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Influence of thermal processing on physicochemical properties and fatty acid composition of grape seed oils

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SUMMARY: In this study, the oils from four different grape seed varieties were heat-treated at 40 and 80 °C for 30 minutes to determine the changes in physicochemical properties and fatty acid composition. Overall, the heat treatments increased the peroxide value and free fatty acids in the oils. The highest total phenolic content values (from 259.67 to 524.77 mg GAE/kg) for all varieties were detected at the control temperature and decreased after both heat treatment applications. Likewise, to total phenolic content and antioxidant activity of the grape seed oils decreased significantly as the temperature applied increased. The dominant fatty acid in all varieties was detected as linoleic acid (from 71.10 to 72.09%), followed by oleic (from 14.55 to 16.64%) and palmitic (from 7.45 to 8.64%) acids. Considering the effect of heat treatment on the major fatty acids, the increase in temperature caused a small decrease in linoleic acid values and a more significant increase in oleic acid values.

KEYWORDS*: Antioxidant activity; Cold press; Grape seed oil; Heat treatment; Oil quality; Total phenol.*

RESUMEN: ***Influencia del procesamiento térmico en las propiedades fisicoquímicas y la composición de ácidos grasos de aceites de semilla de uva***. En este estudio, se trataron térmicamente cuatro variedades diferentes de semillas de uva a 40 y 80 ºC durante 30 minutos para determinar los cambios en las propiedades fisicoquímicas y la composición de ácidos grasos. En general, los tratamientos térmicos aumentaron el índice de peróxido y los ácidos grasos libres de los aceites. Los valores más altos de contenido fenólico total (259,67–524,77 mg GAE/kg) de todas las variedades se detectaron a la temperatura de control y disminuyeron después de las aplicaciones de tratamiento térmico. Asimismo, con respecto al contenido fenólico total, la actividad antioxidante de los aceites de semilla de uva disminuyó significativamente a medida que aumenta la temperatura aplicada. El ácido graso predominante de todas las variedades fue el ácido linoleico (71,10% –72,09%), seguido del ácido oleico (14,55% – 16,64%) y palmítico (7,45% – 8,64%). Considerando el efecto del tratamiento térmico sobre los principales ácidos grasos, el aumento de temperatura provocó una pequeña disminución en los valores de ácido linoleico y un aumento más significativo en los valores de ácido oleico.

PALABRAS CLAVE*: Aceite de semilla de uva; Actividad antioxidante; Calidad del aceite; Fenoles totales; Prensado en frío; Tratamiento térmico.*

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1. INTRODUCTION

The grape (*Vitis Vinifera* L.) is a perennial plant that has received worldwide attention for its nutritional and medicinal benefits. Grape seeds, a byproduct of juice and wine production, represent an often underestimated yet valuable part of the fruit. On a dry weight basis, grape seeds constitute 38-52% of grape pomace. Utilizing grape seeds and their extracts can reduce production costs and prevent profit losses from waste recycling. This approach provides an additional benefit to the food industry and is considered economically promising.

Grape seeds contain approximately 8-20% oil, 25-45% water, 34-46% sugars and polysaccharides, 2-7% organic acids, 4-6% phenolic substances, 4-6.5% nitrogen, and 2-4% minerals. They also consist of inorganic substances and vitamins. The high amounts of phenolic compounds, tannins, fla-

vonoids, and carotenoids in grape seeds contribute to the antioxidant, anti-inflammatory, anticancer, and antimicrobial properties of grape seeds and are due to the high amount of phenolic compounds, tannins, flavonoids and carotenoids (Abouelenein *et al*., 2023; Özcan *et al*., 2018).

