Applied Fruit Science (2025)67:12
https://doi.org/10.1007/s10341-024-01229-y

ORIGINAL ARTICLE

Volatile Composition of Seven New Hybrid Table Grape Cultivars (*Vitis vinifera* L.)

Sevil Canturk[1] · Semih Tangolar[1] · Serpil Tangolar[1] · Melike Ada[1]

Received: 14 March 2024 / Accepted: 4 November 2024
© The Author(s), under exclusive licence to The author(s), exclusively licensed to Springer-Verlag GmbH Germany, a part of Springer Nature 2024

Abstract
Grapes (*Vitis vinifera* L.) are among the most widely cultivated and economically important fruits thanks to their ability to adapt to challenging climate and soil conditions and their various consuming options, such as table, wine, and raisin. Volatile aromatic compounds are considered one of the essential factors for grape and wine quality. However, the studies on table grape aromas are relatively scarce. In this study, the unique volatile composition and concentration of seven new hybrid table grape cultivars were investigated for the first time using solid-phase microextraction technique with GC-MS. A completely randomized design was used in the study. A total of 51 volatile compounds were detected, which consisted of 6 C_6 compounds, 15 aldehydes and ketones, 6 terpenoids, 6 alcohols, 2 acids, 2 furans, 3 esters and 8 aromatic hydrocarbons. 3 miscellaneous compounds (3-decen-1-yne, 2,6,6-trimethyl-bicyclo[3.1.1] hept-3-ylamine and methoxy phenyl oxime) were also identified. The relative distribution of C_6 compounds was 73.2–89.0%, aromatic hydrocarbons 4.1–9.9%, aldehydes and ketones 3.0–8.6%, terpenes 0–11.3%, alcohols 0.2–7.3%, esters 0.3–6.9%, furans 0–3.7%, acids 0–0.8% and other compounds were 0.4–0.8%. 'Efem' and 'Ece' were prominent in terms of total terpene concentration. The highest volatile concentration was determined in 'Ece' (340.10 µg kg^{-1}). 'Ece' was followed by 'Mesir' (302.24 µg kg^{-1}), 'Efem' (252.86 µg kg^{-1}), 'Lidya' (242.13 µg kg^{-1}), 'Beyra' (212.97 µg kg^{-1}), 'Spil Karası' (197.83 µg kg^{-1}) and 'Manisa Pembesi' (185.45 µg kg^{-1}). In the study, 'Efem' and 'Ece' stand out with their characteristic aromas. The present study has provided the first findings on the volatile composition of these seven new hybrid table grape cultivars and made a new contribution to the limited number of sources about the aroma composition of table grapes.

Keywords Table grape · Volatile compounds · Aroma · Terpenes · *Vitis vinifera* L.

Introduction

Grapes (*Vitis vinifera* L.) are among the most cultivated and consumed fruits worldwide thanks to their ability to adapt to various climatic conditions and usage multipurpose. According to FAO (2024) statistics, 74.9 mio. t of fresh grapes were produced worldwide in approximately 6.7 mio. ha of vineyard area. Türkiye is ranked fifth in the world vineyard area with 410 kha and sixth in grape production with 4.2 million tons. According to the annual statistics by OIV, global table grape production has increased since 2000. Turkey ranks third in the world after China and India, with 2.2 million tons of table grape production (OIV 2023). Especially the Çukurova region, located in southern Turkey, stands out for early table grape production due to its very suitable climatic conditions.

Aroma is an important characteristic consisting of the interactions between taste and odor, and it plays a fundamental role in fruit quality, for fruits such as grapes, sugars and organic acids activate taste receptors, while many volatile compounds activate the olfactory receptors. The volatiles comprise many secondary compounds such as esters, terpenes, alcohols, aldehydes, etc. In addition to their positive effects on human health, they influence consumer preferences (Wu et al. 2018). Many factors, such as grape cultivar, climatic conditions, ripeness degree, cul-

✉ Sevil Canturk
canturksevil@gmail.com

Semih Tangolar
tangolar@cu.edu.tr

Serpil Tangolar
stangolar@cu.edu.tr

Melike Ada
melikeada46@gmail.com

[1] Department of Horticulture, Faculty of Agriculture, Cukurova University, Adana, Turkey

Published online: 20 December 2024

tivation methods, the winemaking process, and vegetation year, influence the aromatic concentration and composition of grapes (Duan et al. 2014; Delgado et al. 2022). The sensory effect of aroma compounds depends on their concentration, olfactory perception threshold, and interaction with other aroma compounds. Their concentration in grapes and wines ranges from several mgL^{-1} to a few ngL^{-1} or less (Ribéreau-Gayon et al. 2006; Ruiz-García et al. 2014). Compounds that contribute to the formation of aroma are found free and bound in grapes. Free forms are volatile and highly aromatic, while the bound glycoside form is non-volatile and transformed into odor-active forms (free fractions) through various enzymatic reactions during the ripening and processing of grapes into wine (Cabaroğlu 2003; Kunter et al. 2013; Wu et al. 2016; Feng et al. 2022).

Aromatic composition is one of the determining factors for grape and wine quality, so it is an area that has been well studied. Especially on wine grapes and wines, the effects of many factors such as cultivar (Genovese et al. 2013), ripening stages (Kalua and Boss 2009), ecology (Marais et al. 1999), training systems (Reynolds et al. 1996), cultivation methods such as cluster thinning and leaf removal (Diago et al. 2010) have been investigated on aroma. However, studies about the aroma profile and cultivar effect in table grapes are scarce. A limited number of studies have been conducted to determine the aromatic composition of some hybrid table grape cultivars, especially those that have Muscat-flavored parents (Sun et al. 2020; Xi et al. 2020; Jin et al. 2022; Kaya et al. 2022). In particular, studies on the aromatic composition of table grape varieties are much less in Türkiye (Canturk et al. 2018a, b; Baytin and Keskin 2018; Kaya et al. 2022). Considering that table grapes constitute more than 50% of Türkiye's grape production and consumption pattern, it is clearly noticed that there is a lack of knowledge about the subject of aroma. The seven new hybrids studied have characteristics that meet the demands of producers and consumers. They have attractive skin color and seeded large-sized berries (reaching up to 13 g) (Tangolar et al. 2023). They are suitable cultivars for Mediterranean countries since they are early ripening. Moreover, the fact that the male parents of 'Efem' and 'Mesir' are 'Muscat of Hamburg' suggests they could also meet sensory expectations for table grapes. However, no study has yet been done on the volatile profile of the seven new hybrids. Therefore, the aim of this study was to determine the unique volatile composition of seven new hybrid table grape cultivars obtained from crossbreeding studies conducted in Türkiye. This study presented the first findings regarding the volatile profile of these seven cultivars and made a new contribution to the limited number of sources about the aroma of table grapes.

Materials and Methods

Plant Material

The study was performed during the 2020 growing season. In the study, seven seeded table grape cultivars (*Vitis vinifera* L.) obtained in 2017 with the hybridization studies conducted by Manisa Viticultural Research Institute were used. The parents of all cultivars are belonging to the *Vitis vinifera* L. species. The vines of the grape cultivars used have been grown in the Experimental Vineyard of the Department of Horticulture at Çukurova University in Adana, Türkiye, at an elevation of 70 m on 37°01′49″N and 35°22′50″E. The soil of the experimental area was clayey-loamy, alkaline, and salt-free at depths of 0–20 cm and 20–40 cm. It was determined that the amount of organic matter was low, the lime ratio was high (44.1% and 45.1%), and the amount of phosphorus, potassium, and magnesium was sufficient. The trial plot was created by grafting all cultivars on 1103 P rootstock planted with 2 × 3.5 m row spacing in 2018 and was established with the trained bilateral Guyot system. Fruiting canes were pruned from 5–7 buds, and renewal spurs were pruned from 2 buds in January. The vines were managed according to the standard viticulture (topping, removal of water sprouts, suckers, and fruit zone leaves) and disease control (powdery, downy mildew, and dead arm) practices applied in the Mediterranean region of Türkiye. The vines were irrigated with drip irrigation 2 times in June, and approximately 70–80 L $vine^{-1}$ irrigation water was applied each time. Some of the characteristics of the cultivars are given in Table 1 and Fig. 1. The research region has characteristics of the Mediterranean climate, which is quite warm and arid, with limited precipitation. Some climatic conditions of the research region are given in Table 2. Meteorological data were obtained from the climatic station of the Turkish State Meteorological Service located in the research area.

The experiment was designed with two replications of three vines per experimental unit. The clusters of the cultivars used in the study were hand-picked at commercial maturation (Winkler et al. 1974). In each replication, 50 berries from different positions of three vines were collected. The °brix level of the cultivars was as follows: Beyra 15, Ece 14.2, Efem 16.8, Lidya 15.9, Manisa Pembesi 16.9, Mesir 15.7, and Spil Karası 15.1. After harvest, the samples were immediately frozen and stored at –30 °C until analysis.

