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Effect of exogenous essential oil treatments on the storage behaviour of apricot fruit harvested at different altitudes

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ABSTRACT

Due to the short shelf life of fresh apricots, special postharvest preservation techniques and practices are necessary to avoid significant economic losses. The purpose of the current study is to bring to light an approach that can be used to extend the storage life of apricot fruits treated with essential oils (EOs) (peppermint, thyme and carob EO) and examine the effects of two altitudes (1000 m and 1200 m) on the organic acid levels and respiration rate of apricot fruit during long-term storage. The results show that growing apricots at high altitudes increases the level of organic acids in the fruit, improving its quality and extending its postharvest life. Additionally, treating apricots with EOs postharvest slows down the respiration rate, reducing the consumption of organic acids during storage compared to the untreated fruit. The organic acid content was significantly higher in 'Kabaaşı' than in 'Hacıhaliloğlu', and fruit harvested at 1200 m had significantly higher levels of organic acid than the fruit harvested at 1000 m. During storage, the highest organic acid content and the lowest respiration rate were observed in the fruit of both cultivars treated with peppermint, carob, and thyme oil, as compared to control fruit, respectively. To summarize, the use of EOs as postharvest treatment for apricot is recommended for maintaining the quality of the fruit during extended storage.

Keywords: organic acids, postharvest, quality, respiration rate

INTRODUCTION

Apricot (*Prunus armeniaca* L.) is a species of fruit tree belonging to the Rosaceae family. It is a deciduous tree that is native to China, but is now being widely cultivated in many countries including Europe, the Middle East and America (Delialioglu et al., 2022; Ugur, 2022). Türkiye is one of the largest apricot-producing countries in the world. Apricot farming is an important agricultural activity in the country, particularly in the eastern and central regions (Gecer et al., 2020; Karatas, 2022). Apricots are a rich source of vitamins, minerals and dietary fibre. They contain high levels of vitamin A, vitamin C and potassium, as well as smaller amounts of other essential vitamins and minerals (Xi and Lei, 2020; Milosevic et al., 2021). Moreover, apricots contain several organic acids, including malic acid, citric acid, ascorbic acid and tartaric acid (Karatas et al., 2021;

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Al-Soufi et al., 2022). These organic acids play a crucial role in the taste, preservation and nutritional aspects of apricots. Therefore, apricots are an important fruit crop, for their delicious taste, flavour and nutritional value. They are widely consumed fresh and are also used in a variety of processed food products, such as juices, jams and dried fruit. However, apricots are highly perishable and need to be handled carefully to maintain their quality and extend their shelf life. Proper postharvest handling, such as cold storage, controlled storage and modified atmosphere packing can help to preserve the levels of organic acids and other compounds in apricots (Kuchi and Sharavani, 2019; Zheng et al., 2021).

Low summer temperatures limit fruit-growing in some regions due to their high latitude or altitude, but climate change is likely to make these regions more suitable for this practice. On the other hand, hot and dry regions will become less suitable for fruit-growing (Mosedale et al., 2016). Crop models can help predict how climate change will affect the yield and quality of fruits by simulating the effects of temperature, water and CO_2 changes (Poni et al., 2006; Costa et al., 2015). However, these predictions are not simple because there are many factors that interact with each other. For example, higher CO_2 levels can increase the temperature range for photosynthesis and decrease water loss (Ewert et al., 2002; Schultz and Stoll, 2010). Climate change can also alter the soil microbes and affect how crops cope with drought (Rolli et al., 2015). Therefore, these models need to be very advanced and accurate. Besides studying the traits that help fruits adapt to climate change, we can also study how these traits vary in response to different environmental conditions (Bradshaw, 2006). Perennial fruit crops such as grapevines and other fruit species will need plant materials that can adapt to the changing environment according to the climate change projections (Nicotra et al., 2010; Van Leeuwen et al., 2019).

The altitude at which the fruits are grown can have an effect on their biochemical content. There are a few ways that altitude can impact fruit composition. Light intensity and quality: fruits grown at higher altitudes tend to receive less light and UV radiation compared to fruits grown at lower altitudes. This can impact the levels of pigments, such as carotenoids, and affect the taste and colour of the fruit. Temperature: fruits grown at higher altitudes are exposed to lower temperatures compared to fruit grown at lower altitudes. This can impact the metabolism and respiration rate of the fruit, leading to changes in the levels of organic acids and other compounds. The concentration of CO_2 decreases with increasing altitude. This can impact the rate of photosynthesis and affect the levels of carbohydrates and other compounds in the fruit. Soil characteristics, such as nutrient availability, also vary with altitude and can impact the biochemical content of the fruit. Overall, the altitude at which fruit are grown can have a significant impact on their biochemical content. The specific effects of altitude on fruit composition can depend on the specific fruit and environmental conditions (Timilsina and Tripathi, 2019; Gouvinhas et al., 2020).

The postharvest maintenance of organic acids in fruit is important for several reasons:

1. Flavour and taste: Organic acids play a crucial role in determining the flavour and taste of fruit. Maintaining the levels of organic acids in fruit postharvest helps preserve their taste and quality (Zhang et al., 2021).
2. Preservation: Organic acids act as natural preservatives by inhibiting the growth of harmful microorganisms and slowing down the oxidation process. Maintaining the levels of organic acids in fruit postharvest helps extend their shelf life (Ben Braïek and Smaoui, 2021).
3. Nutritional value: Organic acids are important components of fruit, contributing to their nutritional value. Maintaining the levels of organic acids in fruit postharvest helps preserve their nutritional quality (Maldonado-Celis et al., 2019).
4. Market demand: Consumers increasingly demand high-quality, flavourful, and nutritious fruit. Maintaining the levels of organic acids in fruit postharvest helps meet these consumer expectations and increase market demand (Liu et al., 2022).
5. Shelf life: Organic acids help preserve the fruit and prevent spoilage, thus increasing its shelf life (Ben Braïek and Smaoui, 2021).
6. Economic benefits: Maintaining the levels of organic acids in fruit postharvest helps to reduce waste and increase profitability by increasing the shelf life and marketability of the fruit (Jurić et al., 2023).

In recent years, the use of postharvest essential oils (EOs) has become widespread to extend the shelf life of fruits and vegetables and to preserve their quality. The EOs are highly concentrated plant extracts that are rich in volatile compounds with potent antimicrobial, antifungal and antioxidant properties (Cavusoglu et al., 2021a, 2021b; Wang et al., 2023). EOs work by disrupting the cell membranes of microorganisms and inhibiting their growth and reproduction. They also act as antioxidants by eliminating free radicals and preventing oxidative damage to fruit and vegetables (Fan et al., 2023). Some of the most commonly used EOs for postharvest storage include thyme, peppermint, carob, cinnamon, clove and oregano. Thyme extract is rich in antioxidants and antimicrobial compounds and has been shown to have potential as a natural protective (Palmieri et al., 2020). Like thyme extract, peppermint extract is also rich in antioxidants and antimicrobial compounds. It has been shown to have a positive impact on the quality of fruit and vegetables and is often used in postharvest treatments to extend their shelf life (Kumar et al., 2023). Carob extract is derived from the seeds of the carob tree and is rich in polyphenols, which are potent antioxidants. It has been shown to have a positive impact on the quality and shelf life of fruits and vegetables and is often used

in postharvest treatments to control decay and improve their overall quality (Brassesco et al., 2021). These oils have been shown to be effective in controlling decay and extending the shelf life of fruit and vegetables. The use of EOs in postharvest storage has several advantages, including being a natural and environmentally friendly alternative to synthetic preservatives, being cost-effective and having no negative impact on the flavour, aroma or nutritional value of fruits and vegetables (Shehabeldine et al., 2023).