Grape seed oil, extracted from the seeds remaining after wine, juice, and traditional food production (such as molasses and vinegar), is highly valued for its nutritional value and bioactive components. Oils extracted from grape seeds, which are a high protein source, contain vitamin E and are rich in unsaturated fatty acids. The oil contains considerable amounts of polyunsaturated fatty acids, primarily linoleic acid, which is essential for human metabolism and promotes cardiovascular health. Both grape seeds and grape seed oil are excellent sources of bioactive phytochemicals, and thus have significant nutraceutical and nutritional potential. Grape seed oil and its processing by-products are of interest for use in various fields due to the nutrients and bioactive molecules they contain. (Lucarini *et al.;* 2024; Khan *et al*., 2020; Pérez-Navarro *et al*., 2019; Lachman *et al*., 2015). They exert many health-promoting properties, including antimicrobial, antioxidant, cancer-preventive, and heart-protective effects. It also supports the treatment of cardiovascular diseases, cancer, and several other conditions due to its high content of essential fatty acids, natural antioxidants, and phytochemicals (Ustun Argon *et al*., 2020). The concentration of these components, which make up the chemistry of grape seed oil, may vary depending on the grape variety, degree of maturity, growing and climatic conditions, soil structure, and extraction process. There are many different technical processes for extracting oils of the same origin, each affecting the physicochemical properties and nutritional values of the oil in various ways (Issaoui and Delgado, 2019). For instance, heating food impacts the properties of bioactive compounds, leading to chemical transformation and degradation, which can alter its physicochemical properties (Özcan *et al*., 2021).

Traditional extraction processes involving heat treatment and chemical solvents can alter the physicochemical properties of oil seeds, such as flavor, fatty acid content, color, and bioactive compounds. Oils subjected to refining processes lose their flavor and aroma substances, resulting in a paler color. Additionally, most carotenoids and phenolic substances in refined oils are destroyed, with vitamin E and phytosterols decreasing by 10-40%, and more than 1% *trans* fatty acids may form during refining. Conversely, cold-pressing is a physical process that extracts oil from clean seeds solely through mechanical compression. This chemical-free method retains higher natural characteristics and healthier substances, such as natural antioxidants. The primary advantages of cold-pressed oils are the number of bioactive substances recovered during pressing. They are better sources of beneficial substances, such as antioxidative phenolic compounds and other health-promoting phytochemicals, compared to refined oils (Issaoui and Delgado, 2019). Although this method has a lower oil extraction yield than conventional solvent extraction, there is no concern about solvent residues in the oil, resulting in a safer and more consumer-desired product (Naebi *et al*., 2022; Lutterodt *et al*., 2011).

Previous studies have shown that grape seed oil is of economic importance to the pharmaceutical, cosmetic, and food industries. Therefore, evaluating these wastes, which contain rich compounds obtained from processing grapes into various products, as an alternative oil source is crucial both economically and health-wise. However, information regarding heat treatment and its effects on the fatty acid compositions and phenolic compounds of grape seed oil is scarce. Hence, the major purpose of the current study was to investigate the oil from four different grape seed varieties and analyze the changes in some physicochemical properties and fatty acid profiles of the oils obtained by cold-pressing grape seeds subjected to different temperature treatments.

2. MATERIALS AND METHODS

2.1. Materials

In the present study, seeds of the Cabernet Sauvignon, Shiraz, Hamburg Muscat, and Alfons Lavallee varieties (*Vitis vinifera* L.) from the 2018 harvest period, obtained from Tekirdağ Viticulture Research Institute, were used. After separating the grape seeds from the marc and removing foreign substances, they were dried in the sun and prepared for the cold pressing process to obtain oil. The grape seeds from the four different grape varieties were divided into three equal amounts.

2.2. Heat treatment

The heat treatment was carried out in a home-type oven (Bosch) with adjustable temperature. No heat treatment was applied to the first batch, which was evaluated as a control sample. The second batch was heat treated in the oven at 40 °C for 30 minutes, and the third batch was heat treated in the oven at 80 °C for 30 minutes. All analyses were carried out in the same way for all three batches.

2.3. Cold press method

Grape seeds weighing 3-4 kg, free from foreign substances, were placed in a cold press machine (Model Ekotok-1, Tokul Agro Products Ind. and Trade Ltd. Co., Izmir, Turkey) and the extracted oil was stored in dark-colored bottles at +4 °C under refrigerator conditions.

2.4. Oil content

Crude oil analysis of the grape seed samples was carried out according to the Soxhlet extraction principle using petroleum ether solvent (AOAC, 1990).

2.5. Determination of viscosity value

A viscosity analysis of the grape seed oil samples was conducted using a stress and temperature-controlled rheometer at 25 °C in the range of 1-100 shear rates. The results were given in mPa.s.