Extraction of Volatile Compounds

The solid-phase microextraction technique was used for the extraction of volatile compounds. Berry samples were thawed at room temperature and homogenized in a blender. 3 g of homogenate was transferred to a vial and incubated

Table 1 Grape cultivars used in the study and some of their characteristics

Code	Cultivar	Parents	Skin color
B	Beyra	Mahrabaşı × Cardinal	Dark red-violet
E	Ece	Mahrabaşı × Cardinal	Blue-black
EF	Efem	Mahrabaşı × Muscat of Hamburg	Black
L	Lidya	Tahannebi × Cardinal	Pink-red
MP	Manisa Pembesi	Mahrabaşı × Cardinal	Pink-red
M	Mesir	Mahrabaşı × Muscat of Hamburg	Blue-black
SK	Spil Karası	Mahrabaşı × Trakya Ilkeren	Black
TI	Trakya Ilkeren	Alphonse Lavallée × Perlette	Blue-black
YI	Yalova Incisi	Hönüsü × Siyah Gemre	Green-yellow

at 40 °C for 15 min. Volatile compounds were absorbed from the headspace with a 50/30 µm DVB/Carboxen-PDMS SPME fiber for 45 min under stirring. Then, it was desorbed for 5 min and injected into the DB-WAX capillary column (60 m length × 0.25 mm inner diameter × 0.25 µm thickness; J&W Scientific, Folsom, CA, USA). Before sampling, the fiber was preconditioned in GC injection port at 200 °C for 20 min.

GC-MS Analysis

GC-MS analysis of volatile compounds was performed with Shimadzu GC-MS (Agilent, Triple Quad 7000 Series) Chromatograph equipped with a capillary column (DB-WAX) (60 m × 0.25 mm × i.d., 0.25 µm film thickness). Helium was used as carrier gas at a flow rate of 1 mL min^{-1}. The oven was programmed starting from 40 °C, kept constant for 4 min, and linearly increasing up to 90 °C at the rate of 3 °C/min. After which, it was increased at 4 °C/min up to 130 °C. This was held for another 4 min, followed by an increase to 240 °C at 5 °C/min for 8 min (Amanpour et al. 2019). Identification of the compounds from the peaks was made by NIST library (Fig. 2). The concentrations of volatile compounds were calculated according to the internal standard (4-nonanol) and expressed in µg as a mean value. One black ('Trakya Ilkeren') and one white ('Yalova Incisi') cultivar, widely grown and consumed in Çukurova region, were used as the Control cultivars.

Statistical Analysis

One-way analysis of variance (ANOVA) was performed on data in a completely randomized design using the JMP (v8.00, SAS Institute Inc., USA) software. Differences among the cultivars in terms of volatile composition and concentration were determined by the LSD (Least Significant Difference) test at 5% level. Principal component (PCA) and Correlation analysis were done to establish relationships between the cultivars and some important volatile compounds.

Results and Discussion

A total of 51 volatile compounds were detected in nine grape cultivars (Table 3). It was determined that they consisted of 6 C_6 compounds, 15 aldehydes and ketones, 6 terpenoids, 6 alcohols, 2 acids, 2 furans, 3 esters, and 8 aromatic hydrocarbons. In addition, 3 miscellaneous compounds were identified.

Among the volatiles found in the berries of all the cultivars in this study, C_6 alcohols and aldehydes were the most abundant compounds. C_6 aldehydes, in particular, have been determinant in the aroma of the cultivars due to their low odor threshold. Hexenal, 2-hexenal, 3-hexenal, 1-hexanol, 2-hexenol, and 3-hexen-1-ol have been identified from this group, and their total levels in the cultivars ranged from 140.00 ('Manisa Pembesi') to 272.38 µg kg^{-1} ('Ece'). C_6 aldehydes were reported as the primary contributors to the herbaceous aroma in table grapes (Wu et al. 2016; Wang et al. 2023). Hexanal (58.30–136.20 µg kg^{-1}) and 2-hexanal (52.35–115.40 µg kg^{-1}) were the dominant compounds in all the cultivars. Robinson et al. (2014) reported that C_6 alcohols have a green vegetable odor. Among these, 1-hexanol (11.32–26.66 µg kg^{-1}) was found in the highest amount of all the cultivars and was followed by 2-hexenol (1.93–9.07 µg kg^{-1}). Overall, 'Ece' and 'Mesir' were the cultivars with the highest C_6 compounds. C_6 compounds, including aldehydes and alcohols, are derived from plasma membrane lipids. Linoleic and α-linolenic acids (C18:2 and C18:3) are produced by the acyl hydrolase activity, then they interact with the lipoxygenase and lead to form C_6 aldehydes. Finally, the aldehydes are reduced to alcohols, i.e., 1-hexanol, (Z)-3-hexenol, and (E)-2-hexenol by alcohol dehydrogenase (ADH). Total levels of C_6 compounds depend on the cultivar, grape maturity, temperature regime, and duration of contact with the skin. Mechanical processing like harvesting, transport, crushing, and pressing also increases the levels of these compounds (Oliveira et al. 2006; Moreno and Peinado 2012). In this study, C_6 compounds represent 73.2–89.0% of total volatiles in the studied cultivars (Fig. 3). It could be concluded that berry crushing and homogenization steps during the extraction

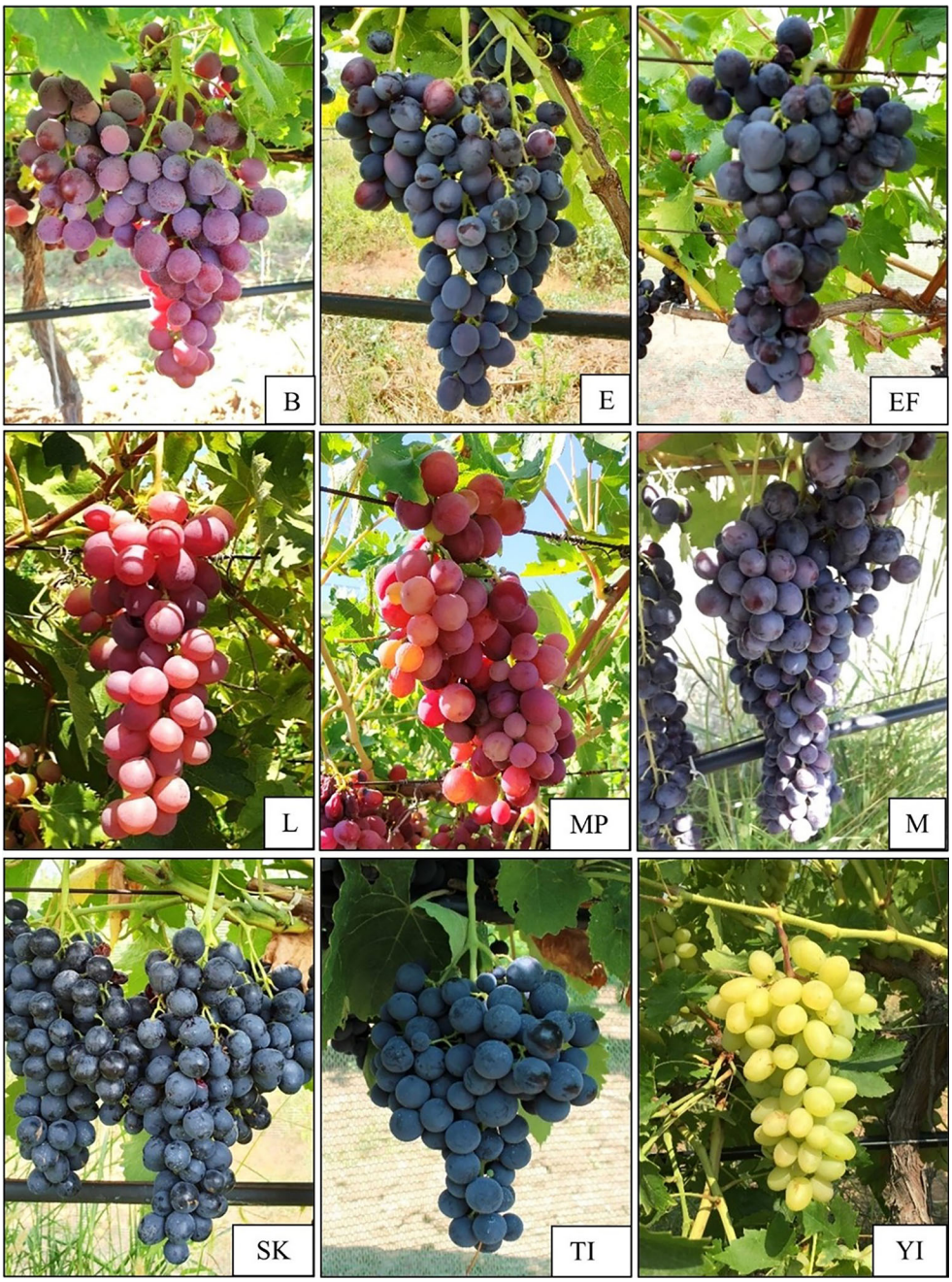


Fig. 1 Table grape cultivars in the study. *B* Beyra, *E* Ece, *EF* Efem, *L* Lidya, *MP* Manisa Pembesi, *M* Mesir, *SK* Spil Karası, *TI* Trakya Ilkeren, *YI* Yalova Incisi

induced the enzymatic reaction and led to the release of C_6 aldehydes. Some authors also showed that more than half of the aromatic composition of table grapes consisted of C_6 compounds, in agreement with our study (Song et al. 2012; Wu et al. 2016; 2018). Aubert and Chalot (2018) reported that in 'Alphonse Lavallée', 'Chasselas', and 'Centennial Seedless', these compounds accounted for more than 98% of total volatiles. Canturk et al. (2018a, b) also determined that C_6 compounds accounted for a considerable amount of total volatile composition in cv. 'Beauty Seedless' (40%), 'Tekirdag Seedless' (72%), and 'Gülüzümü' (68%). Furthermore, it is known that temperature regime and water availability also affect the volatile concentration. It has been reported that stressful conditions triggered by rainfall shortage and/or lower water availability after veraíson increased lipoxygenase and, therefore, levels of aldehydes C_6 (Deluc et al. 2009; Soldateli et al. 2023). In the present study, considering that the experimental region has similar climatic conditions and a very low rainfall level in the 2020 season, high C_6 aldehyde levels may also be attributed to climatic conditions (Table 2). Therefore, optimizing irrigation levels may be a beneficial method to balance the concentration of volatile compounds in such arid conditions. On the other hand, carefully harvesting and

