period, absorbance was measured at 760 nm using a UV-Vis spectrophotometer (PG Instruments. United Kingdom). Calibration was performed using gallic acid standard solutions of varying concentrations (10, 20, 40, 50, 80, and 100 mg/ml). The same procedure was applied to each standard solution, and a standard curve was generated from the absorbance values. The total phenolic content was then calculated and expressed as milligrams of gallic acid equivalent (mg GAE) per 100 grams of dry matter.

Total Antioxidant Capacity

The total antioxidant capacity was evaluated using the DPPH (2.2-Diphenyl-1-picrylhydrazyl) radical scavenging method, as described by Özkan (2022) with some modifications. In this procedure, 0.1 mL of the grape extract was added to a test tube, followed by 4.9 mL of 0.1 mM DPPH solution. The mixture was vortexed and incubated in the dark at room temperature for 20 minutes. Absorbance of the DPPH solution was measured at 517 nm using a UV-Vis spectrophotometer (PG Instruments. United Kingdom). Calibration was performed with Trolox standard solutions at concentrations of 100, 500, 1000, 1500, 2000, and 2500 µmol/L, following the same procedure. A standard calibration curve was generated based on the absorbance values, and the total antioxidant capacity was calculated and expressed as milligrams of Trolox Equivalent (TE) per gram of dry matter.

The total antioxidant capacity was also measured using the CUPRAC (Cupric Ion Reducing Antioxidant Capacity) method, following the modified procedure by Özkan (2022). In this method, 0.1 mL of grape extract (fresh or dried) was transferred to a tube, and sequentially, 1 mL of each of the following solutions was added: $CuCl_2$ (10 mM), neocuproine (7.5 mM, alcoholic), NH_4Ac buffer (1 M. pH 7.0), and distilled water. The mixture was incubated in the dark at room temperature for 1 hour. Absorbance was then measured at 450 nm using a UV-Vis spectrophotometer (PG Instruments, United Kingdom). For calibration, Trolox standard solutions with concentrations of 1000, 1500, 2000, 2500, 3000, and 4000 µmol/L were prepared, and the CUPRAC method was applied for each. A calibration curve was constructed based on the absorbance values and the antioxidant capacity was calculated and expressed as milligrams of Trolox Equivalent (TE) per gram of dry matter.

Total Anthocyanin Content (TAC)

The total anthocyanin content was measured using the pH differential method as described by Özkan (2022). In this method, 0.025 M potassium chloride (KCl) and 0.4 M sodium acetate ($CH_3COONa \cdot 3H_2O$) solutions were prepared using distilled water. For the measurement, 0.8 mL of the grape extract was mixed with 3.2 mL of the potassium chloride solution, and a second 0.8 mL of the extract was mixed with 3.2 mL of the sodium acetate solution in different test tubes. The mixtures were incubated in the dark at room temperature for 30 minutes.

Absorbance values were then recorded at 510 nm and 700 nm using a UV-Vis spectrophotometer (PG Instruments. United Kingdom).

The total anthocyanin content was calculated using Equations 1 and 2:

$$A = [\text{A510nm} - \text{A700nm}]\text{pH1.0} - [\text{A510nm} - \text{A700nm}]\text{pH4.5} \quad (1)$$

$$TA = \frac{A \times MW \times D_f \times 1000}{\varepsilon \times L} \quad (2)$$

Where A is absorbance, A510 is absorbance at 510 nm, A700 is absorbance at 700 nm, MW is molecular weight of malvidin 3-glucoside (463.3 g/mol), D_f is dilution factor, ε is molar absorption coefficient (28.000 L/mol*cm), L is optical path length of the cuvette (1 cm), The results were expressed as mg malvidin-3-glucoside per 100 g dry matter.

Statistical Analysis

In this study. the effects of alkaline dipping and needle micro-perforation pretreatments on bioctive compounds of Kavacık grape were examined using selected independent variables (needle length, drying temperature). All measurements were repeated three times, and statistical differences between pretreatments were determined using analysis of variance (ANOVA) and Tukey's post-hoc test ($P \leq 0.05$). The data are presented in tables containing the means and standard deviations of the results from the three repeated trials.

