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Effects of postharvest citric, oxalic acid and modified atmosphere packaging applications on fruit quality and biochemical properties in persimmon

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Abstract

Background This study aims to investigate the effects of postharvest oxalic acid (OA), citric acid (CA) and modified atmosphere packaging (MAP) applications on fruit quality and preservation of biochemical content in persimmon. This research conducted on "Rojo brillante" variety persimmon (*Diospyros kaki* L), evaluated the effects of various treatment methods on fruit quality during 90 days of storage period. In the study, the parameters such as weight loss, total soluble solids (TSS), titratable acidity, fruit firmness, respiration rate, ethylene production, gas composition, phenolic content, antioxidant activity and organic acids were investigated.

Method In the study, each application consisted of three replications. The first group was control, the second group was 1 mmol CA, the third group was 1 mM OA, the fourth group was MAP, the fifth group was 1 mmol CA + MAP and the sixth group was 1 mM OA + MAP. The fruits were kept in control, CA and OA solutions for 15 min. The fruits were stored for 90 days at 5 °C and 85 ± 5% relative humidity.

Results During storage period, fruit weight loss, water loss and natural physiological changes increased. OA and CA acid applications were not effective in reducing fruit weight loss, but OA + MAP applications were more effective in preserving fruit quality. MAP prevented water loss and preserved fruit quality by decreasing oxygen levels and increasing carbon dioxide levels. The changes in TSS ratio were observed while MAP and OA + MAP treatments kept TSS constant. Application of OA + MAP increased acidity by preserving the stability of acidic compounds. Flesh firmness decreased with storage time, but MAP and OA + MAP combinations gave better results. As the storage period progressed, color changes and respiration rate increased, MAP application slowed down fruit respiration and delayed ripening. An increase in carbon dioxide levels was observed during storage, the highest levels were recorded in OA + MAP and CA + MAP applications. MAP application kept nitrogen levels the highest, the nitrogen levels reached equilibrium with the combination of OA and MAP. In addition, OA and CA applications increased phenolic content and antioxidant activity while it decreased in MAP and control groups. In terms of acidic compounds, the combination of OA and MAP was effective in preserving fruit acids.

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Conclusion OA + MAP treatments were more effective in preserving fruit quality by reducing water loss, maintaining acidity, and improving flesh firmness compared to other applications. MAP treatment also slowed respiration, delayed ripening, and maintained nitrogen levels, contributing to overall fruit preservation during storage. The study revealed the potential use of these methods in extending fruit quality and shelf life.

Keywords Antioxidant activity, Fruit frmness, Organic, Acid, Total phenolic, Weight loss

Background

Persimmon (*Diospyros kaki* L.) is a fruit species that is important in terms of nutrition, especially due to its high sugar content and bioactive components. Persimmon fruits contain many bioactive compounds, including polyphenols, flavonoids, minerals, carotenoids, steroids and terpenoids, which are beneficial for human health [1]. In addition, persimmon is a popular fruit worldwide and is in high demand due to its various health benefits [2, 3]. However, there are significant problems in the post-harvest process of this fruit in developing countries. These problems manifest themselves through negative effects such as color change, softening, surface drying and tannin breakdown in the fruit's texture, which are related to the ripening process of the fruit. The commercially harvested persimmons can only stay fresh for two weeks at room temperature, making long-distance transportation difficult and causing post-harvest fruit quality losses. The ripening process of persimmon results in rapid softening through chemical reactions such as structural changes in the cell walls, breakdown of cellulose and dissolution of pectin. This situation increases the susceptibility of the fruit to mechanical injuries and decay [4, 5]. Therefore, it is of great importance to develop effective strategies to maintain the postharvest quality of persimmon and extend its shelf life. In addition, Persimmon fruits are sensitive to storage temperature [6]. Due to the sensitivity of persimmon fruits to cold, cold damage (CI) may occur, which reduces the economic and nutritional value of the fruits [7, 8]. Cold stress occurring during cold storage causes many physiological disorders in persimmon fruits such as softening of the flesh, browning, change in peel color, membrane damage and loss of antioxidant compounds [9, 10].

Since persimmon fruits are very sensitive to cold, preserving the quality of persimmon fruits is very difficult compared to other fruits. In recent years, postharvest treatments such as methyl jasmonate [11], combinations of calcium lactate with hot water application [12] hydrogen sulfide and γ-aminobutyric acid [8], controlled atmosphere and edible coating combinations [13], ethanol and 1-methylcyclopropene (1-MCP) combinations [14], CO2 and 1-MCP combinations [15], modified atmosphere packaging (MAP) [16], 1-MCP and Aminoethoxyvinylglycine (AVG) combinations [17], Oxalic acid and 1-MCP [18], melatonin and 1-1- MCP [19] and melatonin and modified atmosphere packing (MAP) combinations [6, 20], have been used to preserve the quality of persimmon fruits during cold storage.

However, each preservation technique has some disadvantages, and therefore, postharvest quality preservation strategies of persimmon need to be further developed. In this context, it is thought that organic acids such as OA and CA, which play an important role in many metabolic processes in plants, may be effective in preserving fruit quality. OA is a compound that delays fruit ripening, stands out with its antioxidant properties and provides resistance to various diseases [21, 22]. In addition, it can prevent off-flavors by inhibiting the activity of polyphenol oxidase enzyme, ensuring that fruit pigments remain stable [23]. In addition, CA is an important component in preserving post-harvest fruit quality. This acid, which is widely used in fruit species such as citrus, can extend shelf life by regulating fruit acidity [24]. Previous studies on the effects of CA on improving post-harvest fruit quality and delaying aging show that this application gives successful results in many fruit species [25, 26]. Recent studies have shown that combining different treatments used in the cold storage of persimmons is more effective in maintaining postharvest quality [20]. This may be due to the combined physiological regulatory effects of these treatments [19]. However, the effects of MAP, OA and CA applications on persimmon have not yet been fully investigated. This deficiency constitutes the main purpose of this study. The study aims to determine the effects of postharvest OA and CA applications on the preservation of fruit quality and biochemical content in persimmon. Thus, it is expected to contribute to the development of new strategies for preserving postharvest quality and extending shelf life in persimmon. This study is original and innovative in terms of being one of the large-scale studies on OA, CA and MAP applications and their combinations on the preservation of postharvest fruit quality in persimmon.

Materials and methods

Plant material

In the study, the fruits of the persimmon variety "Rojo brillante", which is commercially grown in Pervari district of Siirt province, were used as material. The harvest of the fruits was carried out by considering the optimum harvest conditions. The harvested fruits were brought to the cold storage of Van Yuzuncu Yil University, Faculty

of Agriculture, Department of Horticulture as soon as possible.

Methods

After harvesting fruits with similar shape, size and color characteristics, they were placed in perforated bags and transported to the laboratory. The fruits were divided into six groups of three replicates each, and each replicate was adjusted to contain 150 fruits. Fruits were first pre-cooled for 24 h in a cold storage at 7 °C and 85 ± 5% relative humidity. After the pre-cooling process, fruits were sized equally and fruits with diseases, pests and mechanical damage were eliminated. After the pre-cooling process, the fruits were first washed in tap water and then kept in 250 ppm sodium hypochlorite for 5 min to ensure sterilization. Then, in order to remove chloride residue, the fruits were rinsed 3 times in pure water and left to dry. After the drying process, the fruits were divided into groups. Group 1 was Control (no treatment), and the samples were kept in pure water for 15 min. Group 2 was kept in 1 mmol CA for 15 min. Group 3 was kept in 1 mM OA for 15 min. Group 4 samples were kept in pure water for 15 min and then packaged in MAP. Group 5: Soaked in 1 mmol CA for 15 min and then packaged in MAP. Group 6: Soaked in 1 mM OA for 15 min and then packaged in MAP. The 15-minutes application time was preferred because it has been used successfully in species such as strawberry [27], tomato [28] and loquat [29]. Each package MAP consisted of 10 fruits, and the atmosphere composition in the bags was 3–5% O2, 5–10% CO2, and a nitrogen balance. The fruits were then transferred to a cold storage facility set at 5 °C and 85 ± 5% relative humidity. The following measurements and analyses were carried out throughout the experiment.

Weight loss (%)

At the beginning of the cold storage, initial weights (Wi) of the fruit were determined by a digital scale with a precision of 0.01 g (Radwag, Poland). Then, on 30th, 60th and 90th days of the storage, final weights (Wf) were determined. The weight loss that occurs in fruit was based on the weight at the beginning of each measurement period and determined as a percentage through the equation given below (Eq. 1).

$$WL = \frac{Wi - Wf}{Wi} \times 100 \quad (1)$$

Fruit color

Fruit color was determined in terms of CIE L*, a* and b*. Fruit color was determined by measuring from points determined at 2 opposite poles of the equatorial part of the fruit by means of a colorimeter (Minolta, model CR-400, Tokyo, Japan) on 10 fruits in each replicate for each treatment.