Table 2 Some climatic data of the experimental vineyard

Months	Daily maximum temperature (°C)		Daily mean temperature (°C)		Daily minimum temperature (°C)		Daily mean sunshine (h)		Total rainfall (mm)	
	2020	1929–2020	2020	1929–2020	2020	1929–2020	2020	1929–2020	2020	1929–2020
January	14.5	14.8	9.7	9.5	5.8	5.3	5.7	2.6	136.0	112.5
February	15.1	16.2	10.1	10.6	6.0	6.0	6.1	3.8	108.1	88.7
March	20.6	19.4	15.0	13.5	9.9	8.3	7.0	5.0	51.40	65.8
April	24.2	23.8	17.5	17.6	12.0	11.9	7.8	6.4	58.7	51.9
May	30.1	28.3	22.9	21.9	16.7	15.8	9.50	8.2	59.6	48.1
June	31.2	31.7	24.4	25.6	18.9	19.8	9.5	9.8	51.8	22.1
July	35.6	33.9	29.2	28.3	24.5	23.0	10.5	11.1	0.4	10.2
August	36.7	34.7	29.8	28.7	24.4	23.5	9.7	10.6	0.7	9.3
September	36.5	33.1	29.6	26.2	24.1	20.2	9.0	9.1	3.3	19.1
October	32.9	29.1	25.6	21.8	19.8	15.8	8.0	6.7	1.4	43.0
November	23.7	22.7	17.8	16.0	13.0	10.8	6.2	4.6	54.5	71.7
December	19.4	16.9	14.1	11.3	9.6	7.0	5.5	2.6	27.4	125.8

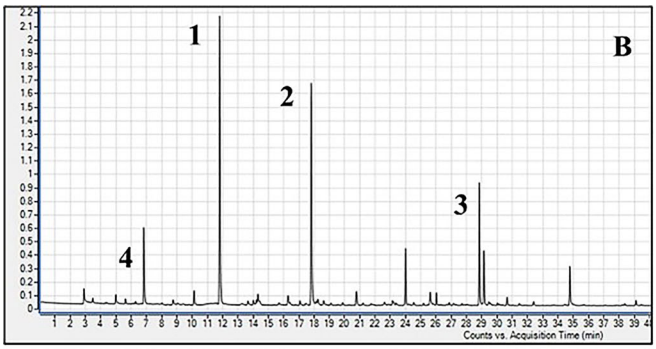
Fig. 2 Chromatograms of volatile compounds of the table grape cultivars. The peak numbers of some important volatiles are as follows: *B*: (*1*) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) 1,2,3-trimethyl-benzene, E: (*1*) hexanal, (*2*) 2-hexanal, (*3*) geranyl vinyl ether, (*4*) 1-hexanol, *EF*: (*1*) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) linalyl formate, *L*: (*1*) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) 2-hexen-1-ol, *MP*: (*1*) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) 2-ethyl hexanol, *M*: (1) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) 2-pentyl-furan, *SK*: (*1*) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) 2-hexen-1-ol, *TI*: (*1*) hexanal, (*2*) 2-hexanal, (*3*) 1-hexanol, (*4*) isopropyl myristate, *YI*: (*1*) 2-hexanal, (*2*) hexanal, (*3*) 1-hexanol, (*4*) geranyl vinyl ether. *B* Beyra, *E* Ece, *EF* Efem, *L* Lidya, *MP* Manisa Pembesi, *M* Mesir, *SK* Spil Karası, *TI* Trakya Ilkeren, *YI* Yalova Incisi

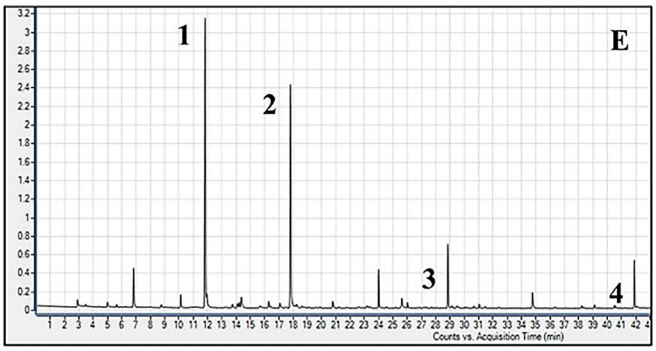
transporting table grapes can also control the level of C_6 compounds to some extent until the grapes are supplied to the consumers.

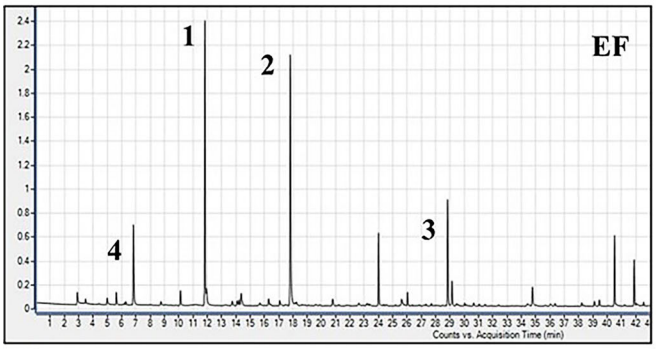
In this study, C_6 compounds were followed by aromatic hydrocarbons proportionally (9.91–26.53 µg kg^{-1}). Xylene and benzene derivatives were identified as aromatic hydrocarbons. Toluene, *p*-xylene, and 1,2,3-trimethyl-benzene of this group were detected in high amounts in all the cultivars.

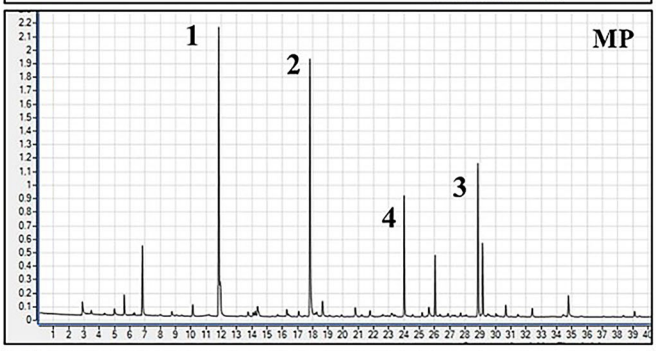
In the group of aldehydes and ketones, other than C_6 aldehydes, 15 compounds were identified, constituting 3–8.6% of the volatiles of each cultivar (Fig. 3). The concentrations of 7 of them were above their sensory threshold. Therefore, the results indicated that they make an important contribution to the overall aroma together with C_6 compounds. The compound detected in the highest amount in this group was nonanal. Its strong, fatty, and citrus-like aroma significantly contributed to the aromas of all the cultivars. The amount of nonanal was ranged from 1.32 µg kg^{-1} ('Spil Karası') to 6.22 µg kg^{-1} ('Ece'). 2-nonenal which has strong, pleasant, fatty, and violet aromas, also contributed significantly to the aroma of 'Mesir' (10.73 µg kg^{-1}) and 'Manisa Pembesi' (2.46 µg kg^{-1}). 2,6-nonadienal with fresh cucumber odor held an important place in the aroma of 'Mesir' (6.90 µg kg^{-1}). Among the aldehydes, decanal, with its fatty, floral, and citrus-like odor, was detected in all the cultivars except 'Trakya Ilkeren' and 'Ece'. The highest amount of aldehydes was identified in 'Mesir', 'Manisa Pembesi', and 'Beyra'. Because their perception threshold is low (Table 3), (*E*)-2-nonenal, octanal, nonanal, decanal, and (*E, Z*)-2,6-nonadienal are reported to be strong odorants (Ferreira et al. 2004).

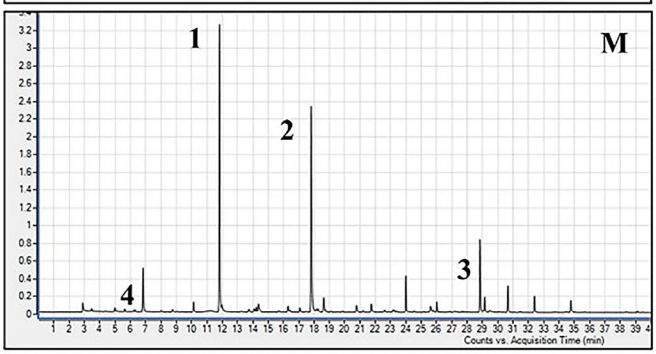
A total of 6 terpene compounds were identified in the cultivars, and their concentrations were generally relatively low. They were detected in 'Efem', 'Ece', 'Beyra', and 'Yalova Incisi' (Control cultivar) (Table 3). Until now, about 40 terpenes have been identified in grapes, and they can be found in the form of hydrocarbons, alcohols, aldehydes, ketones, or esters. Although they are present in most grape varieties and wines, terpenes are responsible for forming the characteristic flavor of grapes and constitute the primary aroma of wines made from Muscat varieties. Linalool,

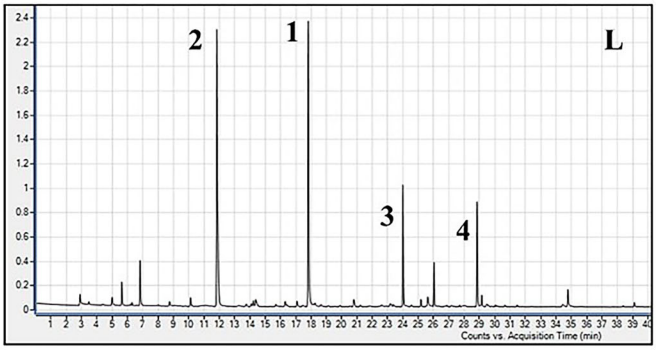

B
1
2
3
4
Counts vs. Acquisition Time (min)