2.6. Determination of color values

The L* (lightness/darkness), a* (redness/greenness), and b* (yellowness/blueness) color values of the grape seed oils were measured using a Minolta Chroma Meter CR 400 (Konica Minolta, Inc., Osaka, Japan). The device was calibrated before measurement, and color values were determined using the CIELab color scale. Readings were taken from three different points to obtain an average value for all samples.

2.7. Determination of free fatty acidity

The IUPAC method numbered 2.201 (IUPAC, 1987) was used to determine the free fatty acidity of the samples. Percent free fatty acidity is stated as the percentage of oleic acid of the total fatty acids that are not bound to the triglyceride structure in the oil.

2.8. Determination of peroxide number

The IUPAC method numbered 2.501 (IUPAC, 1987) was used to determine the peroxide number. The basis of this analysis is that potassium iodide is oxidized by peroxide oxygen in the oil, releasing iodine, and the amount of this free iodine is titrated with thiosulfate.

2.9. Total phenolic content and antioxidant activity (DPPH)

The total phenolic content of the extracted oil samples was measured using the Folin-Ciocalteu assay, as described by Waterhouse (2002). Total antioxidant scavenging activity was determined by the DPPH free radical scavenging capacity method, following the procedure reported by Garzón and Wrolstad (2009).

To prepare grape seed oil samples for analysis, the oil was mixed with methanol (1:1) in a vortex, and the methanolic part was separated. The remaining oil was mixed again with methanol (1:1) and the methanolic portion was separated again. The separated methanolic extract was used in the analysis.

For total phenolic content analysis, all results were expressed in terms of gallic acid equivalent (mg/kg). For antioxidant activity, different amounts of extracts (100, 200, 300 µL) were added to 1.95 mL of DPPH solution. After mixing by vortex, the mixture was left in the dark at room temperature for 30 minutes. Absorbance was read at 517 nm. Results were calculated in 'µmol trolox/g oil'. Samples were analyzed in triplicate.

2.10. Fatty acid composition

The fatty acid composition of the grape oil samples was determined by gas chromatography. The samples were converted into methyl ester derivatives with BF3-methanol according to the method Ce 2-66 of Araujo *et al.* (2008). The extracted oil samples were converted to their fatty acid methyl esters (FAME). The samples were injected into the gas chromatograph (Perkin-Elmer 8320B), equipped with a split injector (split ratio 1:40) (nitrogen was used as the carrier gas) and a flame ionization detector (FID). A silica capillary column (CP Sil 88, 50 m x 250 µm i.d., 0.20 µm film; Chrompack, Middelburg, Netherlands) coated with 100% cyanopro-

pyl polysiloxane was used. The detector temperature was set at 250 °C. Helium was used as the carrier gas at a rate of 1 mL/min. Peak identification was performed by comparing the retention time of each fatty acid with a commercial standard mixture of FAMEs.

2.11. Statistical analyses

All characteristics examined in the experiment, which was set up according to four grape varieties and three temperature applications, were subjected to variance analysis according to the "Random Plot Trial Design". Difference groupings of their means are presented in separate tables. All characteristics in which variety, temperature, and variety x temperature interactions were found to be significant were subjected to the LSD (Least Significant Difference) test at the 0.05 level.

3. RESULTS AND DISCUSSION

3.1. Effect of heat treatment on physicochemical properties of grape seed oils

The crude oil ratios of the grape seeds of the four grape varieties are presented in Table 1. As shown Table 1, the variety with the highest oil content is Hamburg Muscat (9.29%) and it is followed by Alfons Lavallee (8.50%), Shiraz (7.65%) and Cabernet Sauvignon (6.04%). The changes in the oil content of grape seeds depending on the variety were found to be statistically significant ($p < 0.01$). The oil contents of grape seeds (6.04-9.29%) detected in the present study (Table 1) are almost similar to grape seeds (6.93-8.80%) reported by Koç *et al.* (2019) and lower than that reported by Apaydin *et al.* (2017) for Cabernet Franc and Shiraz grape seed samples (11.73-14.77%) and by Juhaimi *et al.* (2017) for Cabernet Sauvignon (10.06 %). The crude oil content of oilseeds and oily fruits depends on the type and variety of seeds (Juhaimi *et al.*, 2017; Apaydın *et al*., 2017; Taşeri *et al*., 2018), seed-growing region (Koç *et al.*, 2018), harvest period (Özcan *et al*., 2017) and post-harvest storage conditions.