Total soluble solids content (%) and titratable acidity (%)

Five fruits taken from each replication were washed with distilled water. The fruits were crushed and homogenized using a blender (Promix HR2653, Philips, Turkey), then filtered through a cheesecloth to obtain the fruit juice. Total soluble solids content was determined using a digital refractometer (Atago PAL-1, USA) and recorded as a percentage (%). For titratable acidity measurement, 10 mL of fruit juice was mixed with 10 mL of distilled water. The solution was titrated with 0.1 N sodium hydroxide (NaOH) until the pH reached 8.2. The titratable acidity was calculated as g malic acid per kg (g kg^{-1}).

Respiration rate, external ethylene production and packaging gas composition

Five fruits were placed in airtight containers, and after a 2-hour waiting period, the amount of CO_2 released into the atmosphere was measured using a Headspace Gas Analyser GS3/L device. The respiration rate was expressed as ml CO_2/kg^{-1} h^{-1}.

$$Respiration\ Rate = (Vj - Vf) \times \%CO2 \times 10/FW \times T$$

$$Vj = Jar\ volume, Vf = Fruit\ volume, FW = Fruit\ Weight\ (kg), T = Time\ (Hour)$$

To determine the external ethylene production, samples taken from the fruits were placed in 1-liter airtight jars. After a 3-hour waiting period, 2 mL gas samples were injected into a GC (Gas Chromatography) device using a gas-tight syringe to obtain chromatograms. The ethylene amount was calculated using the following formula.

$$External\ Ethylene\ Amount = SA \times (Vj - Vf) /G \times T \times 100$$

$$SA = Sample\ area, Vj = Jar\ volume, Vf = Fruit\ volume, FW = Fruit\ Weight(kg), T = Time\ (Hour)$$

During the storage period, the changes in the packaging gas composition (O_2, CO_2 and N_2) of the fig fruits were determined using the Headspace Gas Analyser GS3/L device.

Total phenolic and total antioxidant activity

Approximately 5 fruits from each replication were washed with distilled water, deseeded, and homogenized in a blender. About 30 ml of the homogenized fruit sample was transferred to 50 ml falcon tubes. The fruit

samples were centrifuged at 4℃, 12,000 rpm for 35 min, separating the pulp and juice. Total phenolic content and total antioxidant content were determined from the fruit juice using a UV-Vis spectrophotometer (Shimadzu, Kyoto, Japan). Total phenolic content was measured as mg GAE 100 g^{-1} according to Singleton and Rossi [30], and total antioxidant content as mmol Trolox 100 g^{-1} based on the method by Benzie and Strain [31].

Organic acids

Five g of fruit sample was homogenized with 0.009 N H_2SO_4 in a 1:1 ratio and mixed on a shaker for 1 h. The samples were centrifuged at 15,000 rpm for 15 min. The supernatant was filtered through a 0.45 µm membrane filter and then through a SEP-PAK C18 cartridge for HPLC analysis. Organic acids were analyzed using the method developed by Bevilacqua and Califano [32] on an HPLC (Agilent HPLC 1100 series G 1322 A, Germany) equipped with an Aminex HPX-87 H, 300 mm x 7.8 mm column (Bio-Rad Laboratories, Richmond, CA, USA).

Statistical analysis

The data obtained in the study were subjected to variance analysis (ANOVA). Differences between means were evaluated with Tukey's test at a significance level of $p < 0.05$. Data analysis was performed using the SAS Version 9.1 statistical software package (SAS Institute Inc., Cary, NC, USA). Heatmap clustering analysis and principal component analysis were conducted with the Jmp Pro 17 statistical software package.

Results and discussion

Weight loss

During storage, it was observed that weight loss increased in all applications; this is an expected situation due to the effect of water loss and natural physiological changes of the fruit. It was understood that OA and CA applications were not effective in reducing weight loss on the fruit. On the other hand, OA + MAP application were effective in preserving fruit quality. There was no weight loss during storage with OA + MAP application. These results reveal that MAP and OA applications should be used especially in commercial fruit storage and transportation processes (Fig. 1A). By altering the gas concentration around the fruit, MAP delays the breakdown of cell walls, reduces respiration [33], and minimizes water loss [34], thereby mitigating weight loss. MAP has been shown to be effective in reducing weight loss in many fruit types [35–38]. In various studies, OA application has been shown to inhibit ripening processes and preserve fruit quality, in fruits such as litchi [39] and mango [40]. This study shows that OA may be similarly effective on persimmon and may play an important role in preserving fruit quality. It may be said that OA probably reduced metabolic activity, delayed senescence, and maintained better cellular integrity, thereby working in an integrated manner to reduce fresh weight loss of persimmon fruit under MAP storage.

Total soluble solids content and titratable acidity

Differences were observed in the TSS ratio during storage. On the 30th day of storage, there was no change in the TSS ratio in MAP and OA + MAP applications. In all other applications, an increase in the TSS ratio was observed. The group with the highest increase was the control group. This may indicate that the ripening and sugaring process of the fruit accelerated during storage in the control group. On the 60th day of storage, the increase in TSS ratio continued in other applications except MAP and control group. While a decrease in TSS ratio was observed in the MAP group, the highest TSS value was recorded in the OA + MAP application. However, as of the 60th day, the TSS ratio decreased in the OA application while the increase continued in the other groups. On the 90th day of storage, there was no change in the TSS ratio in the CA and MAP applications (Fig. 1B). During 90 days of storage of persimmon, the changes in titratable acidity were observed inconsistently among different treatments. On the 30th day of storage, a decrease in acidity occurred in OA and OA + MAP treatments, while no change was observed in MAP treatment. Titratable acidity increased in all other treatments. This may lead to an increase in pH and changes in the taste profile, especially in the control group, due to the decrease in acidic compounds during the ripening process of the fruit. On the 60th day of storage, there was a decrease in titratable acidity in the control, MAP and CA + MAP treatments, while there was no change in acidity in the CA and OA treatments. Acidity increased especially in OA + MAP application, suggesting that OA has a positive effect on preserving fruit quality and ensuring the stability of acidic compounds. On the 90th day of storage, titratable acidity decreased in general. However, at the end of the storage, the highest acidity value was recorded in the control group, while the lowest value was obtained with MAP application (Fig. 1C).

TSS and acidity, which are indicators of harvest maturity, are crucial fruit quality attributes that determine the fruit's quality and consumer acceptability [20]. As ripening progresses, the hydrolysis of insoluble polysaccharides increases TSS, while acidity decreases [41]. Changes in SSC content during cold storage are influenced by several factors, including the transformation of sugars into carbon dioxide and water as a result of elevated respiration rates, the hydrolysis of starch into simpler sugars, an increase in dry matter concentration due to moisture loss, and the degradation of cell wall polysaccharides [42]. Meanwhile, the decline in acidity during storage