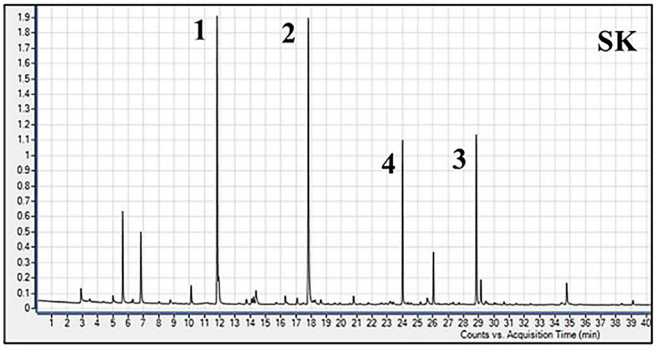

E
1
2
3
4
Counts vs. Acquisition Time (min)

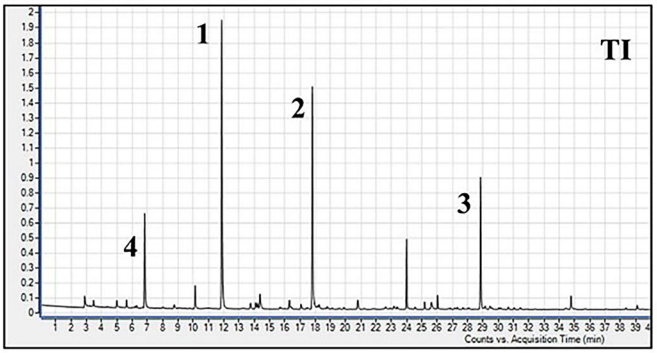

EF
1
2
3
4
Counts vs. Acquisition Time (min)


MP
1
2
3
4
Counts vs. Acquisition Time (min)


M
1
2
3
4
Counts vs. Acquisition Time (min)


L
2
1
3
4
Counts vs. Acquisition Time (min)


SK
1
2
4
3
Counts vs. Acquisition Time (min)


TI
1
2
3
4
Counts vs. Acquisition Time (min)

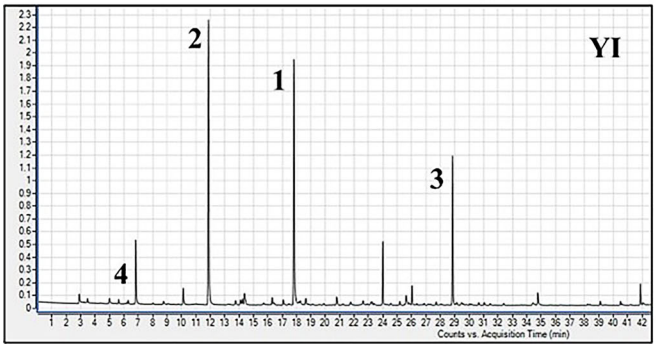

YI
2
1
3
4
Counts vs. Acquisition Time (min)

Table 3 Concentrations of volatile compounds determined in the table grape cultivars [a] (μg kg^{-1})

Compound	RT	OT[b]	Beyra	Ece	Efem	Lidya	Manisa Pembesi	Mesir	Spil Karası	Trakya Ilk-eren	Yalova Incisi
C_6 compounds			*171.51D*	*272.38A*	*185.36D*	*215.55 C*	*140.00E*	*235.17B*	*172.11D*	*145.81E*	*177.19D*
Hexanal	11.819	4.5	79.7 bc	136 a	84.2 bc	91.3 b	58.3 d	122 a	72.0 bcd	69.2 cd	75.8 bcd
(E)-2-hexenal	17.808	17	76.3 cd	115 a	79.9 bcd	85.7 bc	52.4 f	93.3 b	69.5 de	58.8 ef	83.5 bc
3-Hexenal	14.228	0.25	1.56 cd	2.95 a	1.48 cd	1.85 bc	0.89 d	2.35 ab	1.40 cd	1.11 d	1.82 bc
1-Hexanol	23.992	150	11.3 f	15.9 cde	17.1 cd	26.7 a	18.8 bc	14.1 def	22.0 b	12.9 ef	12.2 ef
(E)-2-Hexen-1-ol	26.022	100	2.23 cd	1.93 d	2.57 cd	8.56 a	9.07 a	3.82 c	6.78 b	2.29 cd	3.13 cd
(Z)-3-Hexen-1-ol	25.168	13	0.45 b	–	–	1.49 a	0.60 b	–	0.49 b	1.42 a	0.75 b
Aldehydes and ketones			*11.95B*	*10.49BC*	*7.66D*	*7.31D*	*11.14BC*	*25.86A*	*6.08DE*	*5.61E*	*9.93C*
Acetaldehyde	3.477	17	0.72 b	1.03 a	0.93 ab	0.44 c	0.47 c	0.74 b	0.46 c	1.09 a	0.78 b
3-Methyl-butanal	6.286	0.2	0.48 bc	–	0.72 a	0.54 abc	0.38 c	0.73 a	0.67 ab	0.42 c	0.72 a
3-Ethyl 4-Heptanone	17.488	–	–	–	–	–	–	–	–	0.35	–
Octanal	21.208	0.7	0.55 bc	0.73 a	0.57 abc	0.57 abc	0.45 c	0.73 ab	–	–	0.49 c
Heptanal	22.614	3	0.48 c	0.82 b	0.88 b	0.56 c	–	0.77 b	1.33 a	–	0.59 c
(E)-2-Decenal	22.615	0.4	–	–	–	–	–	–	–	–	0.98
6-Methyl-5-hepten-2-one	23.161	50	0.51 c	–	–	–	0.36 d	0.78 a	0.48 c	0.55 bc	0.64 b
3,7,7-Trimethyl-1,3,5-cyclo-heptatriene	24.545	–	0.83 a	0.75 ab	0.47 cde	0.46 de	0.41 de	0.62 bc	0.35 e	0.56 cd	0.44 de
Nonanal	25.610	1	4.16 b	6.22 a	2.12 de	3.34 bc	2.50 cd	3.20 bc	1.32 e	2.14 de	3.21 bc
3-Ethyl-2-methyl-1,3-hexadi-ene	26.347	–	–	–	–	–	0.41	–	–	–	–
2-Octenal	26.869	3	0.62 a	–	–	–	0.71 a	–	–	–	0.40 b
2,4-Heptadienal	28.066	10	–	–	–	–	0.54	–	–	–	–
Decanal	30.022	0.1	1.06 a	–	0.73 cd	0.93 b	0.61 d	0.67 cd	0.77 c	–	0.94 ab
(E)-2-Nonenal	30.660	0.08	1.79 c	0.94 de	1.24 cd	0.46 e	2.46 b	10.7 a	0.69 de	0.50 e	0.74 de
(E,Z)-2,6-Nonadienal	32.398	0.02	0.75 c	–	–	–	1.86 b	6.90 a	–	–	–
Terpenes			*2.41D*	*22.90B*	*28.23A*	–	–	–	–	–	*12.15C*
Linalool	31.041	6	–	1.60 a	0.76 b	–	–	–	–	–	0.80 b
β-farnesene	36.048	0.05	–	–	1.28	–	–	–	–	–	–

Table 3 (Continued)

Compound	RT	OT[b]	Beyra	Ece	Efem	Lidya	Manisa Pembesi	Mesir	Spil Karası	Trakya Ilk-eren	Yalova Incisi
Citral	38.224	30	–	1.28 a	0.95 b	–	–	–	–	–	–
Linalyl formate	40.517	–	0.72 b	1.26 b	14.9 a	–	–	–	–	–	1.09 b
Geranyl vinyl ether	41.896	–	1.69 d	18.8 a	10.3 b	–	–	–	–	–	5.33 c
Geranic acid	52.894	40	–	–	–	–	–	–	–	–	4.93
Alcohols			*1.71E*	*0.71F*	*8.19B*	*2.24DE*	*13.45A*	*6.19C*	*2.79D*	*0.47F*	*1.70E*
2-Methyl-3-octanol	27.167	–	–	–	–	–	0.30 b	0.69 a	–	–	–
1-Octen-3-ol	27.701	1	0.48 a	–	0.56 a	–	0.53 a	–	–	–	0.59 a
2-Nonen-1-ol	22.617	130	–	–	–	–	–	–	–	–	0.74
2-Ethyl-hexanol	29.138	270	1.22 d	0.71 de	5.52 b	2.24 c	12.6 a	5.50 b	2.80 c	0.47 de	0.37 e
Phenylethyl alcohol	42.556	1100	–	–	0.71	–	–	–	–	–	–
3,7-Dimethyl-2-octen-1-ol	39.452	–	–	–	1.41	–	–	–	–	–	–
Esters			*4.50BC*	*3.79BC*	*2.84CD*	*4.89B*	*2.67CD*	*1.04D*	*1.17D*	*13.16A*	*5.13B*
Ethyl Acetate	5.626	5000	1.28 c	–	2.84 b	4.89 a	2.67 b	1.04 c	1.17 c	1.35 c	0.78 b
Ethyl ester hexanoic acid	18.777	–	–	–	–	–	–	–	–	0.56	–
Isopropyl myristate	46.970	–	3.21 b	3.79 b	–	–	–	–	–	11.26 a	4.28 b
Furans			*1.09CD*	*0.81CD*	*0.69D*	*0.61DE*	*5.10B*	*11.12A*	*1.00CD*	–	*1.41C*
2-Pentyl-furan	19.588	6	1.09 cd	0.81 def	0.69 ef	0.61 f	3.92 b	6.90 a	1.00 de	–	1.41 c
Trans-2-(2-pentenyl) furan	21.740	–	–	–	–	–	1.17 b	4.22 a	–	–	–
Acids			–	*1.02B*	*0.78C*	*0.59CD*	*0.38D*	*0.67C*	*0.74C*	*1.53A*	*1.21B*
Propyl-propanedioic acid	42.043	–	–	1.02 ab	0.78 bc	0.59 cd	0.38 de	0.67 bcd	0.74 bcd	0.93 abc	1.21 a
Nonanoic acid	49.690	3000	–	–	–	–	–	–	–	0.60	–
Aromatic hydrocarbons			*18.84BC*	*26.53A*	*17.38CD*	*9.91F*	*11.23EF*	*20.79B*	*13.06E*	*18.13CD*	*16.31D*
Toluene	10.121	–	3.77 c	6.40 a	4.17 c	2.22 d	2.19 d	4.52 bc	3.78 c	5.32 ab	4.23 bc
Ethyl benzene	13.740	–	1.15 cd	1.97 a	1.46 bc	0.75 e	1.01 de	1.47 b	1.21 bcd	1.36 bc	1.23 bcd
o-Xylene	14.080	–	1.34 bc	4.04 a	1.35 bc	0.86 c	0.87 c	1.80 b	1.14 bc	1.5 bc	1.29 bc
p-Xylene	14.369	–	4.11 a	4.33 a	4.41 a	1.84 b	2.47 b	4.99 a	2.36 b	4.02 a	4.30 a
m-Xylene	16.294	–	2.46 bc	3.53 a	2.02 bcd	1.35 d	1.33 d	2.78 ab	1.45 d	1.87 cd	1.99 cd