To our knowledge, there have been no published studies about the effect of different samples from two apricot-growing regions and EOs (peppermint, thyme and carob oil) on organic acid levels and extending the storage performance of apricot fruit. Therefore, the purpose of the current study is to bring to light an approach that can be used to extend the storage life of apricot fruits treated with EOs and examine the effects of the two altitudes on the organic acid levels and respiration rate of apricot fruit during long-term storage.

MATERIALS AND METHODS

Plant material

In the study, cv. 'Hacihaliloğlu' and cv. 'Kabaaşı' apricot fruit were used. The fruits were harvested at 1000 and 1200 m (from the sea level) at different altitudes in Malatya, Türkiye. Fruit groups were harvested at the same time, and the time from full bloom to harvest was determined to be approximately 120 days. At harvest time, total soluble solid of cv. 'Kabaaşı' was 16.8, and cv. 'Hacihaliloğlu' was 19.4 in the fruit harvested at 1000 m. On the other hand, total soluble solid of cv. 'Kabaaşı' was 16.7, and cv. 'Hacihaliloğlu' was 18.9 in the fruits harvested at 1200 m. Harvested fruits were precooled at +4°C for 12 hr to reduce the internal temperature of the fruit.

Preparation of EOs and treatments

The EOs were purchased from a commercial company, and then peppermint, thyme, and carob oil 1000 ppm solutions were prepared by dissolving in ultrapure water. The fruit were randomly divided into four groups for different treatments. Samples in the first group were considered as control by only dipping in ultrapure water for 5 min. The second, third, and fourth groups were dipped in peppermint, thyme, and carob solutions, prepared in advance, for 5 min. After treatments all samples were dried through a ventilator at 4°C. Later, the samples were placed in foam plates in three repetitions (each package per 500 g) and covered with stretch film (eight microns), then stored at 0°C and 90%–95% relative humidity (RH) for 35 days. Analyses were performed at 5-day intervals following harvest.

Respiration rate

The respiration rate of the apricot fruits was measured with the method stated by Cavusoglu et al. (2021b), and expressed as CO_2 $kg^{-1} \cdot h^{-1}$. To test the CO_2 emission, apricot fruit was placed in closed jars for 2 hr and the fruit emission was detected using a Headspace Gas Analyzer GS3/L (Systech Instruments Ltd, Johnsburg, IL, USA).

Organic acids

Six different stock solutions (oxalic, citric, tartaric, malic, succinic and fumaric) were prepared by dissolving EOs in 50 mL of pure water in a brown volumetric flask. These stock solutions were then gradually diluted to create five different concentrations (50, 100, 200, 400, and 800 $mg \cdot L^{-1}$).

In the organic acid analysis, the method given by Bevilacqua and Califano (1989) was used with modifications. About 2 g of samples were taken and homogenized with 10 mL of ultra-pure water, then centrifuged at 12000 g for 15 min. The supernatant obtained from the centrifugation was filtered through a 0.45-µm membrane and transferred to vials for reading. High-performance liquid chromatography with a diode array detector (HPLC-DAD) was used to determine specific organic acids (oxalic, citric, tartaric, malic, succinic and fumaric) in apricot fruit. In summary, 20 µL samples were injected and analysed on an Inertsil C18 ODS-3 (mean particle size: 5 µm, 4.6 × 250 mm, GL Sciences Inc., Tokyo, Japan). The chromatographic separation was performed using isocratic analysis at a wavelength of 210 nm and a column temperature of 40°C, with a flow rate of 4 $mL \cdot min^{-1}$ for 35 min. The mobile phase used was 0.009 N H_2SO_4. However, oxalic acid was not found in apricot fruits during analysis. Results were calculated as $\mu g \cdot g^{-1}$ (Figure 1).

Data analysis – statistics

The study was conducted using a completely randomized experimental design with three replications. Data was analysed using descriptive statistics (mean and Standard Error of the Mean [SEM]) and a one-way factorial ANOVA. Treatments with different EOs, cultivars, altitudes and storage periods were considered as factors. Duncans' multiple range test comparisons were also used to identify different levels of treatments, whereas independent-samples *T* Testi comparisons were used to identify different levels of cultivars and altitudes. A principal component analysis (PCA) was applied to evaluate the effect of respiration rate and oxalic, citric, tartaric, malic, succinic, and fumaric data on apricot cultivars and treatments at two altitudes. The significance level was set at 5% and all statistical computations were performed using SPSS (Statistical Package for the Social Sciences, version 20).

RESULTS

Respiration rate

During the storage period, the respiration rate showed a decrease on the 5th and 10th days. However, after a brief

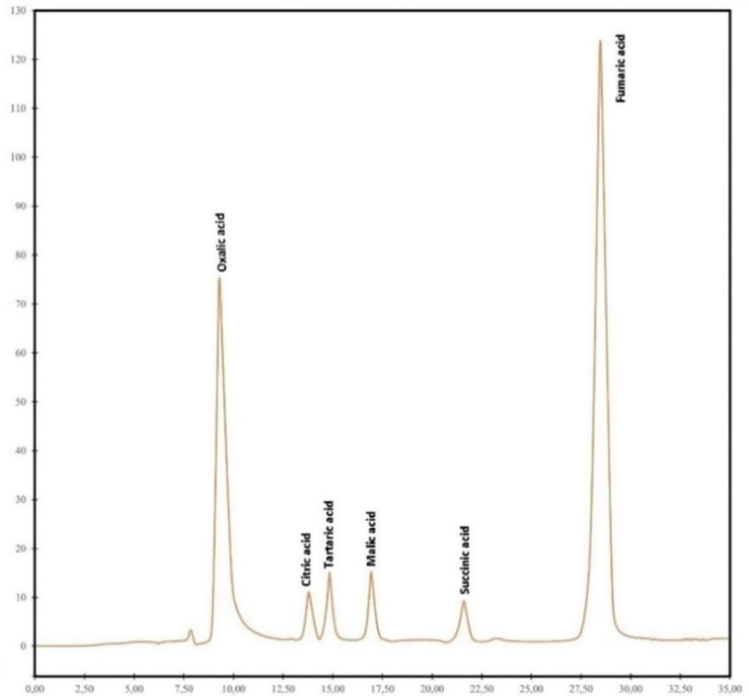

Figure 1. Typical chromatogram of oxalic, citric, tartaric, malic, succinic, and fumaric acid standards obtained from HPLC-DAD. HPLC-DAD, high-performance liquid chromatography with a diode array detector.

increase on the 15th day, the respiration rate decreased again in subsequent analysis days (Table 1).