Result and Discussion

Bioactive contents of fresh grapes are given in Table 1. Total phenolic value of fresh Kavacık grape was found as 1097.97 mg GAE/100 g dw, antioxidant capacity was found as 32.49 µmol TE/g dw by DPPH method, 151.59 µmol TE/g dw by CUPRAC method and total anthocyanin content was found as 14.45 mg mlv-3-glc/100 g dw. Özkan (2022) reported the total phenolic content of the black-scented 'Isabella' grape (Vitis labrusca L. × Vitis vinifera L.), which is rich in bioactive compounds, as 1101.61±35.12 mg GAE/100 g dw. The DPPH Free Radical Scavenging Activity was reported as 34.51±1.21 µmol TE/g dw, the antioxidant activity value by the CUPRAC method was 175.82±5.35 µmol TE/g dw, and the total anthocyanin (TAC) content was 341.88±4.42 mg mlv-3-glc/100 g dw. The total phenolic content (TPC) of the Kavacık grape variety used in this study was found to be similar to that of the black-scented grape, while the TAC value was lower. This difference can be attributed to the use of different grape varieties in the studies, as well as the varying climatic and soil conditions in which the grapes were grown, leading to differences in their bioactive properties.

Table 1. Bioactive content of fresh grape.

	Fresh Grape
TPC (mg GAE/100 g dw)	1097.97 ± 168.95
Antioxidant Capacity (DPPH - µmol TE/g dw)	32.49 ± 2.01
Antioxidant Capacity (CUPRAC -µmol TE/g dw)	151.59 ± 25.99
TAC (mg mlv-3-glc/100 g dw)	14.45 ± 0.36

The bioactive contents of the samples dried with a static dryer are shown in Table 2. While the total phenolic values of dipped grapes (DG) ranged between 440.50 and 604.40 mg GAE/100 g dw, the total phenolic values of micro-perforated grapes (MG) ranged between 427.30 and 886.40 mg GAE/100 g dw. Phenolic compounds not only contribute to the color, taste, and aroma of grapes but also provide significant nutritional and health benefits (Çoklar & Akbulut, 2017). As shown in Table 2, different pretreatments applied to samples dried using a static dryer did not lead to a significant difference in the total phenolic content (TPC) ($P > 0.05$). Additionally, it was found that temperature increase did not cause a significant difference in the TPC of DG and MG0.5 samples ($P > 0.05$), but both low (60°C) and high (80°C) temperatures resulted in a significant difference in TPC for M1.0 and MG1.5 samples ($P < 0.05$). The values obtained in this study are consistent with those reported in the literature. For instance, Barbosa da Silva et al. (2023) found that the total phenolic content of BRS Vitoria grapes ranged from 340.98 to 1794.80 mg GAE/100 g dw following convective drying after ethanol and ultrasound pretreatments. In a previous study, the total phenolic content of freeze-dried and oven-dried BRS Magna grape skin was found to be 148.3 and 149.9 mg/100 g dw, respectively. The total phenolic content in this study is similar to those reported in previous studies (da Silva et al., 2020).

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Table 2. Bioactive content of dried grapes (Static dryer).