Table 3 (Continued)

Compound	RT	OT[b]	Beyra	Ece	Efem	Lidya	Manisa Pembesi	Mesir	Spil Karası	Trakya Ilkeren	Yalova Incisi
1-Ethyl-4-methyl-benzene	18.240	–	1.08 ab	1.29 a	0.89 bcd	0.63 de	0.69 cde	0.96 bc	0.70 cde	0.81 bcde	0.53 e
(1-Methylethyl)-benzene	19.873	–	0.74 a	0.74 a	0.44 cd	–	0.39 d	0.65 b	–	0.50 c	0.39 d
1,2,3-Trimethyl-benzene	20.772	–	4.19 a	4.23 a	2.65 b	2.26 b	2.28 b	3.62 a	2.42 b	2.78 b	2.35 b
Miscellaneous			*0.96C*	*1.46*	*1.73A*	*1.03C*	*1.46AB*	*1.40B*	*0.88C*	*0.91C*	*1.72A*
3-Decen-1-yne	21.749	–	–	–	–	–	–	–	–	–	0.71
2,6,6-Trimethyl-bicyclo[3.1.1] hept-3-ylamine	25.822	–	–	–	0.51 b	–	0.51 b	0.69 a	–	–	–
Methoxy phenyl oxime	39.111	–	0.96 bc	1.46 a	1.22 ab	1.03 bc	0.95 bc	0.71 c	0.88 bc	0.90 bc	1.01 bc
Total volatiles			*212.97EF*	*340.10A*	*252.86C*	*242.13CD*	*185.45G*	*302.24B*	*197.83FG*	*185.62G*	*226.75DE*

RT Retention time (min), '–' indicates that the volatile was not detected

[a] Different letters within the lines indicate significant differences among means ($p \leq 0.05$).

[b] Odor threshold ($\mu g\ L^{-1}$) (Pino and Mesa 2006; Cincotta et al. 2015; Yue et al. 2023)

geraniol, nerol, α-terpineol, citronellol, and hotrienol are some prominent monoterpene compounds that contributed to the generation of fruity, floral, rose-like, and citrus aromas (Moreno and Peinado 2012; Gonzalez-Barreiro et al. 2015).

In this study, the highest terpene concentration was detected in 'Efem' (28.23 µg kg^{-1}). Geranic acid was identified only in 'Yalova Incisi' (4.93 µg kg^{-1}), while *β*-farnesene was detected only in 'Efem' (1.28 µg kg^{-1}). Linalyl formate was determined in a high concentration in 'Efem' (14.90 µg kg^{-1}). Geranyl vinyl ether was detected in high amounts in 'Ece' (18.77 µg kg^{-1}), 'Efem' (10.30 µg kg^{-1}), and 'Yalova Incisi' (5.33 µg kg^{-1}). Linalool and citral concentrations of the cultivars remained at negligible levels. Terpene concentrations were expected to be higher in 'Efem' and 'Mesir', which have 'Muscat of Hamburg' in their parents. However, their concentrations were below the sensory threshold (Table 3); therefore, their contribution to the aroma was low. It was thought that the very high average temperatures and excessive solar exposure of Çukurova region might have a negative impact on the biosynthesis and accumulation of volatile compounds during the ripening period. Some authors have also reported that high temperatures may negatively affect volatile synthesis. In a study by Belancic et al. (1997), in which 'Moscatel de Alejandria' and 'Moscatel Rosada' were exposed to 20%, 50%, and 100% sunlight, the highest concentration of free terpenols was found in the semi-shaded (50%) treatment. In contrast, extreme exposure (100%) led to the least monoterpene accumulation. In the study, linalool was determined to be the most sensitive to exposure to sunlight. Asproudi et al. (2023) also determined that cooler seasonal conditions during ripening promoted the accumulation of terpenoids in grapes. Therefore, growing table grapes under cover or shading nets could optimize terpenoids in regions with high temperatures and solar radiation, such as Çukurova. On the other hand, the concentration of some compounds can also be naturally attributed to the '*terroir*' effect (Jackson and Lombard 1993). Since our findings were obtained in the Adana-Çukurova region, the volatile composition may differ when these cultivars are grown in a region with different climatic conditions. It has been reported that some differences in terpene profiles and concentration may occur within the same cultivar grown in different regions (Reynolds et al. 1996; Ji and Dami 2008; Xue et al. 2023). Finally, the extraction method and GC-MS conditions might also have affected the volatile profile and concentration.

Of the alcohols, other than C_6 and terpene alcohols, 2-methyl-3-octanol, 1-octen-3-ol, 2-ethyl-1-hexanol, 2-nonen-1-ol, phenylethyl alcohol, and 3,7-dimethyl-2-octen-1-ol have been identified. Their concentrations remained below the odor threshold, and the highest alcohol concentration was determined in 'Manisa Pembesi' with

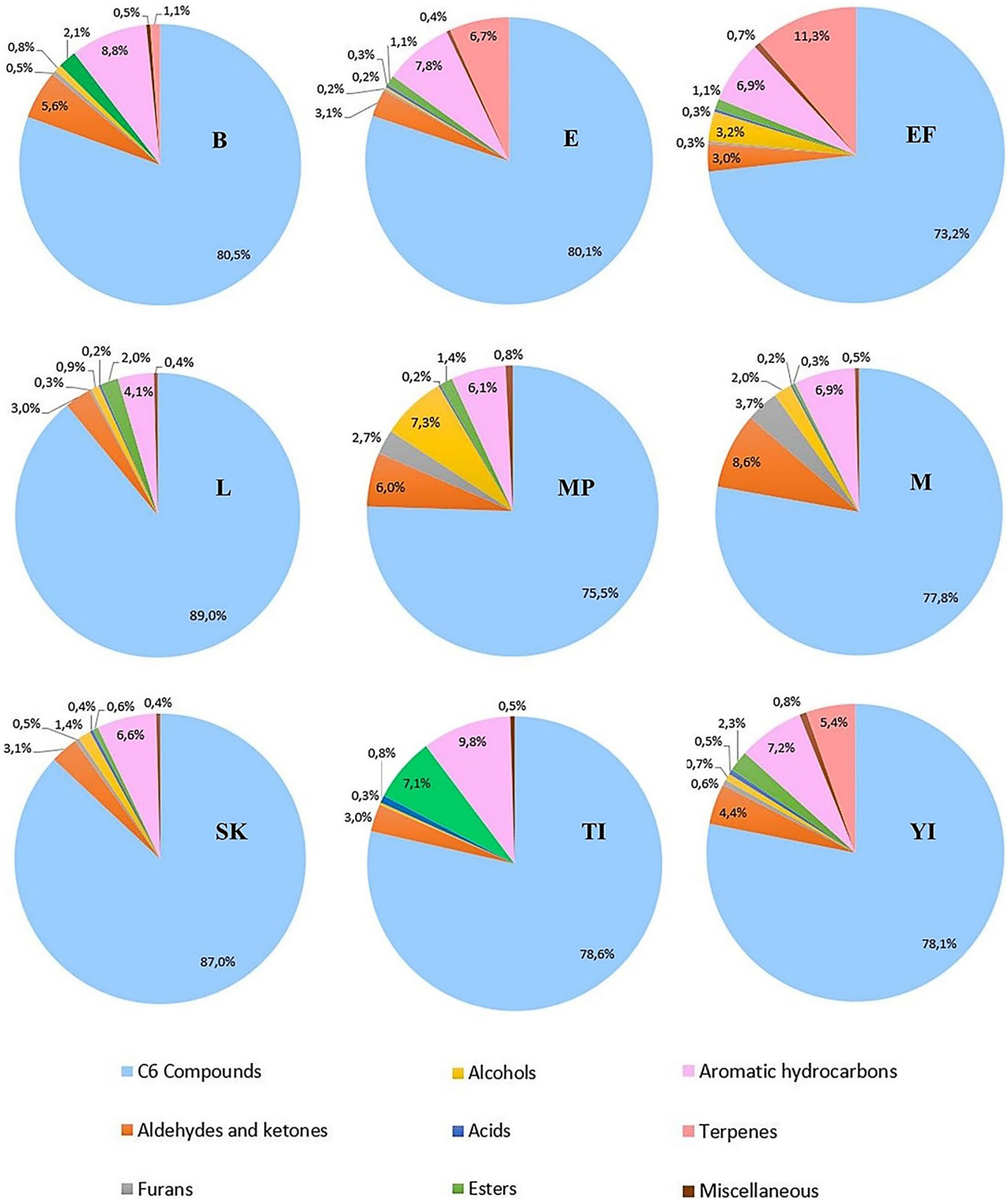


Fig. 3 Percentages of volatile compounds of the cultivars. *B* Beyra, *E* Ece, *EF* Efem, *L* Lidya, *MP* Manisa Pembesi, *M* Mesir, *SK* Spil Karası, *TI* Trakya Ilkeren, *YI* Yalova Incisi