Table 1. Crude oil ratios of grape seeds (%)

Samples	Oil content (%)
Cabernet Sauvignon	6.04d
Alfons Lavallee	8.50b
Shiraz	7.65c
Hamburg Muscat	9.29a
	**

All values are expressed as means of three experimental replicates (n=3)
NS not significant
* Significant at $p < 0.05$
** Significant at $p < 0.01$ according to LSD (Least Significant Difference) test.

Some physicochemical properties of heat-treated grape seeds at different temperatures are presented in Table 2. As seen in Table 2, viscosity values of the control group grape varieties were determined to be between 44.78-52.80 mPa.s. In the control group grape varieties, the highest viscosity was determined in the Alfons Lavallee variety (52.80 mPa.s), while the lowest viscosity was detected in the Cabernet Sauvignon variety (44.78 mPa.s). When examining the changes in the viscosity values of grape seed oils according to temperature applications, it was determined that the viscosity value increased at both temperatures (40 and 80 °C) applied to the Shiraz variety. It was determined that the viscosity values of the Cabernet Sauvignon and Alfons Lavallee varieties first increased and then decreased depending on the applied temperature, while the viscosity value of the Hamburg Muscat variety first decreased and then increased depending on the temperature increase. All these changes in the viscosity values of seed oils due to heat treatment were found to be statistically significant ($p < 0.01$). Previous studies show that viscosity does not always experience a constant increase or decrease with the application of heat to the seeds (Şimşek *et al*., 2015) . It can be said that this situation is due to the fatty acid composition changing under the influence of temperature. The increase in oil viscosity according to temperature increase may be the result of the formation of polymers, polymerization, and the formation of high molecular weight compounds, including carbon–carbon and carbon–oxygen–carbon bridges between fatty acids.

The effects of heat treatment on the free fatty acid and peroxide values of the oil samples are presented in Table 2. The free fatty acid value of control group grape seeds ranged between 0.20 and 0.68% in the present study. The lowest free fatty acidity value was determined at the control temperature in the oils of the Hamburg Muscat variety (0.20%). The peroxide value varied between 7.72 and 9.88 meq O_2/kg for the control group grape seed oils in this study and is compliant with Turkish Food Codex, which

Table 2. Some physicochemical and bioactive properties of grape seed oils

Samples	Temperature	Viscosity (mPa.s)	Free fatty acid (oleic acid, %)	Peroxide value (meq O_2/kg)	Total phenolic content (mg GAE/kg)	Antioxidant activity (µmol trolox/g oil)	Color parameters		
							L*	a*	b*
Cabernet Sauvignon	Control	44.77h	0.68b	7.22f	453.57ab	1.82a	46.85d	11.47ef	79.88
	40 °C	51.90cd	0.71ab	11.02de	331.17c	0.81c	33.39h	11.38ef	57.28
	80 °C	51.67cde	0.79a	13.60b	314.80cd	0.71c	33.14h	11.38ef	56.86
Alfons Lavallee	Control	52.80bc	0.28de	9.88e	418.43b	1.39b	43.24f	11.93d	73.62
	40 °C	62.67a	0.33cd	12.05cd	243.27de	0.70c	12.33ı	7.32g	20.99
	80 °C	51.37cde	0.39c	13.21bc	206.90ef	0.67c	33.65h	11.69de	57.63
Shiraz	Control	45.67gh	0.23e	8.19f	524.77a	1.26b	61.72a	11.39ef	72.49
	40 °C	49.97cf	0.39c	13.10bc	254.20cde	0.89c	47.92c	14.51a	81.62
	80 °C	55.17b	0.71b	14.87a	200.33ef	0.73c	37.18g	13.37b	63.57
Hamburg Muscat	Control	48.93ef	0.20e	7.85f	259.67cde	0.69c	53.27b	11.28f	90.36
	40 °C	47.97fg	0.25de	10.25e	188.73ef	0.64c	44.93e	12.70c	76.80
	80 °C	49.07def	0.31d	13.16bc	148.13f	0.61c	47.43cd	13.19b	80.98
			**	**	*	*	**	**	NS