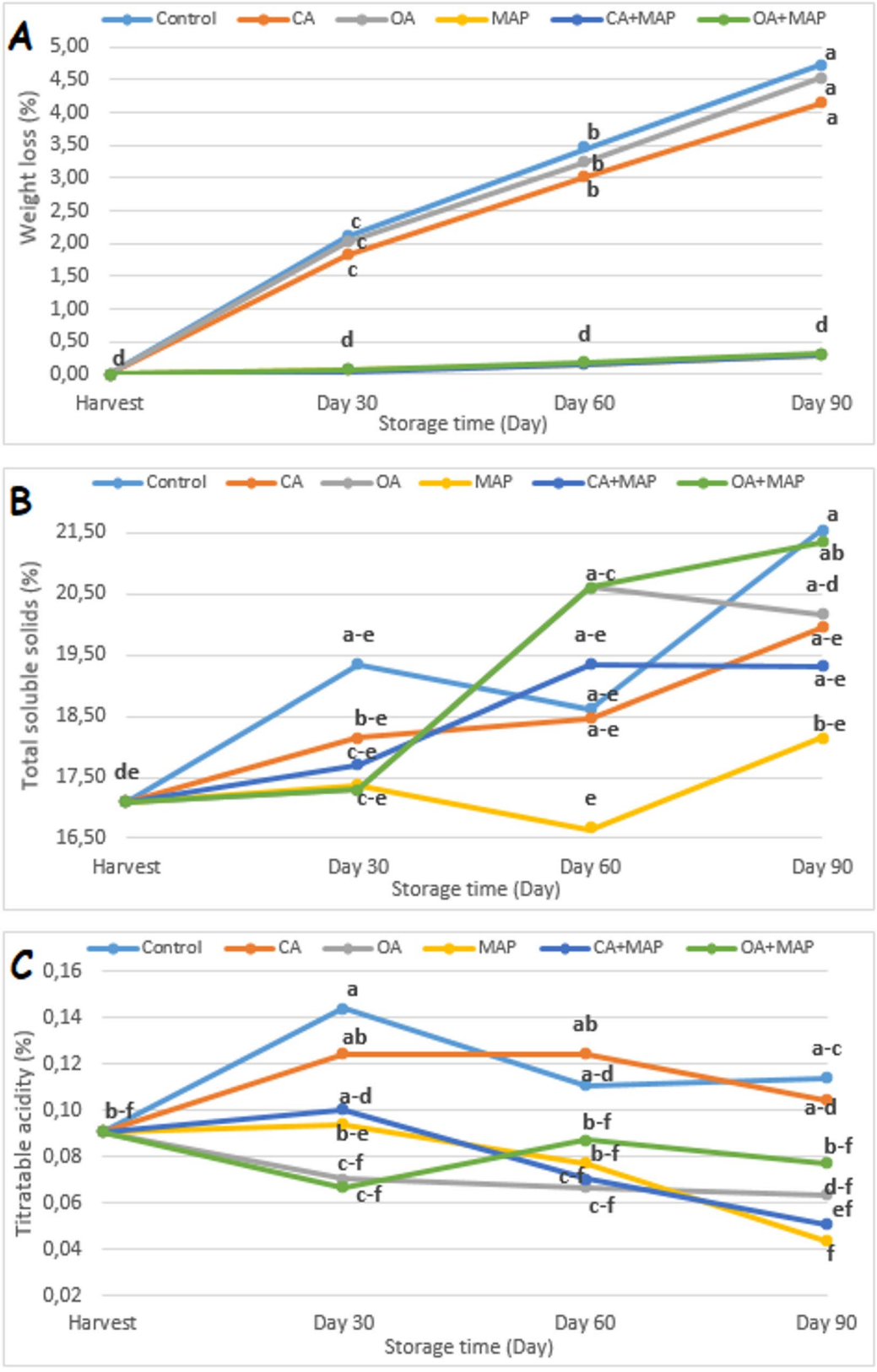


Fig. 1 Effect of oxalic and citric acid treatments on weight loss (**A**), total soluble solids (**B**) titratable acidity (**C**) of persimmons. Significant differences between treatment groups are indicated by letters ($P < 0.05$). CA: Citric acid, OA: Oxalic acid, MAP : Modified Atmosphere Packaging

is primarily attributed to the use of organic acids in the respiration process, which intensifies as respiration rates rise [43].

Fruit flesh firmness

A significant decrease in fruit flesh firmness was observed with increasing storage time. The measurements made on the 30th, 60th and 90th show that storage time has a significant effect on fruit flesh firmness. In this context, the greatest firmness loss occurred on the 90th day of the storage. Although the MAP application was the application that best preserved fruit flesh firmness until the 30th day, it did not provide a significant improvement in firmness alone. On the 60th day of storage, OA and MAP applications were determined to be the most successful in preserving fruit flesh firmness. The CA + MAP application successfully preserved the flesh firmness after the 60th day, while CA + MAP and OA applications successfully preserved the flesh firmness at the end of storage. (Fig. 2A). MAP applications slow down the loss of fruit firmness by reducing cellulose and pectin degradation in the cell wall and by lowering O2 concentrations during storage [44]. The preservation of flesh firmness in OA-treated fruits may be due to the formation of oxalate-insoluble pectin, which slows down the polymerization of pectin [45]. Citric acid is widely used in the food industry as a preservative. It is suggested that the protective action of citric acid is due to its pH-lowering and synergistic effect with antioxidants [46]. Additionally, citric acid helps control fruit ripening by regulating the expression of cell wall-related genes in fruit tissue during postharvest application [25]. Many researchers have reported that MAP [36, 38], OA [45, 47] and CA [25, 48] applications are effective methods for preserving fruit firmness during storage.

Respiration and ethylene ratios

Ethylene production and cellular respiration are the most important physiological activities that determine the quality and storage potential during ripening of harvested fruits and vegetables [49]. In the study, the significant increase in respiration rate was observed with increasing storage time. This indicates an increase in the metabolic activity of the fruits and indicates that the ripening process is accelerated. Respiration rate measurements in persimmon, especially on the 30th, 60th and 90th days of the storage, revealed that the biochemical processes of the fruit changed in parallel with the storage period (Fig. 2B). The high respiration rate suggests increased energy consumption, which may negatively affect fruit quality. The best result on respiration rate on the 30th day of storage was obtained from the OA + MAP application, while the best results on the 60th and 90th days of storage were obtained from the CA application.

Ethylene is a hormone that accelerates fruit ripening and is an important parameter for maintaining fruit quality. The changes observed in ethylene production during storage indicate differences in fruit metabolism and effects of treatments. According to the observations made on the 30th day of storage, the increase in the amount of ethylene occurred in the control application while ethylene production decreased in the other applications. CA application was the application that best suppressed ethylene production on the 60th and 90th days of storage. Additionally, OA and OA + MAP applications showed similar effects in suppressing ethylene production after CA application.

The increases and decreases observed in the control treatment in the study were reported in climacteric fruit species such as persimmon [18, 19, 50] and pear [51]. Accelerated respiration rate and enhanced ethylene production are commonly observed during the ripening processes in climacteric fruits [51]. Since persimmons are climacteric fruits, they produce sufficient ethylene, which plays an important role in the regulation of many physiological processes such as fruit ripening [52]. Low temperature can delay fruit ripening and thus increase fruit shelf life. However, low temperature can also initiate the biosynthesis of ethylene [53]. Because cold stress causes increased ethylene production in cold-sensitive climacteric fruits such as persimmon [54]. As a result of the study, the changes in ethylene production of fruits are consistent with the literature information.

The current study results showed that the most successful application on respiration and ethylene was CA application. Inhibiting fruit ethylene synthesis and reducing fruit respiration intensity prolongs fruit storage time. Citric acid can participate in the tricarboxylic acid cycle (TCA) during fruit ripening and senescence. When exogenous CA enters the tricarboxylic acid (TCA) cycle, it directly causes feedback inhibition of citrate synthase and accelerates the progression of TCA. Thus, it reduces the ethylene production rate in fruits and delays the peak of ethylene release [55].

Fruit color

Statistically significant differences were found between storage time and applications for all color parameters (Table 1). This shows that storage time and treatments used have significant effects on the color parameters of the fruits. The storage time x treatment interaction was also statistically significant. This shows that the effects of different treatments on color parameters may change during storage time and treatments and storage time together affect fruit color. The L* color value indicates the brightness level of the fruit. During the storage period, the brightness level continuously decreases. From day 30 to 90 of the storage, the brightness of the fruit decreased