Respiration rate was found to be lower in the fruit harvested at an altitude of 1200 m than in the cultivar of fruit harvested at 1000 m (Table 1). In addition, the respiration rate was significantly ($p < 0.05$) lower in the cv. 'Kabaaşı' than in the cv. 'Hacıhaliloğlu' at both altitudes during storage. Furthermore, the respiration rate was lower in all EOs-treated fruits than in the control fruit. To summarize, the lowest respiration rates were observed in fruits treated with peppermint, carob, and thyme oil in both cultivars. Significant differences ($p < 0.05$) were observed between EOs-treated and control fruit during storage.

Organic acids

The organic acids in all the fruits decreased over a 35-day storage period, but the fruits treated with EOs had higher levels of organic acids compared to the untreated fruit at every sampling time. The organic acids found in the highest amounts in both harvest and postharvest fruits were citric, succinic/malic (depending on the cultivar and altitude), tartaric and fumaric acids as given in this order. To compare between altitudes, the highest organic acid content was detected in fruits harvested at an altitude of 1200 m. Furthermore, the cv. 'Kabaaşı' had higher organic acid compared to the cv. 'Hacıhaliloğlu' at both altitudes in terms of all organic acid content. During storage, the highest organic acid contents were observed in fruits treated with peppermint, carob, thyme oil, and control fruit in both cultivars, respectively. Significant differences ($p < 0.05$) were observed between EOs-treated and control fruit during storage. Organic acid levels were significantly ($p < 0.05$) higher in the cv. of 'Kabaaşı' than in the cv. of 'Hacıhaliloğlu' at both altitudes.

The citric acid levels in the fruit of 'Kabaaşı', at a higher altitude, were higher compared to the levels in 'Hacıhaliloğlu'. The maximum level was 9454.35 $\mu g \cdot g^{-1}$ on the 0th day at 1200 m in 'Kabaaşı', and the minimum was 4897.61 $\mu g \cdot g^{-1}$ in the control fruit on the 35th day of storage at 1000 m. The citric acid levels in 'Hacıhaliloğlu' ranged from 4790.57 $\mu g \cdot g^{-1}$ to 5424 $\mu g \cdot g^{-1}$ at 1000 m, which were significantly lower (Table 2).

The tartaric acid levels in the fruit of 'Kabaaşı', at a higher altitude, were higher compared to the levels in 'Hacıhaliloğlu'. The maximum level was 276.48 $\mu g \cdot g^{-1}$ on the 0th day at 1200 m in 'Kabaaşı' and the minimum was 116.41 $\mu g \cdot g^{-1}$ in the control fruit on the 35th day of storage at 1000 m (Table 3).

High concentrations of malic acid were observed, with quite higher values in 'Kabaaşı' at 1200 m than 'Hacıhaliloğlu' both altitudes (Table 4).

The succinic acid levels in the fruit of 'Kabaaşı', at a higher altitude, were higher compared to the levels in 'Hacıhaliloğlu'. The maximum level was 5107.85 $\mu g \cdot g^{-1}$ on the 0th day at 1200 m in 'Kabaaşı' and the minimum was 3397.92 $\mu g \cdot g^{-1}$ in the control fruit on the 35th day of storage at 1000 m (Table 5).

Fumaric acid levels were higher in'Kabaaşı' (higher altitude). They were observed to be at a minimum of 13.87 $\mu g \cdot g^{-1}$ in the control fruit on the 35th day at 1000 m and were at a maximum of 24.87 $\mu g \cdot g^{-1}$ on the 0th day at 1200 m. In 'Hacıhaliloğlu', the values were

Table 1. The changes in respiration rate during the storage of apricot harvest at different altitudes during the 35 days at 0°C.

Respiration rate			Storage period					
Altitude	Cultivars	Treatment	0	5	10	15	25	35
1000	Kabaaşı	Control	32.66 ± 1.25 b	30.59 ± 0.63 Ab#	29.04 ± 0.17 Ab#	32.41 ± 0.28 Ab#	30.64 ± 0.10 Ab#	25.95 ± 0.15 Ab#
		Peppermint	32.66 ± 1.25 b	26.20 ± 0.26 Bb#	24.54 ± 0.45 Bb#	26.23 ± 0.56 Bb#	24.72 ± 0.38 Cb#	22.15 ± 0.13 Cb#
		Thyme	32.66 ± 1.25 b	28.09 ± 0.79 Bb#	26.36 ± 0.62 Bb#	28.08 ± 1.86 ABb	26.82 ± 0.41 Bb#	25.09 ± 0.30 A#
		Carob	32.66 ± 1.25 b	27.47 ± 0.36 Bb#	25.29 ± 0.77 Bb#	27.20 ± 1.16 Bb	25.16 ± 0.24 Cb#	24.01 ± 0.40 Bb#
	Hacıhaliloğlu	Control	40.90 ± 1.23 a	38.49 ± 0.24 Aa#	35.59 ± 0.05 Aa#	38.54 ± 0.00 Aa#	36.11 ± 0.41 Aa	33.38 ± 0.28 Aa#
		Peppermint	40.90 ± 1.23 a	32.42 ± 0.49 Ca#	29.77 ± 0.19 Da#	31.52 ± 0.07 Da#	29.57 ± 0.05 Ca#	25.13 ± 0.43 Ca#
		Thyme	40.90 ± 1.23 a	36.03 ± 0.59 Ba#	32.42 ± 0.05 Ba#	33.61 ± 0.05 Ba	31.88 ± 0.55 Ba	28.63 ± 0.95 B#
		Carob	40.90 ± 1.23 a	33.42 ± 0.02 Ca#	31.26 ± 0.23 Ca#	32.52 ± 0.22 Ca	31.34 ± 0.12 Ba#	27.81 ± 0.02 Ba#
1200	Kabaaşı	Control	27.59 ± 0.91 b	25.09 ± 0.62 Ab	24.34 ± 0.21 Ab	26.66 ± 0.12 Ab	26.16 ± 0.32 Ab	23.22 ± 0.24 Ab
		Peppermint	27.59 ± 0.91 b	21.03 ± 0.29 Bb	20.22 ± 0.03 Db	21.78 ± 0.06 Db	20.16 ± 0.07 Cb	19.48 ± 0.18 Cb
		Thyme	27.59 ± 0.91 b	23.01 ± 0.29 Bb	22.45 ± 0.19 Bb	23.63 ± 0.24 Bb	22.62 ± 0.53 Bb	21.01 ± 0.12 Bb
		Carob	27.59 ± 0.91 b	22.37 ± 0.15 BCb	21.64 ± 0.04 Cb	22.82 ± 0.02 Cb	21.96 ± 0.10 Bb	20.77 ± 0.04 Bb
	Hacıhaliloğlu	Control	36.90 ± 0.02 a	34.66 ± 0.15 Aa	33.76 ± 0.04 Aa	37.49 ± 0.24 Aa	34.82 ± 0.10 Aa	29.79 ± 0.57 Aa
		Peppermint	36.90 ± 0.02 a	28.80 ± 0.15 Da	26.65 ± 0.17 Da	28.09 ± 0.05 Ca	25.89 ± 0.76 Ca	23.63 ± 0.14 Ca
		Thyme	36.90 ± 0.02 a	32.08 ± 0.08 Ba	30.95 ± 0.12 Ba	32.78 ± 1.01 Ba	31.73 ± 0.68 Ba	25.60 ± 0.02 Ba
		Carob	36.90 ± 0.02 a	30.83 ± 0.19 Ca	28.70 ± 0.04 Ca	31.36 ± 0.61 Ba	30.12 ± 0.05 Ba	24.62 ± 0.10 BCa