All values are expressed as means of three experimental replicates (n=3)
NS not significant
* Significant at $p < 0.05$
** Significant at $p < 0.01$ according to LSD (Least Significant Difference) test.

permits a maximum of 15 meq O_2/kg for peroxide value and a maximum of 2% in terms of oleic acid for free fatty acidity. Similar results were reported by Koç *et al*. (2019) who found the free fatty acid and peroxide values of grape seed oils obtained by the cold press method to be 0.67-2.74% and 10.45-22.03 meq O_2/kg, respectively. Similarly, Fu *et al*. (2018) determined the free fatty acid value (%) in the Cabernet Sauvignon variety control group grape seeds as 0.55%.

According to Table 2, free fatty acid, as a sign of free fatty acid hydrolysis, and peroxide values, indicative of oxidation in grape seeds, increased significantly ($p < 0.01$) in direct proportion to the increase in temperature. The highest increase in free fatty acid among the varieties was detected in the Shiraz variety after 80 °C heat treatment. The free fatty acid value increased from 0.23 to 0.71% in Shiraz grape seed oil. Likewise, as shown in Table 2, the peroxide number increased from 8.19 to 14.87 meq O_2/kg in Shiraz as a result of 80 °C temperature application. Maximum peroxide numbers in all grape varieties were observed after the 80 °C temperature application, and these values are in agreement with the Turkish Food Codex. It is inferred that the increase in temperature affected lipid oxidation, resulting in the formation of hydroperoxides. Similar to our findings, Herchi *et al*. (2016) investigated the effect of heat treatment (110 °C) on some quality characteristics of flaxseed hull oil and stated that the free fatty acid, initially determined as 0.9%, increased to 1.7% after heat treatment. Şimşek *et al.* (2015) also reported that peroxide and free fatty acid values increased with an increase in roasting temperatures. The increase in free fatty acid value could be attributed to lipid oxidation and hydrolysis, which produce free fatty acids. Additionally, the increase in peroxide numbers indicates that this oil was unstable to oxidative degradation.

Color, one of the physical properties of oils, is an important quality indicator. Color values are expressed as L* (lightness/darkness), a* (red/green), and b* (yellow/blue). The measurements of the L*, a*, and b* color values of the oils from grape varieties after heat treatment are shown in Table 2. The highest L* value in all varieties was observed at the

control temperature. On the other hand, the highest a* values in the oils of Cabernet Sauvignon and Alfons Lavallee varieties were determined at the control temperature, 40 °C in Shiraz, and 80 °C in Hamburg Misket. When examining the changes in the a* values of grape seed oils depending on temperature applications, it was determined that the a* value increased at both temperature levels (40 and 80 °C) applied to the Hamburg Marble variety. When b* values are examined, the highest b* values in the oils of Cabernet Sauvignon, Alfons Lavallee and Hamburg Misket varieties were measured at the control temperature, and the highest b* value in the oils of the Shiraz variety was measured at 40 °C. While changes in the L* and a* values of the seed oils were found to be statistically significant ($p < 0.01$), the changes in the b* value were not statistically significant.

The antioxidant activity and total phenolic content of grape seed oils were determined and are shown in Table 2. The results of the total phenolic contents were expressed as mg equivalents of gallic acid/kg oil, and the results of the antioxidant capacity were shown as μmol trolox/g oil. The phenolic contents of the control grape seed oil samples were found to be 453.57, 418.43, 524.77, and 259.67 mg GAE/kg grape seed for Cabernet Sauvignon, Alfons Lavallee, Shiraz, and Hamburg Muscat, respectively. The antioxidant activity of the control grape seed oil samples was found to be 1.82, 1.39, 1.26, and 0.64 μmol trolox/g grape seed oil for Cabernet Sauvignon, Alfons Lavallee, Shiraz, and Hamburg Muscat, respectively. These values are in accordance with reports in the literature. (Seçen, 2017; Göktürk Baydar *et al*., 2007). The antioxidant activity results obtained from our study are slightly higher than the results obtained by Koç *et al*. (2019) but are compatible with that study. The minor differences between the polyphenol contents of grape seed oils are due to the variety as well as climatic conditions, maturity, and growing region of the grapes. Literature reviews have revealed that the antioxidant activity in raw materials is highly related to the presence of phenolic compounds. When examining the changes in the total phenolic content of grape seed oils depending on temperature applications, it was determined that the highest total phenolic content values for all varieties were detected at the control temperature and decreased after both heat treatment applications. Similar to total phenolic content, the antioxidant activity of the grape seed oils decreased as the temperature applied increased. All these changes were found to be statistically significant ($p < 0.01$). When examining literature studies, it was determined that in some studies (Konuk and Korel, 2015; Perez *et al*., 2015) the total phenolic content decreased with the effect of temperature, while in others (Kim *et al*., 2006) it increased. This difference may be due to the variety, the degree of heat treatment applied, and the presence of phenolic substances in different bound forms in the product.