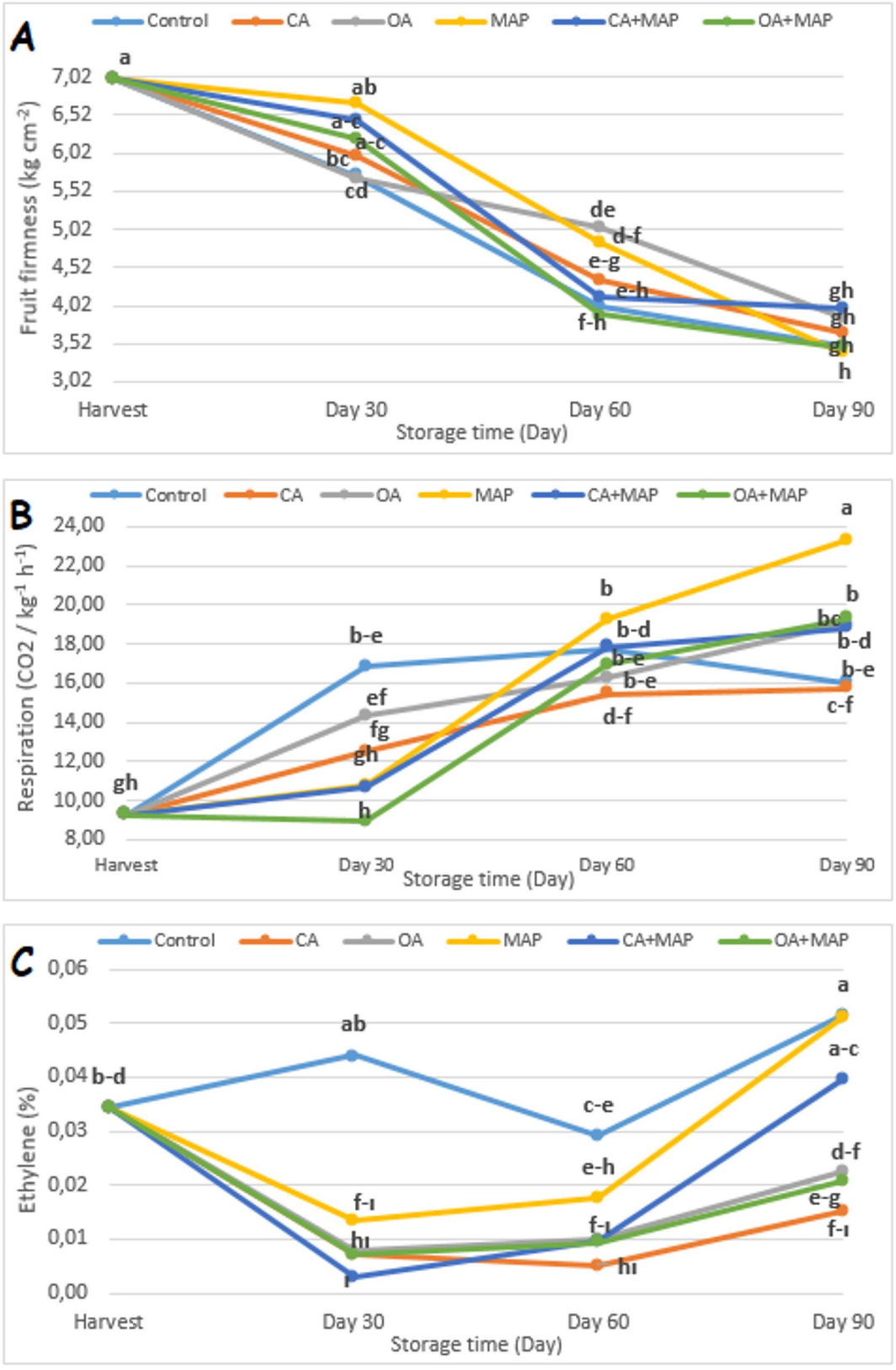


Fig. 2 Effect of oxalic and cirtic acid treatments on fruit firmness (**A**), respiration rate (**B**) and ethylene (**C**) of persimmons. Significant differences between treatment groups are indicated by letters ($P < 0.05$). CA: Citric acid, OA: Oxalic acid, MAP : Modified Atmosphere Packaging

Table 1 Effect of oxalic and citric acid treatments on fruit colour of persimmons

Storage time		L*	a*	b*	Chroma	Hue
Harvest		68.67 a	11.34 c	69.57 a	70.61 a	80.54 a
30th day		67.15 b	16.23 b	68.10 b	70.15 a	76.26 b
60th day		63.57 c	19.66 a	62.20 c	65.67 b	72.20 c
90th day		58.88 d	20.68 a	53.80 d	57.43 c	69.71 d
Treatments						
Control		65.01 ab	16.48 ab	65.39 a	67.70 a	75.54 a
CA		65.50 a	17.58 a	64.19 ab	66.81 ab	74.65 a
OA		65.46 a	17.22 ab	64.56 a	67.04 ab	74.38 ab
MAP		63.84 c	15.85 b	63.69 ab	65.93 bc	75.59 a
CA + MAP		64.15 bc	16.72 ab	62.52 b	64.87 cd	74.91 a
OA + MAP		63.45 c	18.02 a	60.16 c	63.43 d	72.98 b
Storage time × Treatments						
Harvest		68.67 a	11.35 g	69.57 a	70.61 a-c	80.54 a
30th day	Control	67.55 a-c	14.53 fg	69.14 a	70.73 a-c	78.18 ab
	CA	68.09 ab	15.27 e-g	68.98 a	70.73 a-c	77.63 ab
	OA	67.45 a-c	16.45 d-f	67.73 a	69.78 a-c	74.39 b-d
	MAP	66.35 a-d	14.88 fg	69.26 a	70.93 ab	77.91 ab
	CA + MAP	68.05 ab	17.14 c-f	69.47 a	71.64 a	76.18 bc
	OA + MAP	65.43 b-e	19.13 a-e	64.00 bc	67.09 b-d	73.28 c-e
60th day	Control	63.96 d-f	18.04 b-f	65.38 a-c	67.90 a-d	74.48 b-d
	CA	65.59 a-e	21.04 a-c	62.92 c	66.68 cd	71.05 d-g
	OA	64.94 b-e	20.58 a-c	63.43 bc	66.78 b-d	71.99 d-g
	MAP	62.58 e-g	17.27 c-f	62.92 c	65.49 de	74.66 b-d
	CA + MAP	64.37 c-e	19.01 a-e	62.46 c	65.46 de	72.88 c-f
	OA + MAP	60.01 gh	22.05 ab	56.10 d	61.72 ef	68.12 g
90th day	Control	59.89 gh	22.01 ab	57.47 d	61.57 ef	68.96 fg
	CA	59.64 gh	22.69 a	55.28 de	59.21 fg	69.41 e-g
	OA	60.78 f-h	20.52 a-d	57.51 d	61.01 f	70.61 d-g
	MAP	57.75 hı	19.90 a-d	53.00 d-f	56.70 gh	69.25 e-g
	CA + MAP	55.51 ı	19.40 a-d	48.60 f	51.79 ı	70.05 e-g
	OA + MAP	59.70 gh	19.57 a-d	50.98 ef	54.32 hı	69.97 e-g
ANOVA						
F Storage time		326.67 ***	190.41 ***	430.54 ***	381.86 ***	231.36 ***
F Treatments		8.78 ***	4.44 **	19.35 ***	17.04 ***	6.30 ***
F Storage time x MAP, CA and OA		5.60 ***	3.46 **	6.35 ***	6.95 ***	3.85 ***

Means in columns with the same letter do not differ according to Tukey's test at $p < 0.05$ *CA* Citric acid, *OA* Oxalic acid, *MAP* Modified Atmosphere Packaging

and reached the lowest level on the 90th day of the storage. This indicates that the fruit began to become darker due to the ripening and aging processes during storage. From day 30 onwards, the a* value increased, indicating that the fruit became more reddish. The highest a* value was observed on the 90th of the storage. This may indicate that red pigments increased as the fruit ripened. The b* value also decreased during storage, meaning that the fruit shifted from yellow to more blue tones. This may indicate that the color saturation has decreased due to the wilting or aging processes of the fruit and that yellow pigments have been lost. Chroma indicates the intensity of the color. As storage time increased, the Chroma value decreased, indicating a decrease in the intensity of the color. The hue value expresses the angle of the color tone.

In persimmons, the fruit peel color changes from green-orange to yellow-orange and red-orange during the ripening and aging process. Therefore, the increase in fruit peel a* value and the decrease in fruit peel Hue value indicate that fruit ripening is progressing [19]. The decrease in persimmon peel L* value indicates that the fruit pericarp turned black or brown due to cold damage during cold storage [56]. CA and OA applications successfully preserved L* value during storage compared to the control. Control and MAP applications on the 30th day of storage, MAP and control applications on the 60th day of storage, and CA + MAP, OA + MAP and MAP applications on the 90th day of storage effectively maintained the a* value. Control and MAP applications on the 30th day of storage, MAP and control applications on the 60th day of storage, and OA and CA + MAP applications

on the 90th day of storage effectively maintained the hue value. In the control group, the less changes in color parameters were observed during the storage period. This indicates that the control group generally showed a more stable color change and less aging. Ethylene production can be slowed down in cold environments with changing atmospheres and fruit color development can be delayed [57]. Additionally, ethylene production in fruits can lead to changes in skin color by increasing the activity of hydrolyzing enzymes, improving respiration intensity, and degrading chlorophyll and carotenoid pigments [58]. However, persimmon is sensitive to cold damage and does not show significant color changes due to the cold effect despite high ethylene production in cold storage conditions [58, 59]. This situation explains why control and other applications showed similar results on fruit peel color values in the current study.

Packaging gas composition

On the 30th day of the storage, no significant change in oxygen levels was observed in all treatments. This indicates that the oxygen levels in the package remained constant during the first 30 days and that each treatment had no significant effect on oxygen levels initially. This indicates that the packaging conditions and environment were initially stable enough. On the 60th day of the storage, the decrease in the amount of oxygen in the package was observed in all applications. This shows that the oxygen in the package decreases over time as a result of the metabolic activities and oxygen consumption of the fruits and that this is a normal storage process. However, each treatment had different effects on oxygen consumption. The highest oxygen content was recorded in fruits treated with OA + MAP. This suggests that OA and MAP treatment increased oxygen consumption less, allowing more oxygen to remain in the package. The lowest oxygen content was observed in fruits treated with CA + MAP. This shows that CA and MAP accelerated oxygen consumption, causing oxygen to be depleted more quickly in the package. CA may have increased the metabolic rate of the fruits, leading to faster oxygen consumption. At the end of the storage, an increase in oxygen content was observed in MAP and CA + MAP treatments, suggesting that the effect of MAP on limiting oxygen consumption of fruits is strong and its combination with CA can temporarily stabilize oxygen consumption. MAP generally slows down the oxygen consumption of fruits by providing low oxygen and high carbon dioxide environments, which may have caused increased oxygen levels. A decrease in oxygen levels was noted in fruits treated with OA + MAP (Fig. 3A). This suggests that OA causes oxygen to be depleted more rapidly in the package, and OA and MAP may have increased this effect. OA acid is known as a compound that increases the metabolic rate of fruits [60]. In this study, it was observed that the amount of oxygen decreased the most in fruits treated with OA and MAP (Fig. 3A). OA can trigger oxidative processes that can lead to rapid oxygen depletion. OA's anti-aging and antioxidant properties in plants can accelerate oxygen consumption by increasing the metabolic rate of fruits [22]. CA is an effective ingredient to limit oxygen consumption [61]. In particular, the combination of CA + MAP temporarily stabilized oxygen consumption. This may be a result of the stabilizing effect of CA on fruit metabolism. CA may help prevent rapid oxygen depletion by increasing antioxidant enzyme activity in fruit cells [62]. MAP application is a technique generally used to slow down the oxygen consumption of fruits and vegetables. In particular, low oxygen and high carbon dioxide environments slow down the metabolic rate of fruits [63].