Dryer Type		TPC (mg GAE/100 g dw)			
		DG	MG0.5	MG1.0	MG1.5
Static	60°C	604.40 ± 15.6^{Aa}	427.30 ± 129.10^{Aa}	492.90 ± 25.10^{Ab}	555.70 ± 100.10^{Ab}
	70°C	644.60 ± 22.10^{Aa}	724.20 ± 111.40^{Aa}	810.70 ± 34.20^{Aa}	886.40 ± 58.90^{Aa}
	80°C	440.50 ± 109.60^{Aa}	568.90 ± 52.90^{Aa}	442.60 ± 32.10^{Ab}	533.90 ± 20.80^{Ab}
		Antioxidant Capacity (DPPH - µmol TE/g dw)			
	60°C	68.58 ± 2.91^{Aab}	77.44 ± 7.84^{Aa}	64.46 ± 0.90^{Ab}	74.20 ± 5.49^{Aa}
	70°C	60.58 ± 2.13^{Bb}	72.62 ± 0.04^{Aa}	73.17 ± 2.69^{Aa}	68.66 ± 1.68^{Aa}
	80°C	74.20 ± 0.03^{Aa}	64.62 ± 1.79^{Ba}	75.15 ± 0.04^{Aa}	62.40 ± 3.58^{Ba}
		Antioxidant Capacity (CUPRAC -µmol TE/g dw)			
	60°C	178.28 ± 8.36^{Aa}	137.22 ± 9.70^{Bb}	152.31 ± 1.19^{ABa}	147.35 ± 4.33^{Ba}
	70°C	162.66 ± 0.60^{ABa}	173.95 ± 2.24^{Aa}	148.72 ± 11.04^{Ba}	156.43 ± 1.94^{ABa}
	80°C	138.91 ± 3.73^{Ab}	140.42 ± 2.16^{Ab}	124.24 ± 5.67^{Bb}	133.53 ± 2.39^{ABb}
		TAC (mg mlv-3-glc/100 g dw)			
	60°C	65.15 ± 0.95^{Aab}	68.35 ± 4.02^{Aab}	64.37 ± 2.05^{Aa}	66.04 ± 1.89^{Aa}
	70°C	61.81 ± 0.32^{Cb}	70.51 ± 0.95^{Aa}	65.49 ± 0.47^{Ba}	68.50 ± 1.26^{ABa}
	80°C	66.83 ± 1.74^{Aa}	61.69 ± 1.74^{Ab}	63.48 ± 3.00^{Aa}	68.95 ± 1.26^{Aa}

*If means ± standard deviation within a row are shown with different capital letters, there is a statistically significant difference ($P < 0.05$).
**If means ± standard deviation within a column are shown with different lower case letters, there is a statistically significant difference ($P < 0.05$).

Antioxidants are compounds that neutralize free radicals, which are produced through various mechanisms in the human body and contribute to oxidative stress and cellular damage (Kunter & Keskin, 2019). Antioxidant capacity can be measured using different methods, and in this study, antioxidant levels were assessed using the DPPH and CUPRAC methods. The CUPRAC method is based on the reduction of Cu^{2+} to Cu^{+}, while the DPPH method based on the color change resulting from the neutralization of the DPPH radical (Munteanu & Apetrei, 2021). In this study, it was observed that the antioxidant capacity of Kavacık grapes dipped and micro-perforated by DPPH method varied between 60.58 and 77.44 µmol TE/g dw (Table 2). When evaluating the antioxidant capacity of Kavacık grapes measured by the DPPH method, it was found that pretreatments applied during drying at low temperature (60°C) did not significantly affect the antioxidant capacity ($P > 0.05$). After drying at 70°C, the antioxidant capacities of DG samples differed from those of MG samples ($P < 0.05$), with MG samples showing similar antioxidant capacity values ($P > 0.05$). At 80°C, antioxidant capacities of DG and MG1.0 samples were similar but differed significantly from those of MG0.5 and MG1.5 samples ($P < 0.05$). Overall, the data obtained from the DPPH method indicate that drying temperature significantly affected the antioxidant capacity of DG samples, but had no significant effect on MG samples. Furthermore, it was observed that the antioxidant capacity of MG samples (except at high temperatures) was generally higher than that of DG samples. Antioxidant capacity values of Kavacık grapes measured by the Cuprac method ranged between 124.24 and 178.28 µmol TE/g dw (Table 2). When considering the antioxidant capacity values measured by the CUPRAC method, high temperature appeared to significantly influence both DG and MG samples, creating a notable difference ($P < 0.05$). The results from the two methods differed, likely due to the distinct measurement principles. The CUPRAC method evaluates the antioxidant capacity based on the reduction of the Cu^{2+}–neocuproine (2,9-dimethyl-1,10-phenanthroline) complex to the Cu^{+} form at pH 7, with maximum absorbance at 450 nm. Meanwhile, the DPPH (2,2-diphenyl-1-picrylhydrazyl) method assesses antioxidant activity through the sample's ability to scavenge the stable DPPH• free radical, leading to a decrease in absorbance at 517 nm (Patricia and Syaputri, 2021). In a previous study, the antioxidant content of black grapes dried using hot air was reported as 13.71 µmol TE/g dry matter by the DPPH method and 70.71 µmol TE/g dry matter by the CUPRAC method (Özkan et al., 2022). However, the total antioxidant capacity of Kavacık grapes was significantly higher when measured using these two methods.