The difference between treatments that have different capital letters in the same column (same altitude, cultivar and storage time) is significant ($p < 0.05$). The difference between cultivars that take different lower-case letters in the same column (same altitude and treatment) is significant ($p < 0.05$).
Data are presented as means ± SEM.
#The difference between altitudes that indicate the same cultivation, treatment and storage time is significant ($p < 0.05$).
SEM, standard error of the mean.

Table 2. The changes in citric acid during the storage of the apricot harvested at different altitudes during the 35 days at 0°C.

Citric acid			Storage period (day)					
Altitude	Cultivars	Treatment	0	5	10	15	25	35
1000	Kabaaşı	Control	5534.99 ± 97.40 #	5232.17 ± 1.95 Da#	5147.73 ± 2.50 Da#	5097.33 ± 2.44 Da#	4986.61 ± 2.38 Da#	4897.61 ± 2.35 Da#
		Peppermint	5534.99 ± 97.40 #	5486.17 ± 2.19 Aa#	5470.03 ± 1.24 Aa#	5466.47 ± 1.18 Aa#	5394.02 ± 1.76 Aa#	5343.41 ± 2.01 Aa#
		Thyme	5534.99 ± 97.40 #	5332.44 ± 1.17 Ca#	5319.39 ± 2.71 Ca#	5309.86 ± 2.58 Ca#	5246.95 ± 1.72 Ca#	5193.73 ± 1.53 Ca#
		Carob					5300.15 ± 2.80 Ba#	5258.79 ± 2.47 Ba#
	Hacıhaliloğlu	Control	5424.28 ± 459.25 #	5076.67 ± 1.45 Db#	5015.30 ± 5.03 Cb#	4987.34 ± 2.11 Db#	4837.10 ± 2.58 Db#	4790.57 ± 0.89 Db#
		Peppermint	5424.28 ± 459.25 #	5293.33 ± 1.01 Bb#	5287.14 ± 2.98 Ab#	5261.52 ± 25.05 Ab#	5228.73 ± 2.84 Ab#	5107.85 ± 3.50 Ab#
		Thyme	5424.28 ± 459.25 #	5276.24 ± 1.99 Cb#	5228.72 ± 1.83 Bb#	5181.81 ± 16.55 Bb#	5105.37 ± 3.93 Cb#	4997.13 ± 1.86 Cb#
		Carob	5424.28 ± 459.25 #	5299.99 ± 1.25 Ab#	5287.49 ± 2.16 Ab#	5262.82 ± 2.53 Ab#	5210.00 ± 2.64 Bb#	5077.54 ± 2.65 Bb#
1200	Kabaaşı	Control	9454.35 ± 192.98 a	8989.67 ± 1.11 Da	8960.53 ± 5.27 Da	8900.65 ± 2.36 Da	8877.47 ± 2.06 Da	8792.39 ± 1.96 Da
		Peppermint	9454.35 ± 192.98 a	9373.71 ± 2.15 Aa	9308.06 ± 2.07 Aa	9296.02 ± 2.24 Aa	9188.85 ± 1.60 Aa	9192.40 ± 2.86 Aa
		Thyme	9454.35 ± 192.98 a	9167.23 ± 11.00 Ca	9120.45 ± 2.11 Ca	9094.90 ± 3.35 Ca	9011.02 ± 2.28 Ca	8990.02 ± 2.27 Ca
		Carob	9454.35 ± 192.98 a	9291.95 ± 1.59 Ba	9251.88 ± 3.53 Ba	9192.55 ± 3.03 Ba	9106.19 ± 3.60 Ba	9097.61 ± 2.05 Ba
	Hacıhaliloğlu	Control	8080.72 ± 156.63 b	7373.62 ± 1.73 Db	7324.72 ± 1.13 Db	7222.07 ± 1.17 Db	7169.47 ± 1.78 Db	7057.82 ± 3.47 Db
		Peppermint	8080.72 ± 156.63 b	7870.51 ± 2.06 Ab	7817.13 ± 1.50 Ab	7791.21 ± 1.32 Ab	7713.78 ± 1.45 Ab	7591.01 ± 2.25 Ab
		Thyme	8080.72 ± 156.63 b	7787.51 ± 2.05 Cb	7711.75 ± 1.48 Cb	7605.27 ± 3.71 Cb	7493.53 ± 2.25 Cb	7364.23 ± 1.67 Cb
		Carob	8080.72 ± 156.63 b	7811.56 ± 1.89 Bb	7790.81 ± 1.45 Bb	7636.52 ± 1.96 Bb	7541.97 ± 1.71 Bb	7410.47 ± 2.80 Bb

The difference between treatments that have different capital letters in the same column (same altitude, cultivar, and storage time) is significant ($p < 0.05$). The difference between cultivars that take different lower-case letters in the same column (same altitude and treatment) is significant ($p < 0.05$).
Data are presented as means ± SEM.
#The difference between altitudes that indicate the same cultivation, treatment and storage time is significant ($p < 0.05$).
SEM, standard error of the mean.

Table 3. The changes in tartaric acid during the storage of apricot harvested at different altitudes during the 35 days at 0°C.