Up to the 60th day of the storage, the increase in the amount of carbon dioxide was observed in all applications. This increase indicates that the metabolic activities of the fruits continue and that carbon dioxide production increases during this process. As a result of the respiratory activities of the fruits, carbon dioxide production increases in parallel with oxygen consumption, which leads to accumulation in the packaging. This increase is related to the aging process of the fruits, since fruit respiration increases with increasing storage time. During this process, the carbon dioxide production of the fruits can accumulate in the environment and reach high levels in the packaging. During the storage period, significant differences in carbon dioxide levels were observed in different treatments. This indicates that different treatments affect the respiration rate of the fruits and therefore the carbon dioxide production in different ways. On the 30th and 90th of the storage, the highest carbon dioxide levels were recorded in fruits treated with OA + MAP. This suggests that OA and MAP may have increased the respiration rate of the fruits, resulting in more carbon dioxide production. OA may have an accelerating effect on fruit respiration, which may have increased carbon dioxide production, leading to higher levels accumulating in the packaging. On days 60, the highest carbon dioxide levels were observed in fruits treated with CA + MAP. It is possible that CA may have also increased the production of carbon dioxide by accelerating the metabolism of fruits, especially on these days. This may have caused CA to affect the respiration of fruits, resulting in high carbon dioxide levels. Carbon dioxide levels were lowest in MAP-treated fruits. During storage, OA + MAP and CA + MAP applications recorded the highest values in carbon dioxide production while MAP was the application that kept carbon dioxide levels the lowest. The increase in carbon dioxide during storage is directly related to the respiration activities of the fruits.

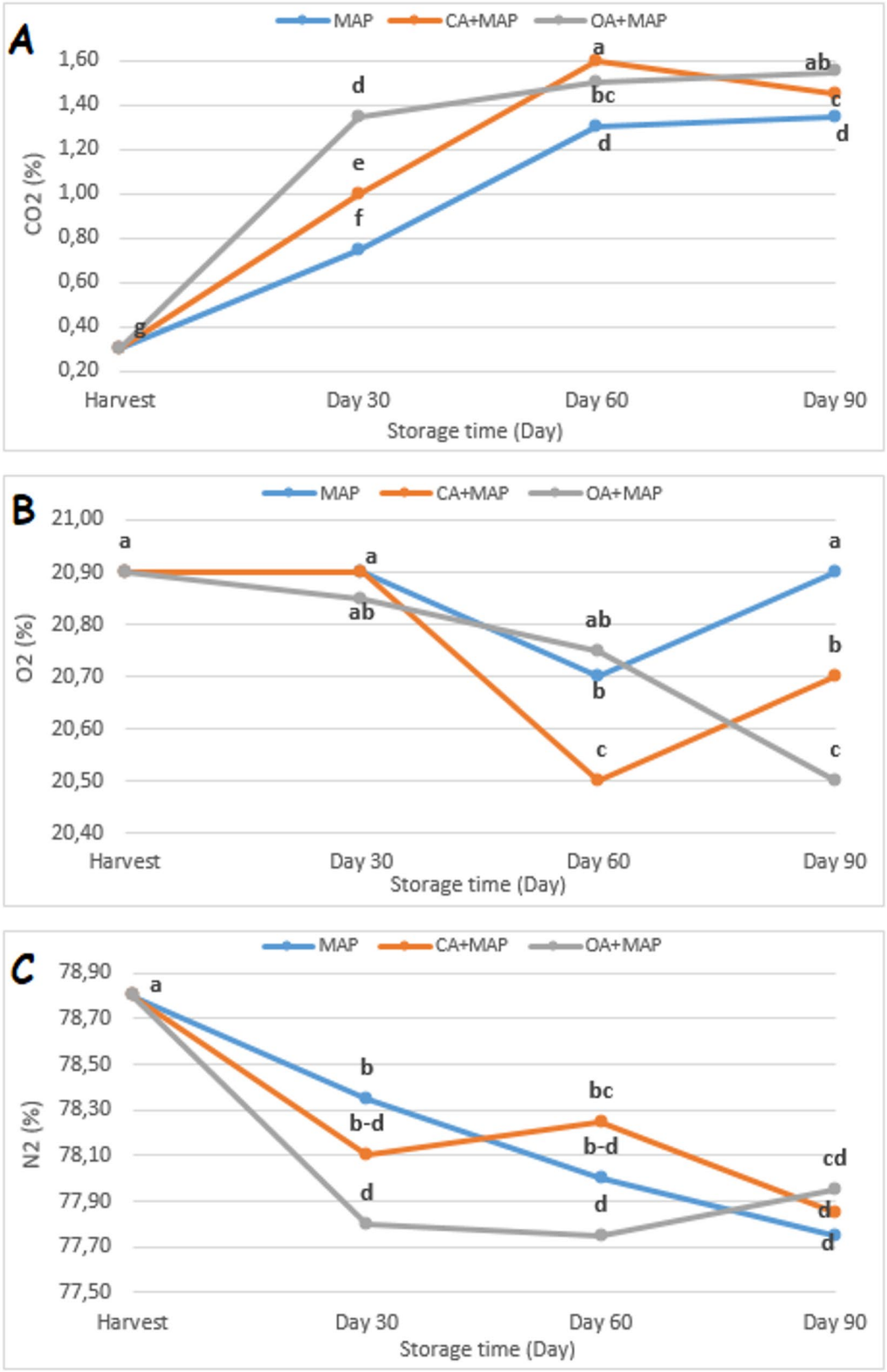


Fig. 3 Effect of oxalic and cirtic acid treatments on fruit firmness (**A**), respiration rate (**B**) and ethylene (**C**) of persimmons. Significant differences between treatment groups are indicated by letters ($P < 0.05$). CA: Citric acid, OA: Oxalic acid, MAP : Modified Atmosphere Packaging

This increase shows that the metabolic processes of the fruits continue and these processes accelerate as the storage period progresses (Fig. 3B). It has been confirmed in various studies that OA has an effect of increasing fruit respiration. Huang et al. [64] studies show that OA accelerates the ripening of banana fruit, leading to more carbon dioxide production. In addition, Zheng and Tian [65] state that OA prevents the spoilage of mango fruits during cold storage. Koyuncu et al. [66] research reveals that OA affects the biological components and quality of fruits such as pomegranate, providing better quality under controlled atmosphere storage conditions. CA has been observed to have a slowing effect on fruit respiration. Liu et al. [25] reported that CA improved fruit quality by affecting the ripening process of cherimoya fruit and the expression of cell wall-related genes. In addition, Terdbaramee et al. [48] reported that CA preserved fruit quality by controlling browning of lychee fruit during cold storage. These studies suggest that the effects of CA, which slows down fruit respiration, may help limit carbon dioxide accumulation. MAP application stands out as an effective method for limiting fruit respiration. Khan et al. [67] stated that MAP application protects fruit quality by preventing postharvest decay and browning of long pineapple fruits. In another study by Khan and Singh [68], the combination of MAP application and 1-methylcyclopropene (1-MCP) improved the quality of Japanese plums by affecting ethylene biosynthesis and fruit softening during cold storage.