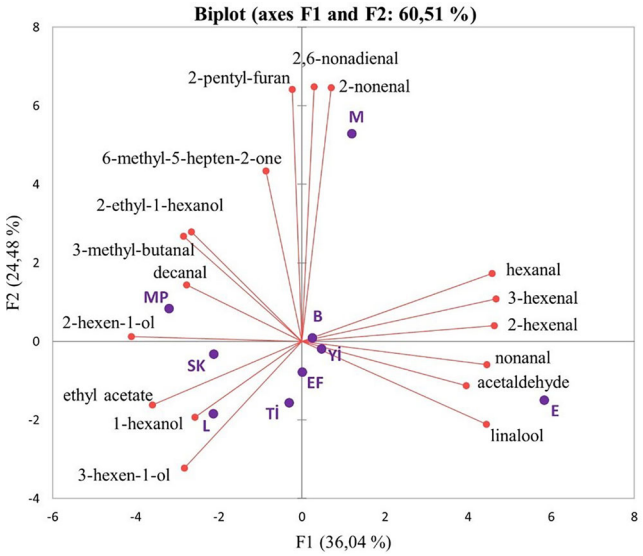


Fig. 4 Principal component analysis (PCA) of some important volatile compounds detected in the table grape cultivars. *B* Beyra, *E* Ece, *EF* Efem, *L* Lidya, *MP* Manisa Pembesi, *M* Mesir, *SK* Spil Karası, *TI* Trakya Ilkeren, *YI* Yalova Incisi

7.25% (Fig. 3). Yao et al. (2021) reported that their contributions to the overall aroma are small due to their high odor thresholds, in accordance with our study. 2-Ethyl-1-hexanol, which has an oily, sweet, and slightly floral odor, was detected in high amount in 'Manisa Pembesi' (12.62 µg kg^{-1}) compared to other cultivars. 2-Nonen-1-ol has been identified only in 'Yalova Incisi' (0.74 µg kg^{-1}). 3,7-dimethyl-2-octen-1-ol (1.41 µg kg^{-1}) and phenylethyl alcohol (0.71 µg kg^{-1}) have been detected only in 'Efem'. Phenylethyl alcohol with a honey, spicy, rose/lilac aroma is considered to play an important role in white wine aroma (Francis and Newton 2005). 2-Methyl-3-octanol has been detected in Mesir (0.69 µg kg^{-1}) and 'Manisa Pembesi' (0.30 µg kg^{-1}).

Esters are important compounds that contribute sweet-fruity aromas of wines (Robinson et al. 2014). Among them, ethyl acetate, ethyl ester-hexanoic acid, and isopropyl myristate were identified. Ethyl acetate, which has a pleasant fruity odor, was determined in all the cultivars except 'Ece'. It has been detected in higher amounts in Lidya (4.89 µg kg^{-1}), Efem (2.84 µg kg^{-1}), and Manisa Pembesi (2.67 µg kg^{-1}); however, it could not reach concentrations above its odor threshold value. Ethyl acetate is also one of the compounds primarily associated with strawberry aroma and found in high concentrations in *V. labrusca* and its hybrids (Yang et al. 2009; Li et al. 2023). Ethyl ester-hexanoic acid was determined only in 'Trakya Ilkeren' (0.56 µg kg^{-1}) (Control cultivar). It has a powerful, fruity odor with pineapple–banana notes. Isopropyl myristate that has a slightly fatty odor was determined in 'Ece' (3.79 µg kg^{-1}), 'Beyra' (3.21 µg kg^{-1}), 'Trakya Ilkeren' (11.26 µg kg^{-1}), and 'Yalova Incisi' (4.28 µg kg^{-1}).

Two furan compounds were identified, namely 2-pentyl-furan and trans-2-(2-pentenyl) furan. While 2-pentyl-furan was found in all the cultivars except 'Trakya Ilkeren', its concentration reached a notable level only in 'Mesir' (6.90 µg kg^{-1}) according to the odor threshold level (Table 3). *Trans*-2-(2-pentenyl) furan was detected only in 'Mesir' (4.22 µg kg^{-1}) and 'Manisa Pembesi' (1.17 µg kg^{-1}). Furan derivatives have also been regarded as important aromatic compounds in some fruits, such as strawberries, blackberries, raspberries, guava, and pineapple (Robinson et al. 2014).

Acids contributed very little to the aroma of the varieties and it can be concluded that they were negligible, considering their odor threshold. Of this group, propyl-propanedioic acid (0–1.21 µg kg^{-1}) was identified. Nonanoic acid with a fatty, cheesy, and waxy flavor was detected only in 'Trakya Ilkeren' (0.60 µg kg^{-1}), which was the control cultivar.

When evaluated in terms of grape cultivars, it could be concluded that C_6 compounds and aromatic hydrocarbons were found in high concentrations and similar amounts in all the cultivars. Although 'Efem' and 'Ece' reached a higher amount than the other varieties in the study in terms of terpene concentration (11.28% and 6.73%, respectively), they still remained at low levels due to the abovementioned reasons. In 'Mesir', significant amounts of aldehydes and ketones (8.56%) and furans (3.68%) were detected. Alcohols (7.25%) and aldehyde and ketone groups (6%) were prominent in 'Manisa Pembesi', and aldehydes and ketones (5.6%) in 'Beyra'. In 'Spil Karası' and 'Lidya', there was no prominent compound group in terms of concentration and proportion, except for C_6 compounds and aromatic hydrocarbons. The volatile characteristics of Control cultivars ('Trakya Ilkeren' and 'Yalova Incisi') were also different from each other. In 'Trakya Ilkeren', unlike all the other varieties, esters (7.1%) were one of the main contributors to the aroma. On the other hand, terpenes (5.36%), aldehydes, and ketones (4.38%) were prominent in 'Yalova Incisi'.

PCA was used to analyze the interrelation between 17 volatile compounds and the cultivars (Fig. 4). For PCA analysis, volatile compounds that are important in grapes and could be distinctive for the cultivars in the study were selected. The two PCs explained 60.5% of the total variance. The PC1 is responsible for 36% of the variation and is associated with acetaldehyde, ethyl acetate, hexanal, 3-hexenal, 2-hexenal, nonanal, 2-hexen-1-ol, and linalool. The second component contained 2-pentyl-furan, 6-methyl-5-hepten-2-one, 2-nonenal, and 2,6-nonadienal. As expected, strong positive correlations were determined between C_6 aldehydes (hexanal, 3-hexenal, 2-hexenal). This confirmed that these compounds shared the same biosynthetic pathway and