Tartaric acid			Storage period					
Altitude	Cultivars	Treatment	0	5	10	15	25	35
1000	Kabaaşı	Control	158.44 ± 2.96 a#	142.20 ± 0.69 Ca#	136.46 ± 1.10 Ca#	129.49 ± 1.26 Ca#	120.97 ± 1.61 Ca#	116.41 ± 1.17 Ca#
		Peppermint	158.44 ± 2.96 a#	156.48 ± 1.04 Aa#	154.33 ± 1.13 Aa#	152.27 ± 0.98 Aa#	149.97 ± 1.32 Aa#	144.00 ± 1.63 Aa#
		Thyme	158.44 ± 2.96 a#	148.41 ± 1.04 Ba#	146.41 ± 1.15 Ba#	144.57 ± 0.69 Ba#	137.59 ± 1.06 Ba#	130.33 ± 0.92 Ba#
		Carob	158.44 ± 2.96 a#	151.57 ± 1.31 Ba#	149.87 ± 0.34 Ba#	149.45 ± 0.80 Aa#	146.25 ± 1.04 Aa#	140.10 ± 0.53 Aa#
	Hacıhaliloğlu	Control	133.23 ± 4.03 b#	118.36 ± 0.97 Cb#	114.58 ± 1.31 Bb#	109.30 ± 0.85 Cb#	101.11 ± 0.88 Cb#	96.39 ± 0.93 Cb#
		Peppermint	133.23 ± 4.03 b#	130.28 ± 1.28 Ab#	126.40 ± 1.16 Ab#	122.77 ± 1.12 Ab#	116.54 ± 0.91 Ab#	111.25 ± 1.04 Cb#
		Thyme	133.23 ± 4.03 b#	124.73 ± 1.04 Bb#	121.91 ± 1.55 Ab#	116.29 ± 0.30 Bb#	109.34 ± 0.89 Bb#	103.98 ± 0.29 Bb#
		Carob	133.23 ± 4.03 b#	126.51 ± 1.05 ABb#	124.46 ± 0.77 Ab#	120.30 ± 1.16 Ab#	113.80 ± 0.49 Ab#	108.33 ± 1.23 Ab#
1200	Kabaaşı	Control	276.48 ± 1.93 a	246.31 ± 0.95 Ca	240.81 ± 0.45 Da	235.51 ± 0.91 Ca	228.12 ± 1.77Da	218.66 ± 1.19 Da
		Peppermint	276.48 ± 1.93 a	268.06 ± 1.81 Aa	264.90 ± 0.34 Aa	262.40 ± 0.89 Aa	251.14 ± 1.05 Aa	244.86 ± 1.37 Aa
		Thyme	276.48 ± 1.93 a	262.58 ± 1.00 Ba	257.41 ± 1.15 Ca	254.94 ± 1.38 Ba	238.77 ± 1.14 Ca	230.73 ± 0.71 Ca
		Carob	276.48 ± 1.93a	265.25 ± 1.00 ABa	261.33 ± 0.94 Ba	258.80 ± 0.66 ABa	245.78 ± 0.78 Ba	236.46 ± 1.01 Ba
	Hacıhaliloğlu	Control	207.47 ± 3.81 b	189.44 ± 0.79 Cb	186.41 ± 1.15 Cb	184.19 ± 0.93 Cb	176.58 ± 1.98 Cb	172.27 ± 1.98 Cb
		Peppermint	207.47 ± 3.81 b	203.05 ± 0.84 Ab	202.34 ± 0.89 Ab	199.39 ± 0.74 Ab	192.87 ± 1.39 Ab	189.86 ± 1.35 Ab
		Thyme	207.47 ± 3.81 b	196.98 ± 1.49 Bb	194.71 ± 0.82 Bb	190.36 ± 1.10 Bb	182.70 ± 1.71 BCb	181.69 ± 0.80 Bb
		Carob	207.47 ± 3.81 b	199.49 ± 1.03 ABb	199.24 ± 0.98 Ab	196.32 ± 0.74 Ab	189.06 ± 1.50 ABb	186.44 ± 1.19 ABb

The difference between treatments that have different capital letters in the same column (same altitude, cultivar and storage time) is significant ($p < 0.05$). The difference between cultivars that take different lower-case letters in the same column (same altitude and treatment) is significant ($p < 0.05$).
Data are presented as means ± SEM.
#The difference between altitudes that indicate the same cultivation, treatment and storage time is significant ($p < 0.05$).
SEM, standard error of the mean.

Table 4. The changes in malic acid during the storage of apricots harvested at different altitudes during the 35 days at 0°C.

Malic acid			Storage period					
Altitude	Cultivars	Treatment	0	5	10	15	25	35
1000	Kabaaşı	Control	3636.16 ± 118.16 #	3455.07 ± 1.18 Da#	3396.69 ± 1.57 Da#	3352.74 ± 1.47 Da#	3292.51 ± 2.94 Da#	3246.75 ± 1.49 Da#
		Peppermint	3636.16 ± 118.16 #	3521.69 ± 0.45 Aa#	3507.78 ± 2.49 Aa#	3499.43 ± 0.80 Aa#	3444.85 ± 2.71 Aa#	3393.81 ± 1.46 Aa#
		Thyme	3636.16 ± 118.16 #	3480.71 ± 2.14 Ca#	3448.73 ± 1.48 Ca#	3394.46 ± 4.19 Ca#	3343.42 ± 2.14 Ca#	3283.36 ± 1.89 Ca#
		Carob	3636.16 ± 118.16 #	3500.07 ± 1.22 Ba#	3461.29 ± 1.00 Ba#	3455.46 ± 2.81 Ba#	3386.93 ± 1.34 Ba#	3343.63 ± 2.64 Ba#
	Hacıhaliloğlu	Control	3222.97 ± 87.25 #	2984.41 ± 1.12 Db#	2948.71 ± 1.42 Db#	2905.76 ± 4.49 Db#	2863.75 ± 1.57 Db#	2829.24 ± 1.97 Db#
		Peppermint	3222.97 ± 87.25 #	3153.84 ± 1.48 Ab#	3117.42 ± 5.16 Ab#	3099.46 ± 4.24 Ab#	3058.33 ± 2.92 Ab#	3011.48 ± 1.79 Ab#
		Thyme	3222.97 ± 87.25 #	3057.37 ± 1.08 Cb#	3020.02 ± 2.15 Cb#	2982.91 ± 2.65 Cb#	2906.58 ± 3.98 Cb#	2892.85 ± 2.56 Cb#
		Carob	3222.97 ± 87.25 #	3106.25 ± 1.04 Bb#	3079.80 ± 1.43 Bb#	3070.42 ± 4.84 Bb#	3026.83 ± 1.42 Bb#	2992.46 ± 2.81 Bb#
1200	Kabaaşı	Control	5165.81 ± 30.45 a	5008.97 ± 1.68 Da	4964.07 ± 1.82 Da	4942.91 ± 2.65 Da	4903.33 ± 2.23 Da	4852.42 ± 2.16 Da
		Peppermint	5165.81 ± 30.45 a	5140.25 ± 1.04 Aa	5107.61 ± 1.65 Aa	5092.24 ± 2.03 Aa	5021.40 ± 1.86 Aa	5003.93 ± 1.80 Aa
		Thyme	5165.81 ± 30.45 a	5078.41 ± 1.12 Ca	5022.46 ± 1.23 Ca	5006.08 ± 3.82 Ca	4942.85 ± 2.39 Ca	4911.68 ± 0.83 Ca
		Carob	5165.81 ± 30.45 a	5112.87 ± 1.41 Ba	5091.23 ± 0.66 Ba	5052.73 ± 2.57 Ba	4993.05 ± 1.53 Ba	4954.48 ± 0.84 Ba
	Hacıhaliloğlu	Control	4859.52 ± 55.74 b	4763.87 ± 1.98 Db	4724.81 ± 1.55 Db	4699.97 ± 2.44 Db	4644.26 ± 3.97 Db	4615.73 ± 4.26 Db
		Peppermint	4859.52 ± 55.74 b	4811.35 ± 0.91 Ab	4801.46 ± 1.81 Ab	4795.34 ± 3.92 Ab	4738.93 ± 2.36 Ab	4713.35 ± 2.09 Ab
		Thyme	4859.52 ± 55.74 b	4786.35 ± 0.89 Cb	4762.76 ± 2.50 Cb	4747.74 ± 1.84 Cb	4699.07 ± 3.18 Cb	4673.13 ± 1.34 Cb
		Carob	4859.52 ± 55.74 b	4796.90 ± 1.36 Bb	4777.37 ± 0.89 Bb	4767.84 ± 2.38 Bb	4715.77 ± 1.48 Bb	4690.61 ± 0.62 Bb