On the 30th day of storage, the decrease in nitrogen content was observed in all treatments. This may explain some changes in the gas composition in the package due to the continuation of the respiration processes of the fruits. In particular, as a result of the metabolic activities of the fruits, oxygen consumption and carbon dioxide production increase while the decrease in nitrogen content is a natural process. The highest nitrogen level was recorded with MAP application. MAP generally creates low oxygen and high carbon dioxide environments, which results in less nitrogen consumption or loss. Therefore, nitrogen levels remained higher in MAP-applied fruits. The lowest nitrogen level was observed in fruits treated with OA + MAP. The increase in the metabolic rate of fruits due to the effect of OA may have caused faster nitrogen consumption. In addition, MAP application may have caused more nitrogen loss in the environment. On the 60th day of the storage, no significant change was observed in the amount of nitrogen with OA + MAP application. This shows that OA and MAP application have a balancing effect on nitrogen levels. The acceleration of metabolism of fruits due to the effect of OA may have caused nitrogen levels to be kept stable. The decrease in nitrogen amount was recorded with MAP application. This may suggest that MAP application causes more nitrogen displacement in the package because it limits oxygen consumption and increases carbon dioxide production. The increase in nitrogen was observed in the CA + MAP application. The change in the metabolism of the fruits and the different respiration rates due to the effect of CA may have caused more nitrogen accumulation. At the end of the storage, the decrease was observed in the MAP and CA + MAP applications. The combination of CA and MAP may have also affected the respiration rate of the fruits, causing more nitrogen depletion. An increase in nitrogen was recorded in the OA + MAP application. (Fig. 3C). This suggests that the combined use of OA and MAP changed the metabolism of the fruits, resulting in greater accumulation of nitrogen. OA may have had the effect of slowing down fruit respiration, especially towards the end of storage, which may have resulted in more nitrogen remaining in the medium. In fruits such as persimmon, which are rich in bioactive components such as carotenoids, tannins and ascorbic acid, the respiration rate is high and this rate affects the gas compositions [69, 70]. The fact that the nitrogen level remains higher with MAP application can be attributed to the fact that this method increases carbon dioxide production by limiting oxygen consumption in the environment [71, 72]. OA and CA applications are known to be effective in preserving fruit quality. These acids delay fruit ripening and prevent fruit aging with their antioxidant properties [73]. OA application prevents off-flavors and helps the fruit stay fresh for longer periods, especially by ensuring that fruit pigments remain stable [21, 74]. CA contributes to the preservation of quality, especially by regulating fruit acidity. Positive effects of CA applications have been observed in different fruit species (Cherimoya, Lichi, etc.) [63, 75]. It can be predicted that CA may have similar effects on quality preservation in persimmon. This can slow down fruit respiration and ensure that nitrogen consumption occurs in a more controlled manner. The study results are consistent with similar studies in the literature [22, 71, 74] and indicate that the combination of OA and MAP is an effective method for preserving the postharvest quality of climacteric fruits such as persimmon.

Total phenolic content

Total phenolic content in fruits in the control treatment did not show any significant change during the storage period until the 60th day of storage. However, after 60th day, phenolic content decreased significantly and the lowest phenolic content was observed in fruits in the control group at the end of storage. In fruits treated with CA, no significant change in total phenolic content was observed during the storage period. At the end of the storage, this group had the highest phenolic content compared to other treatments. This result reveals that CA has the

potential to preserve the phenolic components of fruits for a longer period. In MAP treatment, total phenolic content decreased significantly during the storage period. This may suggest that MAP application has a limited effect on preserving the phenolic compounds of fruits or that this method may not be ideal for long-term storage. At the end of the storage, MAP-applied fruits had the lowest phenolic content. This indicates that MAP application performed below expectations in terms of fruit preservation and was insufficient in preserving phenolic contents. The phenolic content also decreased during the storage period in fruits treated with OA. However, at the end of the storage, the highest phenolic content was observed in fruits treated with OA. This suggests that OA may help preserve phenolic compounds and this compound improves fruit quality during storage. There was a significant decrease in phenolic content in the application with the combination of CA and MAP (Fig. 4A). The stability of phenolic compounds is directly related to the freshness period of fruits, and phenolic compounds

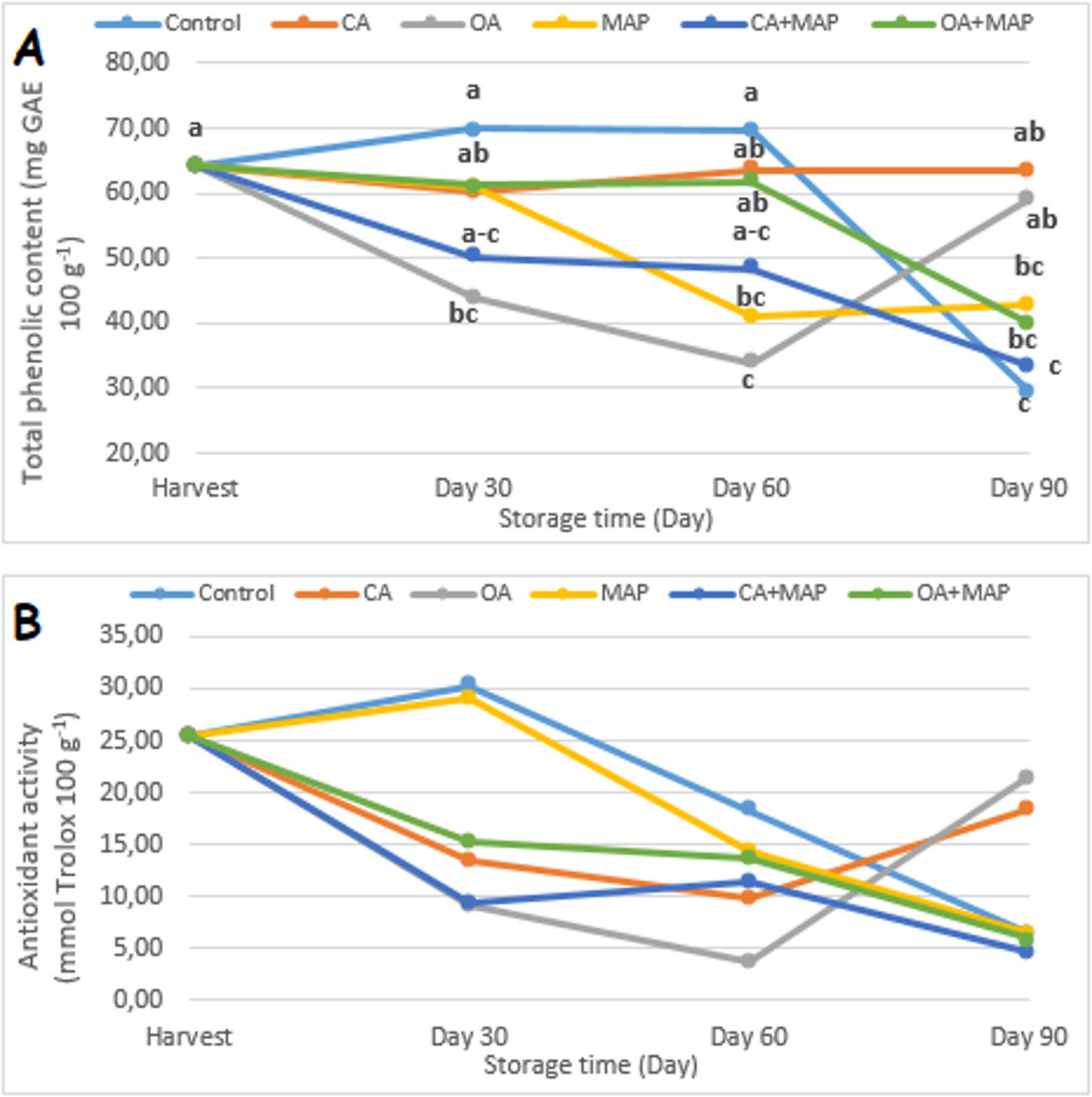


Fig. 4 Effect of oxalic and citric acid treatments on total phenolics (**A**), and antioxidant activity (**B**) of persimmons. Significant differences between treatment groups are indicated by letters ($P < 0.05$). CA: Citric acid, OA: Oxalic acid, MAP : Modified Atmosphere Packaging

are known to have antioxidant properties that increase fruit quality [61]. In fruits treated with CA, no significant change in total phenolic content was observed. This finding indicates the potential of CA to stabilize fruit phenolic compounds. Liu et al. [25] reported that CA improved postharvest quality in sliced lotus roots and Terdbaramee et al. [48] and Kumar et al. [26] in lychee fruits. The antioxidant properties of CA can prevent the degradation of phenolic compounds during fruit storage [62]. The antioxidant properties of OA can improve the quality of fruits during storage. Zheng et al. [60] and Ali et al. [76] stated that OA has an anti-browning effect on fruits and protects fruit quality by reducing oxidation reactions. In addition, OA has been reported to have delaying fruit ripening and anti-aging effects [76].