3.2. Effect of heat treatment on fatty acid composition of grape seed oil

The fatty acid composition of the oils from the grape varieties used in this study is presented in Table 3. According to Table 3, the dominant fatty acid in all varieties is linoleic acid, followed by oleic, palmitic, and stearic acids, respectively. While the linoleic acid content of the control group grape seed oils ranges from 71.10 to 72.09%, the oleic acid and palmitic acid contents vary between 14.55 and 16.64% and 7.45 and 8.64%, respectively. It was determined that these fatty acid values in the control samples of all grape varieties did not differ significantly. All four varieties (Cabernet Sauvignon, Alfons Lavallee, Shiraz, and Hamburg Muscat) of grape seed oil were rich in linoleic, oleic, palmitic, and stearic acids. These fatty acids are well known for their health benefits and determine the health-promoting and nutritional features of oils. Other fatty acids were found at low levels. Our findings were similar to previous results reported by other authors, who also identified linoleic acid as the dominant fatty acid in grape seed oils. Ustun Argon *et al*. (2020) investigated the specific characteristics of cold-pressed grape seed oil in terms of chemical properties, production practices, nutritional profile, alternative usages, health effects, and adulteration. They stated that linoleic, palmitic, stearic, and oleic acids are the main fatty acids in cold-pressed grape seed oil (Ustun Argon *et al*., 2020). Similarly, Khan et al. (2020) reported that the major fatty acids in the Manjari Medika variety grape seed oil included linoleic acid (60–70%), oleic acid (8–13%), palmitic acid (4.5–8%) and stearic acid (4–6%). Apaydin *et al*., (2017) obtained values for linoleic acid content at 72.19 and 61.35% for seed

Table 3. Fatty acid compositions of grape seed oils (%)

Fatty acids	Cabernet Sauvignon			Alfons Lavallee			Shiraz			Hamburg Muscat		
	Control	40 °C	80 °C	Control	40 °C	80 °C	Control	40 °C	80 °C	Control	40 °C	80 °C
C16:0	7.88f	8.07e	7.70g	7.45i	7.26j	7.47i	8.64c	8.86b	9.88a	8.38d	7.56h	6.75k
C18:0	4.38b	4.50a	4.53a	3.66de	3.62e	3.66de	3.83c	3.49f	3.70d	3.33g	3.50f	3.70d
C18:1	14.55h	15.41i	15.18fg	16.64d	16.90c	16.64d	15.21f	20.33b	24.65a	15.50e	15.11g	15.45e
C18:2	72.09c	70.96i	71.46e	71.10h	71.27g	71.37f	71.30g	66.13j	59.79k	71.88d	72.96a	72.70b
C18:3	0.33b	0.34b	0.29bcd	0.27cd	0.31bc	0.27cd	0.26cd	0.33b	0.55a	0.24d	0.24d	0.29bcd
SFA	12.62e	12.95b	12.60e	11.65g	11.20j	11.43h	12.86c	12.70d	14.00a	11.98f	11.32i	11.11k
MUFA	14.96i	15.75f	15.65fg	16.89d	17.22c	16.95d	15.59gh	20.84b	25.66a	15.90e	15.48h	15,90e
PUFA	72.42c	71.30h	71.75e	71.37h	71.58fg	71.64f	71.55g	66.46i	60.34j	72.12d	73.20a	72.99b
UFA	87.38f	87.05g	87.39f	88.36d	88.80ab	88.57c	87.17g	87.48f	86.00h	88.02e	88.68bc	88.90a