The difference between treatments that have different capital letters in the same column (same altitude, cultivar and storage time) is significant ($p < 0.05$). The difference between cultivars that take different lower-case letters in the same column (same altitude and treatment) is significant ($p < 0.05$).
Data are presented as means ± SEM.
#The difference between altitudes that indicate the same cultivation, treatment and storage time is significant ($p < 0.05$).
SEM, standard error of the mean.

Table 5. The changes in succinic acid during the storage of apricots harvested at different altitudes during the 35 days at 0°C.

Succinic acid			Storage period					
Altitude	Cultivars	Treatment	0	5	10	15	25	35
1000	Kabaaşı	Control	3799.79 ± 110.33 a#	3523.46 ± 2.20 Ca#	3496.68 ± 1.54 Da#	3487.01 ± 1.64 Da#	3430.89 ± 1.65 Da#	3397.92 ± 1.66 Da#
		Peppermint	3799.79 ± 110.33 a#	3692.20 ± 2.06 Aa#	3676.25 ± 2.01 Aa#	3658.04 ± 2.19 Aa#	3617.43 ± 1.79 Aa#	3596.98 ± 1.58 Aa#
		Thyme	3799.79 ± 110.33 a#	3611.35 ± 1.10 Ba#	3596.27 ± 1.13 Ca#	3591.10 ± 1.11 Ca#	3518.41 ± 3.17 Ca#	3491.55 ± 1.99 Ca#
		Carob	3799.79 ± 110.33 a#	3618.42 ± 2.84 Ba#	3621.74 ± 1.50 Ba#	3607.70 ± 2.58 Ba#	3590.88 ± 1.34 Ba#	3543.06 ± 1.21 Ba#
	Hacıhaliloğlu	Control	2927.82 ± 110.79 b#	2762.46 ± 2.89 Db#	2706.85 ± 4.37 Db#	2697.75 ± 3.51 Db#	2636.73 ± 2.15 Db#	2603.07 ± 2.59 Db#
		Peppermint	2927.82 ± 110.79 b#	2896.84 ± 1.39 Ab#	2849.22 ± 2.25 Ab#	2816.67 ± 1.57 Ab#	2802.03 ± 3.18 Ab#	2747.43 ± 1.84 Ab#
		Thyme	2927.82 ± 110.79 b#	2811.69 ± 1.43 Cb#	2768.29 ± 2.94 Cb#	2761.39 ± 1.83 Cb#	2712.83 ± 2.29 Cb#	2686.55 ± 1.66 Cb#
		Carob	2927.82 ± 110.79 b#	2842.90 ± 2.34 Bb#	2804.27 ± 3.02 Bb#	2791.06 ± 1.11 Bb#	2756.88 ± 1.76 Bb#	2713.83 ± 2.42 Bb#
1200	Kabaaşı	Control	5107.85 ± 27.92	4956.98 ± 1.34 Da	4939.73 ± 2.49 Da	4930.59 ± 1.27 Da	4889.89 ± 1.32 Da	4840.33 ± 1.92 Da
		Peppermint	5107.85 ± 27.92	5057.46 ± 2.02 Aa	5023.35 ± 2.11 Aa	5017.66 ± 2.51 Aa	4987.56 ± 2.02 Aa	4926.38 ± 0.84 Aa
		Thyme	5107.85 ± 27.92	4981.19 ± 1.30 Ca	4966.42 ± 0.84 Ca	4960.05 ± 1.41 Ca	4943.60 ± 2.04 Ca	4865.44 ± 4.20 Ca
		Carob	5107.85 ± 27.92	5021.64 ± 1.54 Ba	4998.56 ± 1.00 Ba	4993.55 ± 1.99 Ba	4973.30 ± 1.93 Ba	4898.50 ± 3.39 Ba
	Hacıhaliloğlu	Control	4953.63 ± 33.00	4867.01 ± 1.52 Cb	4826.42 ± 2.22 Db	4798.05 ± 3.47 Db	4786.39 ± 1.18 Db	4731.95 ± 1.83 Db
		Peppermint	4953.63 ± 33.00	4903.42 ± 2.84 Ab	4893.69 ± 1.57 Ab	4877.20 ± 2.92 Ab	4854.93 ± 1.30 Ab	4813.51 ± 1.77 Ab
		Thyme	4953.63 ± 33.00	4872.01 ± 1.89 Cb	4841.73 ± 1.51 Cb	4823.40 ± 2.25 Cb	4808.29 ± 2.00 Cb	4756.73 ± 0.95 Cb
		Carob	4953.63 ± 33.00	4887.23 ± 1.03 Bb	4880.55 ± 1.86 Bb	4853.26 ± 1.70 Bb	4834.99 ± 1.42 Bb	4786.88 ± 1.39 Bb

The difference between treatments that have different capital letters in the same column (same altitude, cultivar and storage time) is significant ($p < 0.05$). The difference between cultivars that take different lower-case letters in the same column (same altitude and treatment) is significant ($p < 0.05$).
Data are presented as means ± SEM.
#The difference between altitudes that indicate the same cultivation, treatment and storage time is significant ($p < 0.05$).
SEM, standard error of the mean.

Table 6. The changes in fumaric acid during the storage of apricots harvested at different altitudes during the 35 days at 0°C.