Antioxidant activity

In the study, the antioxidant activity increases were observed in fruits in MAP and control applications on the 30th day of storage. It can be said that MAP application can improve antioxidant activity by reducing the oxygen level and increasing the carbon dioxide level of the fruits (Fig. 4B). MAP may help slow down biochemical reactions within the fruit, especially oxidation. This suggests that low oxygen and high carbon dioxide environments may have an effect of increasing antioxidant activity [65]. On the 60th day of the storage, the significant increase in antioxidant activity was observed, especially in fruits treated with CA and OA (Fig. 4B). This shows that OAacid and CA are effective in preventing oxidation and stabilizing fruit pigments by inhibiting the activity of polyphenol oxidase enzyme in fruit cells [21]. OA's inhibition of fruit softening by reducing the activity of polygalacturonase enzyme in fruit cells and increasing the activities of antioxidant enzymes are also important mechanisms in this process [22, 77]. On the other hand, the decrease in antioxidant activity was observed in fruits from the MAP and control groups. This indicates that oxidative stress increased over time in these groups and the capacity to provide antioxidant protection was insufficient (Fig. 4B). The effects of oxidative stress on fruits in the MAP and control groups may be a result of natural processes that lead to deterioration over time. These conditions, where oxidative stress increases, reveal that low oxygen levels and long-term storage lead to weakening of fruit cells [78, 79]. As a result, the change in antioxidant activity during storage clearly reflects the effects of the applications on the fight against oxidative stress in fruits. In this context, especially CA and OA applications stand out as the most effective methods in increasing antioxidant activity. CA and OA are compounds that can be effective in preserving fruit quality and extending shelf life. The decrease in antioxidant activity in the MAP and control groups shows that these methods do not sufficiently protect fruits against oxidative stress (Fig. 4B).

Organic acids

The amount of oxalic acid increased during the storage period. A significant increase was observed from the 30th day to the 90th day and the highest value was obtained on the 90th day. This may indicate that the amount of oxalic acid increased with the ripening of the fruits. The amount of citric acid decreased with the storage period. This decrease continued on the 30th day and reached the lowest levels on the 60th and 90th days. This shows that the acidic properties of the fruits decreased over time. The amount of malic acid increased during the storage period. This increase accelerated especially after the 30th day and reached the highest level on the 90th day of storage. Malic acid is generally known as the main component of the acidic taste of fruits and this increase may indicate changes in the taste of fruits. A variable situation was observed in the amount of succinic acid with storage time. Although there was an increase from the 30th day, this increase stopped after the 60th day and stabilized on the 90th day of storage. This indicates that succinic acid reaches a constant level with fruit ripening. The amount of fumaric acid increased during storage and the highest value was recorded on the 90th day of storage. The increase in fumaric acid reflects the change in acidic structure of the fruits with aging. The amount of tartaric acid fluctuated during storage. A significant increase was observed on the 30th and 60th days, while it remained at high levels on the 90th day of storage. The significant changes were observed in some acid components in the control group compared to the other groups. Oxalic acid and tartaric acid levels remained somewhat more stable whereas malic acid levels increased less than the other treatment groups. CA application generally increased acidic components. Significant increases were observed especially in malic acid and tartaric acid levels. The amount of malic acid was quite high on the 90th day of storage, which may indicate that fruit ripening and acidic changes during ripening were accelerated by CA application. OA application also caused an increase in acidic components. Significant increases were observed especially in malic acid and tartaric acid values. This treatment may have caused an increase in acidic compounds during storage by preserving the acidic structure of the fruit. MAP application is an effective method to control the acidic components of fruits. It was observed that MAP application generally increased the amounts of oxalic acid and malic acid less than the other groups. This may indicate the effect of MAP application in slowing down the ripening process of the fruits. The combination of CA and MAP led to a large increase in the level of tartaric acid in particular. The significant increase in

malic acid values was also observed, suggesting that the combined treatment method was effective in preserving acidic compounds. The combination of OA and MAP led to an increase in the acidic components of the fruits, and significant increases were observed in compounds such as tartaric acid. This shows that the combination of OA and MAP has a strong effect in preserving fruit acids. The statistically significant differences were found between storage time and treatment methods for all acid components, indicating that different storage times and treatment methods had significant effects on fruit acid components. The storage time-treatment interaction was also statistically significant. This indicates that the effects of treatment methods changed with storage time and the effect of treatment method on fruit acid components varied during storage time (Table 2). OA plays an important role, especially in relation to the fruit ripening process and is considered an important component in preventing enzymatic browning and preserving fruit quality after harvest [64, 76]. OA can affect the taste of fruits by causing cellular changes and an increase in acidic compounds during fruit ripening [77]. It has also been shown that OA applications can increase the acidic structure of fruits during storage [22]. CA plays an important role in terms of its effects on fruit ripening and acidic components. Liu et al. [25] stated that CA and chitosan coatings are effective in controlling fruit ripening. However, it has also been observed that CA can improve fruit quality by regulating enzymatic activities during the ripening process [62]. The increase in malic acid in the study can be considered as a result of the fruit maintaining its acidic properties and the ripening process [64]. This increase in malic acid may reflect changes in fruit taste and, similar to CA, may be an effective component in preserving

Table 2 Effect of oxalic and citric acid treatments on organic acids of persimmons

Storage time		Oxalic Acid	Citric Acid	Malic Acid	Succinic Acid	Fumaric Acid	Tartaric Acid
Harvest		1.53 c	18.96 a	109.24 d	3.24 b	0.69 b	3.00 b
30th day		2.05 b	11.13 ab	198.04 c	21.93 a	0.81 b	44.96 a
60th day		1.61 bc	6.50 b	277.56 b	20.65 a	1.25 b	36.42 a
90th day		3.73 a	6.11 b	430.49 a	17.96 a	10.78 a	47.07 a
Treatments							
Control		2.21 ab	7.50	220.78 cd	12.43 bc	7.71 a	18.35 b
CA		2.45 a	10.70	253.38 bc	17.72 ab	1.16 b	21.24 b
OA		2.10 ab	10.44	301.00 a	17.19 ab	1.39 b	28.41 b
MAP		1.85 b	8.89	210.48 d	10.50 c	7.42 a	24.64 b
CA + MAP		2.31 a	14.54	256.54 bc	20.07 a	1.17 b	50 85 a
OA + MAP		2.46 a	11.99	280.83 ab	17.77 ab	1.45 b	53.67 a
Storage time × Treatments							
Harvest		1.53 d	18.96	109.24 k	3.24 c	0.69 b	3.00 e
30th day	Control	2.11 b-d	0.65	156.03 jk	13.70 a-c	1.46 b	22.75 c-e
	CA	2.37 b-d	12.21	257.39 f-j	27.94 a	0.90 b	13.51 e
	OA	3.18 a-c	16.82	277.97 e-ı	28.15 a	1.22 b	36.28 b-e
	MAP	1.14 d	2.34	119.57 k	9.89 bc	0.41 b	45.71 a-e
	CA + MAP	1.64 cd	18.43	188.02 ı-k	27.39 a	0.76 b	85.34 a
	OA + MAP	1.84 cd	16.36	189.25 ı-k	24.53 ab	0.10 b	66.19 a-d
60th day	Control	1.52 d	4.41	303.31 e-h	17.66 a-c	0.48 b	29.26 b-e
	CA	1.58 cd	8.13	207.24 g-k	23.34 ab	0.96 b	24.02 c-e
	OA	2.11 b-d	1.27	339.67 c-f	21.15 ab	1.41 b	24.56 c-e
	MAP	1.05 d	7.73	196.03 h-k	14.03 a-c	1.30 b	31.59 b-e
	CA + MAP	1.35 d	12.57	252.76 f-j	26.35 a	1.02 b	39.23 a-e
	OA + MAP	2.08 cd	4.89	366.38 b-e	21.38 ab	2.36 b	69.83 a-c
90th day	Control	3.69 ab	5.99	314.52 d-g	15.14 a-c	28.22 a	18.37 de
	CA	4.30 a	3.52	439.63 a-c	16.36 a-c	2.10 b	44.45 a-e
	OA	1.59 cd	4.71	477.13 a	16.22 a-c	2.23 b	49.81 a-e
	MAP	3.69 ab	6.52	417.08 a-d	14.84 a-c	27.29 a	18.27 e
	CA + MAP	4.72 a	8.20	476.12 a	23.29 ab	2.20 b	75.82 ab
	OA + MAP	4.39 a	7.74	458.43 ab	21.92 ab	2.66 b	75.67 ab
F Storage time		72.67 ***	7.77 ***	285.35 ***	58.66 ***	9.74 ***	32.50 ***
F Treatments		2.44 *	0.87 ^{ns}	12.14 ***	7.03 ***	2.80 *	12.34 ***
F Storage time x MAP, CA and OA		6.58 ***	0.66 ^{ns}	6.42 ***	1.90 *	2.91 ***	3.19 ***

Means in columns with the same letter do not differ according to Tukey's test at $p < 0.05$ *CA* Citric acid, *OA* Oxalic acid, *MAP* Modified Atmosphere Packaging

fruit quality. MAP application is an important treatment method that controls fruit acidic components. The effect of MAP application on slowing down fruit ripening shows that the amounts of oxalic acid and malic acid increased less than the other groups. This suggests that MAP provides a stabilizing and preserving effect on fruit acid components [67]. It has been stated that MAP can ensure long-term preservation of fruit quality by increasing the stability of oxalic acid and other acidic components [68]. In addition, studies have shown that the combination of OA and MAP has a strong effect on preserving the acid content in the fruit [66, 67].