Compounds	Acetaldehyde	Ethyl acetate	3-Methyl-butanal	Hexanal	3-Hexenal	2-Hexenal	2-Pentyl-furan	6-Methyl-5-hepten-2-one	1-Hexanol	3-Hexen-1-ol	Nonanal	2-Hexen-1-ol	2-Ethyl-1-hexanol	Decanal	2-Nonenal	Linalool	2,6-Nonadienal
Acetaldehyde	**1**	-0.519	-0.315	0.358	0.304	0.320	-0.257	-0.049	-0.662	-0.207	0.338	**-0.886**	-0.441	-0.659	-0.048	0.564	-0.114
Ethyl acetate	-0.519	**1**	0.257	-0.329	-0.379	-0.301	-0.118	-0.476	**0.716**	0.496	-0.335	0.653	0.339	0.401	-0.185	-0.417	-0.146
3-Methyl-butanal	-0.315	0.257	**1**	-0.354	-0.327	-0.284	0.250	0.428	0.036	0.017	**-0.700**	0.115	0.084	**0.675**	0.295	-0.460	0.269
Hexanal	0.358	-0.329	-0.354	**1**	**0.958**	**0.929**	0.264	-0.216	-0.068	-0.502	**0.729**	-0.381	-0.279	-0.326	0.440	0.559	0.375
3-Hexenal	0.304	-0.379	-0.327	**0.958**	**1**	**0.982**	0.160	-0.190	-0.081	-0.445	**0.784**	-0.383	-0.415	-0.213	0.306	0.646	0.239
2-Hexenal	0.320	-0.301	-0.284	**0.929**	**0.982**	**1**	0.047	-0.311	-0.047	-0.462	**0.772**	-0.413	-0.443	-0.142	0.204	**0.707**	0.126
2-Pentyl-furan	-0.257	-0.118	0.250	0.264	0.160	0.047	**1**	0.511	-0.139	-0.420	-0.027	0.207	0.581	0.135	**0.930**	-0.277	**0.957**
6-Methyl-5-hepten-2-one	-0.049	-0.476	0.428	-0.216	-0.190	-0.311	0.511	**1**	-0.556	0.013	-0.298	-0.142	-0.028	0.164	0.517	-0.475	0.539
1-Hexanol	-0.662	**0.716**	0.036	-0.068	-0.081	-0.047	-0.139	-0.556	**1**	0.311	-0.242	**0.798**	0.242	0.181	-0.236	-0.206	-0.205
3-Hexen-1-ol	-0.207	0.496	0.017	-0.502	-0.445	-0.462	-0.420	0.013	0.311	**1**	-0.284	0.369	-0.244	0.007	-0.451	-0.468	-0.389
Nonanal	0.338	-0.335	**-0.700**	**0.729**	**0.784**	**0.772**	-0.027	-0.298	-0.242	-0.284	**1**	-0.379	-0.328	-0.258	0.027	0.637	0.001
2-Hexen-1-ol	**-0.886**	0.653	0.115	-0.381	-0.383	-0.413	0.207	-0.142	**0.798**	0.369	-0.379	**1**	0.587	0.324	-0.045	-0.503	0.043
2-Ethyl-1-hexanol	-0.441	0.339	0.084	-0.279	-0.415	-0.443	0.581	-0.028	0.242	-0.244	-0.328	0.587	**1**	0.114	0.336	-0.295	0.404
Decanal	-0.659	0.401	**0.675**	-0.326	-0.213	-0.142	0.135	0.164	0.181	0.007	-0.258	0.324	0.114	**1**	0.074	-0.391	0.074
2-Nonenal	-0.048	-0.185	0.295	0.440	0.306	0.204	**0.930**	0.517	-0.236	-0.451	0.027	-0.045	0.336	0.074	**1**	-0.253	**0.992**
Linalool	0.564	-0.417	-0.460	0.559	0.646	**0.707**	-0.277	-0.475	-0.206	-0.468	0.637	-0.503	-0.295	-0.391	-0.253	**1**	-0.317
2,6-Nonadienal	-0.114	-0.146	0.269	0.375	0.239	0.126	**0.957**	0.539	-0.205	-0.389	0.001	0.043	0.404	0.074	**0.992**	-0.317	**1**

Fig. 5 Pearson's correlation matrix of some important volatile compounds detected in the table grape cultivars. Values in *bold* are different from 0 ($p \leq 0.05$)

were influenced by common factors in berry metabolism. Nonanal and acetaldehyde also exhibited a positive correlation with each other and C_6 aldehydes. On the other hand, the compounds 2-pentyl-furan, 2-nonenal, and 2,6-nonadienal showed strong positive correlations that indicated they had related origins. Another strong association was also observed between 3-methyl-butanal and 2-ethyl-1-hexanol.

Regarding cultivar differentiation, Manisa Pembesi' showed a strong positive correlation with 2-ethyl-1-hexanol and 2-pentyl-furan, indicating these compounds are a distinctive aromatic signature for this cultivar. 'Mesir' appeared strongly associated with 2-pentyl-furan, 2-nonenal, and 2,6-nonadienal, suggesting these compounds have been key contributors to its aroma profile. 'Beyra' has been characterized by higher levels of aldehydes. While 'Ece' and 'Efem' had strong associations with linalool, nonanal, and acetaldehyde were also important compounds for 'Ece'. C_6 alcohols and ethyl acetate were prominent in 'Lidya'. 'Spil Karası' had been identified as having more balanced volatile profiles without strong associations to specific compounds except C_6 compounds.

Considering the total volatile concentration, it could be concluded that the most aromatic cultivar in the study was 'Ece' (340.10 µg kg^{-1}). 'Ece' was followed by 'Mesir' (302.24 µg kg^{-1}), 'Efem' (252.86 µg kg^{-1}), 'Lidya' (242.13 µg kg^{-1}), 'Beyra' (212.97 µg kg^{-1}), 'Spil Karası' (197.83 µg kg^{-1}) and 'Manisa Pembesi' (185.45 µg kg^{-1}). According to the findings, we concluded that the volatile composition of all the cultivars except 'Manisa Pembesi' was richer than 'Trakya Ilkeren' (185.62 µg kg^{-1}) (Control cultivar). While 'Ece', 'Mesir', 'Efem', and 'Lidya' showed better aromatic performance than 'Yalova Incisi' (226.75 µg kg^{-1}), the total volatile concentration of 'Beyra', 'Spil Karası', and 'Manisa Pembesi' remained lower than 'Yalova Incisi'.

The correlation analysis identified that hexanal, 3-hexenal, and 2-hexenal exhibit strong positive correlations, suggesting that these compounds consistently increase or decrease together (Fig. 5). They also showed strong positive correlations with nonanal, indicating a close relationship in their behavior. 2-Pentyl-furan demonstrated strong positive correlations with both 2-nonenal and 2,6-nonadienal. Notably, 2-nonenal and 2,6-nonadienal share a higher correlation, implying that these compounds may follow similar biosynthesis and/or degradation processes. On the other hand, 2-hexen-1-ol and acetaldehyde displayed a strong negative correlation, while nonanal and 3-methyl-butanal were also strongly negatively correlated, indicating that these pairs of compounds tend to behave oppositely.

Conclusion

In this study, the first findings on the volatile composition of these seven new hybrid table grape cultivars have been obtained, and their aromatic characteristics were described in general terms. While the results of the study exhibited the unique characteristics of the new hybrids, 'Efem' and 'Ece' stood out regarding volatile composition among the studied cultivars. However, the concentration of volatiles could also be attributed to numerous factors, which are generally expressed as the '*terroir*' concept. It has been concluded that the high average temperatures of the Çukurova region during the ripening period could have negatively impacted the biosynthesis and accumulation of volatile compounds and caused a relatively low volatile concentration. Therefore, more detailed studies are needed in both plain and higher elevations to fully reveal the aromatic profile of the grape cultivars because of the terroir effect. In future studies, we suggest that these grape cultivars, which have been notice-

able in their superior characteristics, should also be investigated regarding the other morphologic and phytochemical properties, such as phenolic compounds, vitamins, skin color, cluster, and berry characteristics.

Acknowledgements The authors are grateful to Manisa Viticultural Research Institute for providing the cuttings of hybrid grape cultivars and to Çukurova University Coordinatorship of Scientific Research Projects for financial support.

Funding This study was supported by Çukurova University Coordinatorship of Scientific Research Projects (Project no: FBA-2021-13277).

Author Contribution Conceptualization: Semih Tangolar; Methodology, formal analysis and investigation: Sevil Cantürk, Serpil Tangolar; Writing—original draft preparation: Sevil Cantürk; Writing—review and editing: Sevil Cantürk, Semih Tangolar; Supervision: Serpil Tangolar; Monitoring of trial vines, Cultural practices, Sampling: Melike Ada.

Conflict of interest S. Canturk, S. Tangolar, S. Tangolar and M. Ada declare that they have no competing interests.

References

Amanpour A, Kelebek H, Selli S (2019) Characterization of aroma, aroma-active compounds and fatty acids profiles of cv. Nizip Yaglik oils as affected by three maturity periods of oils. J Sci Food Agric 99:726–740. https://doi.org/10.1002/jsfa.9241

Asproudi A, Bonello F, Ragkousi V, Gianotti S, Petrozziello M (2023) Aroma precursors of Grignolino grapes (*Vitis vinifera* L.) and their modulation by vintage in a climate change scenario. Front Plant Sci 14:1179111. https://doi.org/10.3389/fpls.2023.1179111

Aubert C, Chalot G (2018) Chemical composition, bioactive compounds, and volatiles of six table grape varieties (*Vitis vinifera* L.). Food Chem 240:524–533. https://doi.org/10.1016/j.foodchem.2017.07.152

Baytin R, Keskin N (2018) Determination of aroma compounds in Erciş grape cultivar. Acta Biol Turcica 31(2):49–55

Belancic A, Agosin E, Ibacache A, Bordeu E, Baumes R, Razungles A, Bayonov C (1997) Influence of sun exposure on the aromatic composition of Chilean Muscat grape cultivars Moscatel de Alejandria and Moscatel Rosada. Am J Enol Vitic 48(2):181–186. https://doi.org/10.5344/ajev.1997.48.2.181

Cabaroğlu T (2003) Aroma components in grapes and their importance in winemaking (in Turkish). Gıda 28(6):599–605

Canturk S, Kunter B, Coksari G (2018a) Effects of kaolin and dicarboxylic acid based stress inhibitors on aroma composition of two table grape cultivars (*V.vinifera* L.). Acta SciPolHortorum Cultus 17(5):37–46

Canturk S, Kunter B, Keskin N (2018b) Aromatic composition of pink skinned grape cultivar: Gülüzümü (*V.vinifera* L.). Yüzüncü Yil Univ J Agric Sci Spec Issue 28:40–44

Cincotta F, Verzera A, Gianluca T, Concetta C (2015) Determination of sesquiterpenes in wines by HS-SPME coupled with GC-MS. Chromatography 2:410–421. https://doi.org/10.3390/chromatography2030410

Delgado JA, Osorio Alises M, Alonso-Villegas R, Sánchez-Palomo E, González-Viñas MA (2022) Effects of the irrigation of Chelva grapevines on the aroma composition of wine. Beverages 8(38):1–12. https://doi.org/10.3390/beverages8030038

Deluc LG, Quilici DR, Decendit A, Grimplet J, Wheatley MD, Schlauch KA, Mérillon J, Cushman JC, Cramier GR (2009) Water deficit alters differentially metabolic pathways affecting important flavor and quality traits in grape berries of Cabernet Sauvignon and Chardonnay. BMC Genomics 10:212. https://doi.org/10.1186/1471-2164-10-212