Fumaric acid			Storage period					
Altitude	Cultivars	Treatment	0	5	10	15	25	35
1000	Kabaaşı	Control	17.93 ± 0.28 a#	14.96 ± 0.06 Da#	14.80 ± 0.03 Da#	14.52 ± 0.01 Da#	13.87 ± 0.03 Da#	12.88 ± 0.03 Da#
		Peppermint	17.93 ± 0.28 a#	17.38 ± 0.26 Aa#	16.98 ± 0.03 Aa#	16.54 ± 0.02 Aa#	15.45 ± 0.02 Aa#	14.82 ± 0.03 Aa#
		Thyme	17.93 ± 0.28 a#	15.73 ± 0.19 Ca#	15.51 ± 0.02 Ca#	15.17 ± 0.02 Ca#	14.54 ± 0.02 Ca#	13.61 ± 0.01 Ca#
		Carob	17.93 ± 0.28 a#	16.69 ± 0.10 Ba#	16.00 ± 0.03 Ba#	15.88 ± 0.03 Ba#	14.81 ± 0.02 Ba#	14.21 ± 0.03 Ba#
	Hacıhaliloğlu	Control	14.89 ± 0.43 b#	12.13 ± 0.12 Db#	11.73 ± 0.05 Db#	11.43 ± 0.02 Db#	11.02 ± 0.01 Db	10.22 ± 0.02 Db#
		Peppermint	14.89 ± 0.43 b#	14.34 ± 0.11 Ab#	14.02 ± 0.04 Ab#	13.75 ± 0.04 Ab#	13.12 ± 0.02 Ab#	12.28 ± 0.03 Ab#
		Thyme	14.89 ± 0.43 b#	13.35 ± 0.10 Cb#	12.92 ± 0.03 Cb#	12.61 ± 0.01 Cb#	12.16 ± 0.01 Cb#	11.41 ± 0.01 Cb#
		Carob	14.89 ± 0.43 b#	13.81 ± 0.10 Bb#	13.54 ± 0.02 Bb#	13.43 ± 0.01 Bb#	12.68 ± 0.01 Bb#	12.03 ± 0.02 Bb#
1200	Kabaaşı	Control	24.87 ± 0.31	21.39 ± 0.31 Ca	21.49 ± 0.02 Da	21.18 ± 0.02 Da	19.83 ± 0.03 D	18.81 ± 0.02 Da
		Peppermint	24.87 ± 0.31	23.41 ± 0.15 Aa	22.90 ± 0.05 Aa	22.80 ± 0.01 Aa	21.89 ± 0.04 Aa	20.89 ± 0.03 Aa
		Thyme	24.87 ± 0.31	22.40 ± 0.16 Ba	21.98 ± 0.04 Ca	21.73 ± 0.02 Ca	20.51 ± 0.02 Ca	19.58 ± 0.02 Ca
		Carob	24.87 ± 0.31	22.98 ± 0.04 ABa	22.42 ± 0.03 Ba	22.20 ± 0.10 Ba	21.13 ± 0.04 Ba	20.24 ± 0.02 Ba
	Hacıhaliloğlu	Control	22.76 ± 0.54	19.15 ± 0.10 Cb	18.43 ± 0.03 Db	18.55 ± 0.01 Db	15.74 ± 1.48 B	16.14 ± 0.02 Db
		Peppermint	22.76 ± 0.54	21.28 ± 0.08 Ab	20.84 ± 0.05 Ab	20.84 ± 0.03 Ab	19.41 ± 0.03 Ab	18.34 ± 0.01 Ab
		Thyme	22.76 ± 0.54	20.35 ± 0.11 Bb	19.45 ± 0.03 Cb	19.27 ± 0.03 Cb	18.23 ± 0.04 Abb	17.29 ± 0.04 Cb
		Carob	22.76 ± 0.54	20.90 ± 0.12 Ab	20.40 ± 0.10 Bb	20.29 ± 0.07 Bb	18.92 ± 0.03 Ab	17.81 ± 0.03 Bb

The difference between treatments that have different capital letters in the same column (same altitude, cultivar and storage time) is significant ($p < 0.05$). The difference between cultivars that take different lower-case letters in the same column (same altitude and treatment) is significant ($p < 0.05$).
Data are presented as means ± SEM.
#The difference between altitudes that indicate the same cultivation, treatment and storage time is significant ($p < 0.05$).
SEM, standard error of the mean.

significantly lower, ranging from 22.76 μg · g^{-1} to 11.02 μg · g^{-1}, at 1000 m (Table 6).

PCA

The first two principal components (PC1 and PC2) accounted for 96.6% of the total variability, with PC1 explaining 83.8% and PC2 explaining 12.8%. Samples taken from higher altitudes (1200 m) were found on the side of the *x*-axis, while samples from lower altitudes (1000 m) were located on the side of the *y*-axis. Organic acids (oxalic, citric, tartaric, malic, succinic and fumaric) were located on the positive side of the *x*-axis, while the respiration rate was located on the negative side of the *y*-axis (Figure 2).

In general, it was observed that there was a positive correlation among organic acids, but a negative correlation between organic acids and the respiration rate. In the study, PCA effectively differentiated samples from the two apricot-growing regions and the two cultivars. The results indicate that the organic acids were significantly impacted by the altitude and the type of cultivars (Figure 2).