Anthocyanins are pigments responsible for the red, purple, blue, and black colors in grapes (Eroğlu, 2012). In this study, it was found that the anthocyanin content of Kavacık grapes was significantly influenced by pretreatment only during the drying process at 70°C ($P < 0.05$). Specifically, MG samples dried at 70°C exhibited higher anthocyanin levels. The effect of drying temperature was more pronounced in DG samples, where the temperature caused a significant difference in total anthocyanin content (TAC) values ($P < 0.05$). In general, the TAC values of MG samples were not significantly affected by changes in drying temperature. In a previous study, the anthocyanin content of black grapes dried using the hot air method was reported to be 46.81 mg mlv-3-glc/100 g

dry matter (Ozkan et al., 2022). In contrast, the anthocyanin content of Kavacık grapes in this study ranged from 61.81 to 70.51 mg mlv-3-glc/100 g dry matter (Table 2), which was higher than the previous findings. This difference can be attributed to variations in grape variety and the pretreatment methods used.

The bioactive contents of the samples dried with a convective dryer are shown in Table 3. It was found that pretreatments caused a significant difference in terms of total phenolic content (TPC) at all drying temperatures ($P < 0.05$). Total phenolic values of MG samples were found to be higher than DG samples for all drying temperatures. While the TPC values of DG samples ranged between 802.70-992.40 mg GAE/100 g dw, the TPC values of MG samples ranged between 953.15-1364.50 mg GAE/100 g dw (Table 3). The results are similar to previous studies and it is thought that the differences are due to the grape variety. For example, it was previously found that the total phenolic content of BRS Vitoria grapes after ethanol and ultrasound pretreatments and convective drying had values between 340.98 and 1794.80 mg GAE/100 g dw (Barbosa da Silva et al., 2023). In another study, the effect of different drying methods on the total phenolic content (TPC) of seedless purple raisins was investigated. The TPC values for room-dried (PRD), shielding film-dried (PFD), and sun-dried (PSD) samples were reported as 536.8 ± 22.3, 436.8 ± 9.2, and 220.5 ± 2.2 mg GAE/100 g, respectively (Qin et al., 2020). These results indicate that the drying method has a significant influence on the preservation of phenolic compounds. In addition, it was observed that the TPC amounts of Kavacık grapes used in these experiments were higher than those used in the static method (Table 2).

In this study, the antioxidant content of Kavacık grapes was evaluated using the DPPH and CUPRAC methods. The results indicated that the antioxidant capacities measured by the DPPH method were significantly influenced by the drying pretreatments, particularly at 60°C and 80°C ($P < 0.05$). It was observed that antioxidant capacity decreased with increasing drying temperature for all samples, and both DG and MG samples showed a significant temperature effect on their antioxidant capacities. However, when the antioxidant capacities measured by the CUPRAC method were considered, pretreatments did not significantly affect the samples dried at the same temperature ($P > 0.05$). Also, it was found that the antioxidant capacities of MG samples were significantly influenced by the drying temperature, while no significant effect was observed in DG samples. The antioxidant values obtained using the DPPH and CUPRAC methods ranged from 57.02 to 161.90 µmol TE/g dry matter and 156.96 to 234.60 µmol TE/g dry matter, respectively (Table 3). The antioxidant values of Kavacık grapes were found to be higher than those reported in studies on black grapes in the literature. For example, the antioxidant content of black grapes dried using the hot air method was 13.71 µmol TE/g dry matter by the DPPH method and 70.71 µmol TE/g dry matter by the CUPRAC method (Ozkan et al., 2022). Similarly, a study by Çoklar and Akbulut (2017) reported the antioxidant capacity of freeze-dried Ekşikara black grapes (Vitis vinifera L.) as 60 µmol TE/g dry matter by the DPPH method. These findings highlight that the antioxidant values of Kavacık grapes are generally higher than those of black grape varieties.

Table 3. Bioactive content of dried grapes (Convective dryer).