Means in the same row with different letters show statistically significant differences ($p < 0.05$) according to LSD (Least Significant Difference) test. (n=3)
SFA: Saturated fatty acids, MUFA: Monounsaturated fatty acids, PUFA: Polyunsaturated fatty acids, UFA: Unsaturated fatty acids

oils of Cabernet Franc and Shiraz varieties, respectively. Similarly, Dabetic *et al*. (2021) indicated that the major fatty acid found in six different grape varieties was linoleic acid, reporting that linoleic acid ranged from 61.42 to 67.59%.

The saturated and unsaturated fatty acid values of the oils from the grape varieties used in the study are shown in Table 3. While the saturated fatty acid (SFA) contents of the control group grape seed oils range from 11.65 to 12.86%, the content of polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) vary between 71.37–72.42% and 14.96–16.89%, respectively. This is in accordance with literature reports which generally classify the fatty acids in the grape seed oil of the control groups as PUFA > MUFA > SFA (Dabetic *et al*., 2021; Khan *et al*., 2020; Apaydin *et al*., 2017; Juhaimi *et al*., 2017). Linoleic acid, which is associated with a high rate of unsaturated fatty acids, was the key fatty acid in grape seed oils of all grape varieties. Moreover, the high amount of unsaturated fatty acids indicates that grape seed oil has a high nutritional value, making it indispensable for human health. The fatty acid composition of grape seed oil is affected by grape variety, climatic conditions, ripening time, and the fruit-growing region (Odabaşioglu *et al.* 2023; Dabetic *et al*., 2021).

As well as genetic factors and grape variety, the processes applied also affect the fatty acid composition of grape seed oil (Dabetic *et al*., 2021). After heat treatment, the fatty acid profiles of the oils changed slightly, and this change was observed more clearly in the Shiraz variety compared to other varieties. Regarding the degree to which varieties are affected by heat treatment, the highest change in fatty acids was detected in Shiraz oils, and the lowest change was detected in oils belonging to the Alfons Lavallee variety. Considering the effect of heat treatment on the major fatty acids, the increase in temperature caused a slight decrease in linoleic acid values and a more significant increase in oleic acid values. Therefore, while the PUFA value of oils decreased, the MUFA value increased, leading to an increase in UFA, which is the total unsaturation value. Grape variety and applied temperatures were effective in all these statistically significant changes in quality parameters. Similar to our findings, Herchi *et al*. (2016) stated that the value of polyunsaturated fatty acids of flaxseed hull oil decreased as a result of heat treatment.

4. CONCLUSIONS

The results of this research demonstrate that grape seed oil, regardless of variety, is a rich food source in terms of linoleic acid, highlighting its high unsaturation feature and essential fatty acids for human health. Although the quality properties of the grape seed oils in our study, which were higher at the control temperature, decreased with temperature application, these decreases were not very significant.

In conclusion, heat treatment application brings about some physicochemical changes in the oils from grape varieties. However, it has been determined that the values of the properties are within the legal limits specified in the Turkish Food Codex in all raw and heat-treated samples. The main reason for this is that the bioactive components in the food penetrate into the oil without deterioration, since the oils are obtained by the cold-pressing method and are processed at partially low temperatures. Although the research results suggest that the applied heat treatment is reasonable, it seems advantageous to work at low temperatures to preserve rich phenolic substances and antioxidant capacity, low free fatty acidity, and peroxide numbers. From this perspective, it can be said that 40 ˚C is a more suitable operating temperature among the heat treatment degrees applied in the present study in terms of preserving oil yield and functional properties. Although higher heat treatment degrees may provide higher oil yield, it is not recommended because they may not preserve the functional properties of the oils. In addition, they are not economical, and they inhibit the detection of imitation and adulteration situations.

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DECLARATION OF COMPETING INTEREST

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U. Gecgel: corresponding author, validation, methodology, visualization, supervision, editing.

D. Kırca: methodology, visualization, writing of original draft, writing review and editing.

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