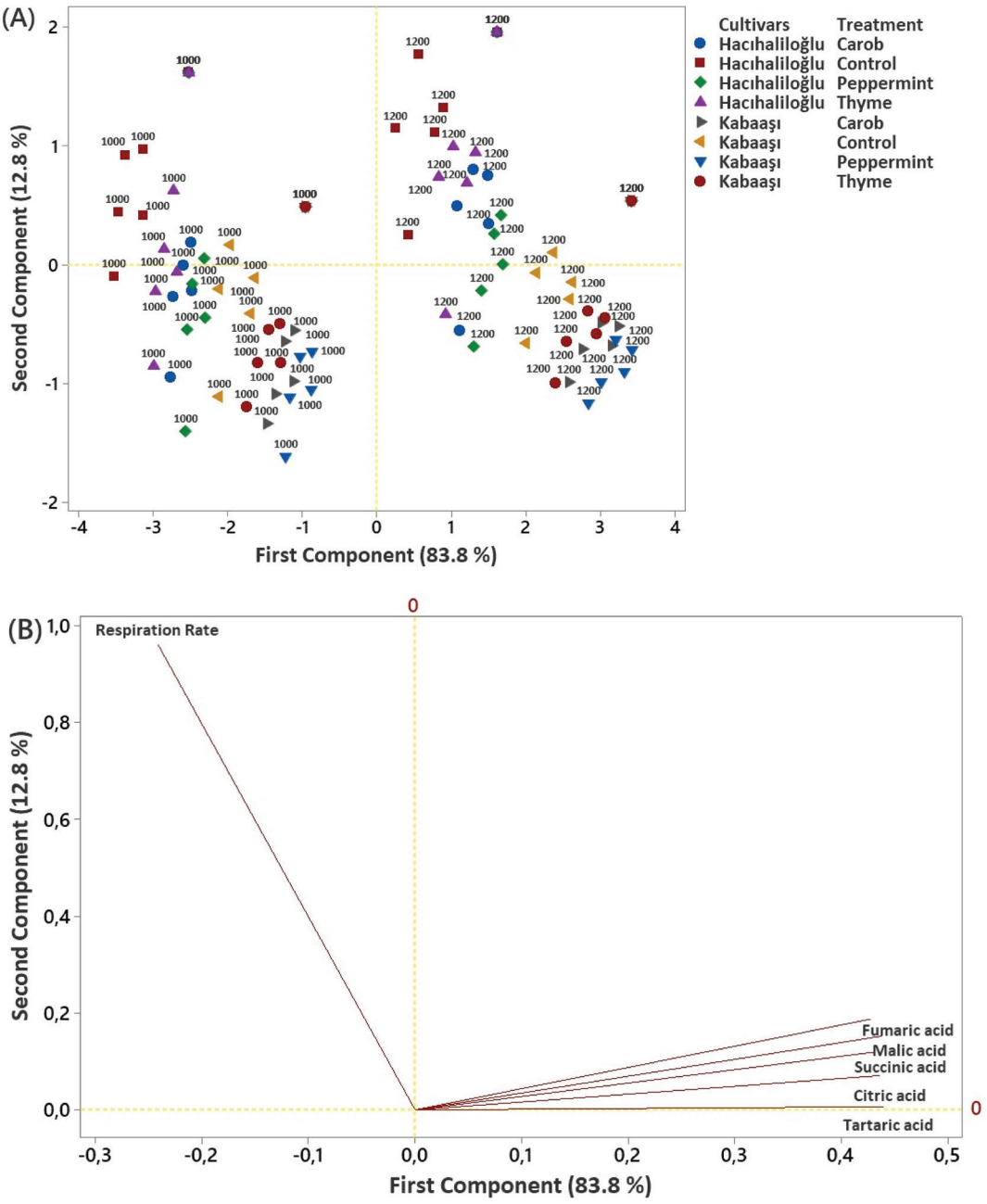

Figure 2. (A) The first and second PCA scores plot of fruits harvested at different altitudes in terms of cultivars and treatment. (B) The first and second PCA scores plot of the correlation in the analysed parameters. PCA, principal component analysis.

DISCUSSION

The organic acid content in plants or tissues is determined by the interplay between the processes of acid synthesis, degradation, utilization and compartmentalization. Factors such as temperature, light, fertilization, water supply and plant-management practices can impact the source: sink ratio can, as a result, affect the organic acid content. Temperature has a significant effect on plants, which is largely mediated by changes in the plant biochemistry (Robles et al., 2019; Zhang et al., 2020). The temperature of growth influences both the titratable acidity (TA) and the stored organic acid content of the plant. The optimal temperature range for most plant physiological processes is between 0°C and 40°C. However, the ideal temperature range for the growth and development of fruit and vegetable crops is much more limited and varies depending on the species and ecological conditions (Vallarino and Osorio, 2019). Increased temperatures have a detrimental effect on photosynthesis and respiration in plants through changes in enzyme activity and the electron transport chain. Indeed, increased temperatures during fruit ripening generally give rise to a decrease in the tricarboxylic acid (TCA) cycle acids due to an increase in metabolic processes. Therefore, higher temperatures in all plant tissues result in an acceleration of metabolism, leading to increased consumption of sugars and stored TCA cycle acids that serve as metabolic substrates (Nievola et al., 2017). Changes in organic acid metabolism in response to temperature are likely caused by the impact of temperature on enzyme activities and transport systems involved in processes such as glycolysis, TCA cycle respiration, fermentation and gluconeogenesis. In other words, increased temperatures during fruit growth typically result in a decrease of TA, as seen in studies of tomato and grape fruit. The response of organic acids to temperature changes is dependent on the age of the plant or fruit, too. In the current study, higher organic acid content was found in fruit harvested at higher altitudes (Wang and Camp, 2000; Richardson et al., 2004; Vallarino and Osorio, 2019). This situation is consistent with other studies, which suggest that the maximum temperatures (<30°C) during the growth cycle lead to increased synthesis and preservation of organic acids in grape fruit (De Oliveira et al., 2019). Moreover, it was reported in other studies that organic acids are influenced by environmental conditions (Koyuncu, 2004) and that organic acid rates in the fruit are sensitive to altitude levels (Trad et al., 2013). The quality of fruit is affected by high temperatures between ripening and harvest stages. Thus, the fruit may have too much sugar, too little acid and less-fresh and complex aromas at low-altitude cultivation (Van Leeuwen and Seguin, 2006; Pons et al., 2017). The current study is consistent with the finding that apricots grown at low altitudes have fewer organic acids.

Postharvest treatment with EOs can affect the respiration rate in fruit. EOs contain volatile compounds that can modulate the respiration rate by altering the atmospheric composition around the fruit. This can be used to slow down the respiration rate and extend the postharvest life of the fruit (Shehata et al., 2020). Agricultural products with substances such as EOs and plant extracts could maintain the freshness during storage because they act as a physical barrier to reduce dehydration and to alleviate side effects of respiration (Ramezanian et al., 2016). In addition, the control of fruit ripening by EOs has been linked to their antioxidant properties. These properties reduce the diffusion of oxygen and increase the accumulation of CO_2 around the fruit surface, leading to reduced water loss and slowing down the activity of enzymes and biochemical reactions that cause pigment synthesis (Perdones et al., 2016). It was reported that the treatment of postharvest min oil (Yousefizad et al., 2015; Owolabi et al., 2021) and thyme oil (Sapper et al., 2019; Cai et al., 2020) reduced respiration rate during storage and extend the postharvest fruit life. Furthermore, the treatment of postharvest peppermint oil (Yousefizad et al., 2015; Owolabi et al., 2021) and thyme oil (Sapper et al., 2019; Cai et al., 2020) reduced respiration rate during storage and extend the postharvest fruit life in fresh fruit.

CONCLUSIONS

In the present study, it can be stated that apricot cultivation at high altitudes increased the amount of organic acids in the fruit. The increase in organic acids has positive effects on fruit quality, thus leading to extension of postharvest life. Based on the information mentioned, the treatment of postharvest EOs in apricot fruits has been shown to slow down the respiration rate, which in turn reduces the consumption of organic acids in the treated fruit during storage compared to untreated fruit. During storage, the highest organic acid content and the lowest respiration rate in both cultivars were observed in the fruit treated with peppermint, carob, thyme oil and control fruit, respectively.

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AUTHOR CONTRIBUTIONS

N.Y. and S.C. – conceptualization. S.E., S.C., N.Y. and F.I. – writing-original draft preparation. N.Y., F.I. and S.C. – data curation. N.Y., F.I. and S.C. – validation. N.Y., F.I. and S.C. – visualization. S.E., N.Y., F.I. and S.C. – writing-review and editing. N.Y., F.I. and S.C. – investigation. S.E. and S.C. – methodology. S.C. – supervision. N.Y. and F.I. – resource. N.Y., F.I. and S.C. – software. N.Y., F.I. and S.C. – formal analysis.

CONFLICT OF INTEREST

All authors have read and agreed to the published version of the manuscript and declare that no conflict of interest exists.

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