Diago MP, Vilalonga M, Blanco JA (2010) Effect of mechanical thinning on wine composition and sensory attributes of Grenache and Tempranillo varieties (*Vitis vinifera* L). Aust J Grape Wine Res 16:314–326. https://doi.org/10.1111/j.1755-0238.2010.00094.x

Duan L-L, Pan Q-H, Tang X-J, Yang Q, Jiang R, Shi Y, Duan C-Q (2014) Characteristic aroma compounds in two new Vitis vinifera cultivars (table grapes) and impact of vintage and greenhouse cultivation. S Afr J Enol Vitic 35(2):264–277. https://doi.org/10.21548/35-2-1015

Feng M-X, Jin X-Q, Yao H, Zhu T-Y, Guo S-H, Li S, Lei Y-L, Xing Z-G, Zhao X-H, Xu T-F, Meng J-F (2022) Evolution of volatile profile and aroma potential of 'Gold Finger' table grapes during berry ripening. J Sci Food Agric 102:291–298. https://doi.org/10.1002/jsfa.11357

Ferreira V, Culleré L, López R, Cacho J (2004) Determination of important odor-active aldehydes of wine through gas chromatography–mass spectrometry of their O-(2,3,4,5,6-pentafluorobenzyl)oximes formed directly in the solid phase extraction cartridge used for selective isolation. J Chromatogr A 1028(2):339–345. https://doi.org/10.1016/j.chroma.2003.11.104

Food and Agriculture Organization (2024) https://www.fao.org/faostat/en/#data/QCL

Francis IL, Newton JL (2005) Determining wine aroma from compositional data. Aust J Grape Wine Res 11:114–126. https://doi.org/10.1111/j.1755-0238.2005.tb00283.x

Genovese A, Lamorte SA, Gambuti A, Moio L (2013) Aroma of Aglianico and Uva di Troia grapes by aromatic series. Food Res Int 53(1):15–23. https://doi.org/10.1016/j.foodres.2013.03.051

González-Barreiro C, Rial-Otero R, Cancho-Grande B, Simal-Gándara J (2015) Wine aroma compounds in grapes: A critical review. Crit Rev Food Sci Nutr 55(2):202–218. https://doi.org/10.1080/10408398.2011.650336

Jackson DI, Lombard PB (1993) Environmental and management practices affecting grape composition and wine quality—A review. American Journal of Enology and Viticulture 44, 409–430. https://doi.org/10.5344/ajev.1993.44.4.409

Ji T, Dami IE (2008) Characterization of free flavor compounds in Traminette grape and their relationship to vineyard training system and location. J Food Science 73(4):262–267. https://doi.org/10.1111/j.1750-3841.2008.00736.x

Jin X-Q, Feng M-X, Yao H, Guo S-H, Chen X-Y, Zheng H-T, Dong X-Y, Xu T-F, Meng J-F (2022) Evolution of aroma profiles and potential in Shine Muscat grape berries during ripening. SAJEV 43(2):113–124

Kalua CM, Boss PK (2009) Evolution of volatile compounds during the development of Cabernet Sauvignon grapes (*Vitis vinifera* L.). J Agric Food Chem 57(9):3818–3830. https://doi.org/10.21548/43-2-5103

Kaya Ö, Incesu M, Ateş F, Keskin N, Verdugo-Vásquez N, Gutiérrez-Gamboa G (2022) Study of volatile organic compounds of two table grapes (cv. Italia and Bronx Seedless) along ripening in vines established in the Aegean region (Turkey). Plants 11(15):1935. https://doi.org/10.3390/plants11151935

Kunter B, Cantürk S, Keskin N (2013) Histochemical structure of grape berry. (in Turkish) Iğdır Univ J Inst Sci Tech 3(2):17–24

Li Y, He L, Song Y, Zhang P, Chen D, Guan L, Liu S (2023) Comprehensive study of volatile compounds and transcriptome data providing genes for grape aroma. BMC Plant Biol 23(171):1–18. https://doi.org/10.1186/s12870-023-04191-1

Marais J, Hunter JJ, Haasbroek PD (1999) Effect of canopy microclimate, season and region on Sauvignon Blanc grape composition

and wine quality. S Afr J Enology Vitic 20:19–30. https://doi.org/10.21548/20-1-2223

Moreno J, Peinado R (2012) Must aromas. In: Moreno J, Peinado R (eds) Enological chemistry. Academic Press, pp 23–39

OIV (2023) Annual assessment of the world vine and wine sector in 2022

Oliveira JM, Faria M, Sá F, Barros F, Araújo IM (2006) C_6-alcohols as varietal markers for assessment of wine origin. Anal Chim Acta 563:300–309. https://doi.org/10.1016/j.aca.2005.12.029

Pino JA, Mesa J (2006) Contribution of volatile compounds to mango (*Mangifera indica* L.) aroma. Flavour Fragr J 21:207–213. https://doi.org/10.1002/ffj.1703

Reynolds AG, Wardle DA, Naylor AP (1996) Impact of training system, vine spacing, and basal leaf removal on Riesling. Vine performance, berry composition, canopy microclimate, and vineyard labor requirements. Am J Enol Vitic 47(1):63–76. https://doi.org/10.5344/ajev.1996.47.1.63

Ribéreau-Gayon P, Glories Y, Maujean A, Dubourdieu D (2006) The chemistry of wine—stabilization and treatments. Handbook of enology, vol 2. John Wiley and Sons https://doi.org/10.1002/0470010398

Robinson AL, Boss PK, Solomon PS, Trengove RD, Heymann H, Ebeler SE (2014) Origins of grape and wine aroma. Part 1. Chemical components and viticultural impacts. Am J Enol Vitic 65(1):1–24. https://doi.org/10.5344/ajev.2013.12070

Ruiz-García L, Hellín P, Flores P, Fenoll J (2014) Prediction of Muscat aroma in table grape by analysis of rose oxide. Food Chem 154:151–157. https://doi.org/10.1016/j.foodchem.2014.01.005

Soldateli FJ, Both V, Thewes FR, Wendt LM, Batista CB, Thewes FR, Wagner R, Brackmann A, Fukui CM (2023) Overall quality, phenolic compounds, and volatile profile of a *Vitis vinifera* L. variety and hybrids 'BRS Isis' and 'BRS Nubia' table grapes in two terroirs. Erwerbs-Obstbau 65:2095–2108. https://doi.org/10.1007/s10341-023-00940-6

Song J, Shellie KC, Wanga H, Qian MC (2012) Influence of deficit irrigation and kaolin particle film on grape composition and volatile compounds in Merlot grape (Vitis vinifera L.). Food Chem 134(2):841–850. https://doi.org/10.1016/j.foodchem.2012.02.193

Sun L, Zhu B, Zhang X, Wang H, Yan A, Zhang G, Wang X, Xu H (2020) The accumulation profiles of terpene metabolites in three Muscat table grape cultivars through HS-SPME-GCMS. Nature 7(5):1–6. https://doi.org/10.1038/s41597-019-0321-1

Tangolar S, Tangolar S, Cantürk S, Ada M, Korkmaz E (2023) etermination of bud fruitfulness in some table grape cultivars (*V. vinifera* L.) obtained by crossbreeding. Çukurova J Agric Food Sci 38(2):299–316. https://doi.org/10.36846/CJAFS.2023.120

Wang W-N, Qian Y-H, Liu R-H, Liang T, Ding Y-T, Xu XL, Huang S, Fang YL, Ju YL (2023) Effects of table grape cultivars on fruit quality and aroma components. Foods 12(3371):1–20. https://doi.org/10.3390/foods12183371

Winkler AJ, Cook JA, Kliewer WM, Lider LA (1974) General viticulture. University of California Press, Berkeley, Los Angeles.

Wu Y, Duan S, Zhao L, Gao Z, Luo M, Song S, Xu W, Zhang C, Ma C, Wang A (2016) Aroma characterization based on aromatic series analysis in table grapes. Sci Rep 6(3):1–16. https://doi.org/10.1038/srep31116

Wu Y, Zhang W, Duan S, Song S, Xu W, Zhang C, Bondada B, Ma C, Wang S (2018) In-depth aroma and sensory profiling of unfamiliar table-grape cultivars. Molecules 23(7):1–17. https://doi.org/10.3390/molecules23071703

Xi X, Zha Q, He Y, Tian Y, Jiang A (2020) Influence of cluster thinning and girdling on aroma composition in Jumeigui table grape. Nature 10(6877):1–10. https://doi.org/10.1038/s41598-020-63826-7

Xue H, Sekozawa Y, Sugaya S (2023) Investigating the aromatic compound changes in table grape varieties during growth and development, using HS-SPME-GC/MS. Horticulturae 9(85):1–17. https://doi.org/10.3390/horticulturae9010085

Yang C, Wang Y, Liang Z, Fan P, Wu B, Yang L, Wang Y, Li S (2009) Volatiles of grape berries evaluated at the germplasm level by headspace-SPME with GC-MS. Food Chem 114(3):1106–1114. https://doi.org/10.1016/j.foodchem.2008.10.061

Yao H, Jin X, Feng M, Xu G, Zhang P, Fang Y, Xu T, Meng J (2021) Evolution of volatile profile and aroma potential of table grape Hutai-8 during berry ripening. Food Res Int 143:110330. https://doi.org/10.1016/j.foodres.2021.110330

Yue X, Ju Y, Cui Y, Wei S, Xu H, Zhang Z (2023) Evolution of green leaf volatile profile and aroma potential during the berry development in five *Vitis vinifera* L. cultivars. Food Chem X. https://doi.org/10.1016/j.fochx.2023.100676

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.