Dryer Type		TPC (mg GAE/100 g dw)			
		DG	MG0.5	MG1.0	MG1.5
Convective	60°C	802.70 ± 34.20^{Cb}	1020.00 ± 58.90^{ABb}	953.15 ± 7.80^{Bb}	1128.10 ± 16.90^{Aab}
	70°C	850.20 ± 73.70^{Bab}	1069.30 ± 53.30^{ABb}	1118.60 ± 28.60^{Aa}	1022.70 ± 53.30^{ABb}
	80°C	992.40 ± 35.50^{Ba}	1364.50 ± 20.80^{Aa}	1161.70 ± 25.10^{ABa}	1295.90 ± 130.00^{Aa}
		Antioxidant Capacity (DPPH - µmol TE/g dw)			
	60°C	132.61 ± 5.26^{Ba}	154.14 ± 1.23^{ABa}	152.40 ± 6.83^{ABa}	161.90 ± 7.05^{Aa}
	70°C	112.19 ± 11.53^{Aab}	128.10 ± 0.35^{Aab}	115.20 ± 0.78^{Aab}	116.15 ± 0.56^{Ab}
	80°C	96.99 ± 6.16^{ABb}	122.60 ± 15.70^{Ab}	77.40 ± 22.40^{ABb}	57.02 ± 8.06^{Bc}
		Antioxidant Capacity (CUPRAC -µmol TE/g dw)			
	60°C	156.96 ± 8.06^{Aa}	199.28 ± 12.69^{Aab}	180.28 ± 1.64^{Ab}	205.72 ± 8.06^{Aab}
	70°C	173.63 ± 1.19^{Aa}	178.80 ± 12.09^{Ab}	187.14 ± 0.90^{Ab}	190.52 ± 1.79^{Ab}
	80°C	182.20 ± 19.90^{Aa}	229.67 ± 1.94^{Aa}	232.31 ± 8.06^{Aa}	234.60 ± 17.00^{Aa}
		TAC (mg mlv-3-glc/100 g dw)			
	60°C	12.49 ± 8.20^{Ab}	9.15 ± 1.58^{Ab}	25.55 ± 3.31^{Ab}	18.18 ± 2.68^{Aa}
	70°C	50.76 ± 3.00^{Aa}	14.06 ± 4.10^{Bb}	13.05 ± 2.37^{Bc}	18.63 ± 7.42^{Ba}
	80°C	14.84 ± 8.68^{Ab}	33.02 ± 1.58^{Aa}	33.13 ± 0.47^{Aa}	26.11 ± 2.84^{Aa}

*If means ± standard deviation within a row are shown with different capital letters, there is a statistically significant difference ($P < 0.05$).
**If means ± standard deviation within a column are shown with different lower case letters, there is a statistically significant difference ($P < 0.05$).

Total anthocyanin values of convective dryer-dried, pretreated Kavacık grapes ranged between 12.49 and 50.76 mg mlv-3-glc/100 g dw, while those of micro-perforated Kavacık grapes ranged between 61.69 and 70.51 mg mlv-3-glc/100 g dw (Table 3). In this study, it was found that pretreatments at both low (60°C) and high (80°C) temperatures did not significantly affect the anthocyanin content of Kavacık grapes ($P > 0.05$). A significant difference was observed between DG and MG samples at 70°C, although no significant difference was noted among MG samples with varying needle lengths. Furthermore, the drying temperature influenced the anthocyanin content in all samples except for the MG1.5 samples. In a previous study conducted with Carmenere grapes, the anthocyanin content of freeze-dried and oven-dried grape skins was found to be 14.33 and 12.38 mg mlv-3-glc/100 g dw, respectively (de Torres et al., 2010). In the current study, the anthocyanin content of Kavacık grapes was found to be similar to that of the previous study. The observed differences are likely attributed to variations in pretreatment methods and grape variety.

Conclusion

This study showed that needle micro-perforation is an effective pretreatment method for drying grapes and offers equivalent or superior performance to the traditional immersion method in preserving bioactive compounds. Needle micro-perforation significantly increased the retention of total phenolics, antioxidant capacity and anthocyanins in Kavacık grapes during both static and convective drying processes. Higher bioactive compound values were observed in needle micro-perforated grapes, especially at increasing drying temperatures. The differences were evident in convective drying, indicating the combined effectiveness of airflow and micro-perforation in preserving nutritional quality. Overall, needle micro-perforation is a non-chemical pretreatment alternative that can be used to improve the quality of dried fruits.

Acknowledgements

This study is supported by the TUBITAK 1002-A program, project number 223O043.

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