Heatmap and PCA analyses

In this study, Heatmap and PCA analysis were performed to statistically reveal the effects of storage period and MAP, CA, OA, CA + MAP and OA + MAP applications on the changes in the quality characteristics and organic acid contents of persimmon fruit during storage and to determine the effectiveness of the examined characteristics. Heatmap analysis reveals the evaluation of all applications and characteristics within the scope of the study whereas PCA analysis reveals the effectiveness of the examined characteristics within the scope of the study. Heatmap and PCA analysis graphs of storage period of applications in persimmon fruits are presented in Fig. 5A and B. According to the heatmap analysis results, the storage periods were divided into two groups. Harvest alone constituted one group while storage periods constituted the other group. The examined characteristics were also divided into two groups. Antioxidant activity, citric acid, total phenolic, fruit firmness, hue, chroma, b* and L* constituted one group, while other parameters constituted the other group. At harvest time, antioxidant activity, citric aicd, total phenolic, fruit firmness, hue, chroma, b*, L*, titratable acidity and ethylene parameters had the highest values. When we examined the storage periods, succenic, tartaric, titratable acidity, L*, b* and chroma parameters had the highest values on the 30th day of storage, respiration, total soluble solids, pH, succenic parameters on the 60th day and weight loss, a*, respiration, total soluble solids, pH, tartaric, ethylene, oxalic and fumaric parameters had the highest values on the 90th da of the storage. In general, as storage time increased, color values, total phenolic and antioxidant contents decreased. As a result of PCA analysis, 79.4% of the examined properties were explained by PCA1 and 17.3% by PCA2.

Heatmap and PCA analysis graphs of MAP, CA, OA, CA + MAP and OA + MAP applications in persimmon fruits are given in Fig. 5C and D. Applications were formed into two groups according to heatmap analysis. Control and MAP application formed one group, CA, OA, CA + MAP and OA + MAP applications formed the other group. The parameters examined in the study were divided into two groups. Tartaric aicd, succenic acid, citric acid, malic acid, oxalic acid, a*, total soluble solids, fruit firmness and pH parameters formed one group while other parameters formed the other group. According to the heatmap analysis, in the control application, the parameters except tartaric acid, succenic acid, citric acid, malic acid, oxalic acid, a*, fruit firmness and pH parameters exhibited high values. In MAP application, the highest values were found in hue, respiration, fumaric acid, antioxidant activity and fruit firmness, a* and oxalic acid parameters; CA application, weight loss, L*, b* chroma, titratable acidity, total phenolic and malic acid parameters; in OA application, weight loss, L*, b* and chroma parameters; CA + MAP application, c itriacidc, succenic acid and tartaric acid parameters; OA + MAP application, tartaric acid, malic acid, oxalic acis, a*, total soluble solids and pH. As a result of PCA analysis, 46.1% and 26.2% of the investigated properties were explained by PCA1 and PCA2, respectively. The effects of the applications on the investigated parameters within the scope of the study differed.

Heatmap and PCA analysis graphs of MAP, CA, OA, CA + MAP and OA + MAP applications and storage time interactions in persimmon fruits are given in Fig. 5E and F. According to the Heatmap analysis, application interactions were divided into two main groups, while each group was divided into two subgroups. In the heatmap analysis graph, it is seen that the control 90th day, MAP 90th day, CA 60th day, OA 60th day, OA + MAP 60th day, CA + MAP 90th day and OA + MAP 90th day applications form one group while the other application and storage period interactions form separate groups. The characteristics examined on the application dose and storage period interactions are divided into two groups. Fruit firmness, hue, chroma, b*, L*, antioxidant activity, total phenolic and titratable acidity parameters formed one group while other parameters formed the second group. Applications and storage time interactions had different effects on the parameters examined in the study. As a result of PCA analysis of application dose and storage time interactions.

Heatmap and PCA analysis are statistical methods commonly used by researchers to determine the effectiveness of the traits examined in the studies and to interpret the study results. Heatmap and PCA analysis were used to reveal the changes in the quality traits and organic acid contents of fruits due to MAP, CA and OA applications during storage in many fruit species. 47.0% of the examined characteristics were explained by PCA1 and 14.0% by PCA2. Quality traits and organic acids may differ depending on fruit species. However, the changes in fruit quality traits and organic acids of MAP, CA and OA applications during storage in nectarine [80],

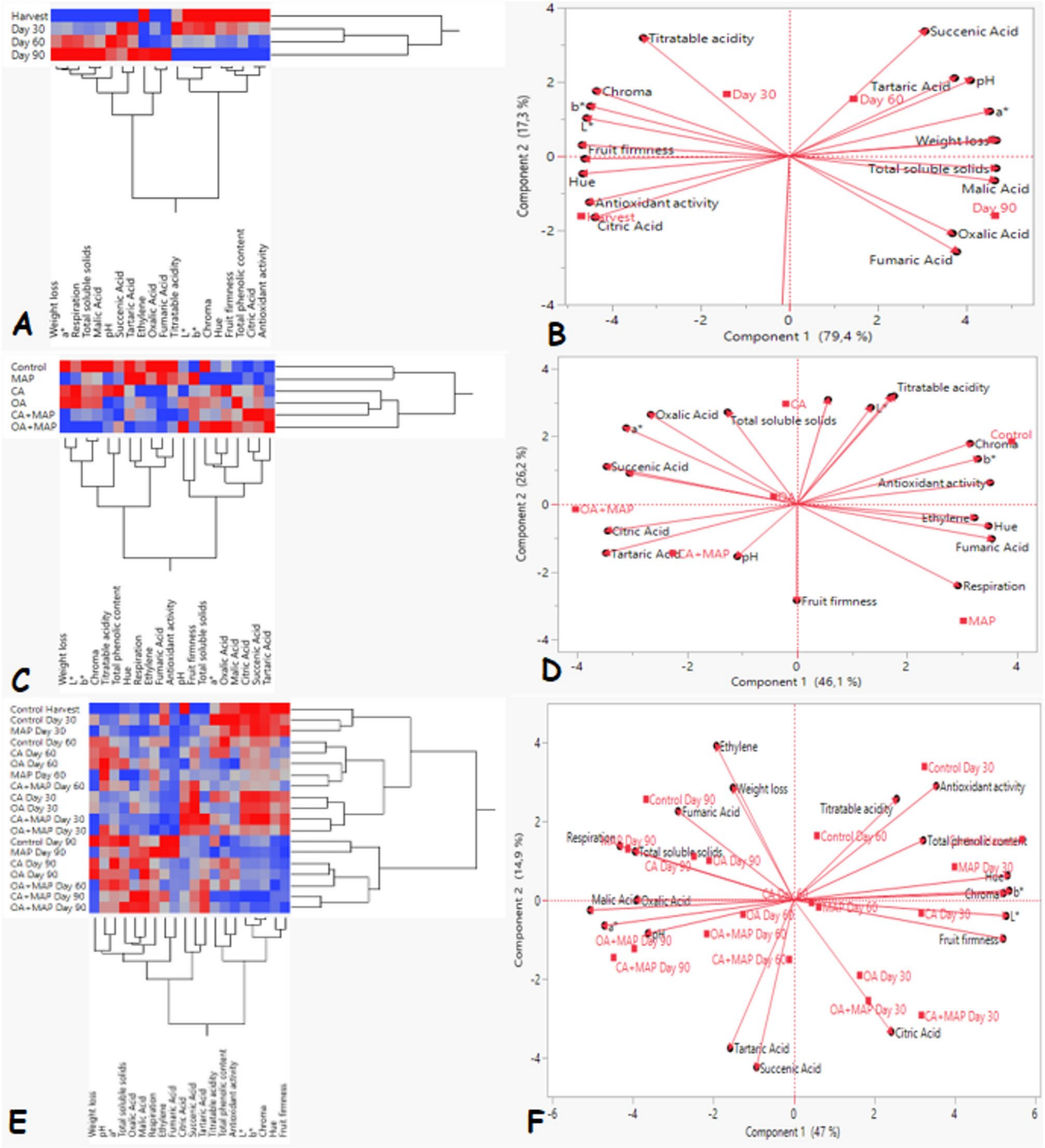


Fig. 5 Heatmap (**A**) and PCA analysis (**B**) of storage period of CA and OA applications, Heatmap (**C**) and PCA analysis (**D**) of MAP, CA, OA, CA + MAP and OA + MAP applications and Heatmap (**D**) and PCA analysis (**E**) of interactions of applications and storage period in persimmon fruits. CA: Citric acid, OA: Oxalic acid, MAP : Modified Atmosphere Packaging

blueberry [81], blackberry [82], and hawthorn [83] were parallel to our study results.

Conclusion

The study revealed the effects of different treatment methods applied during storage on the quality of persimmon. MAP and OA applications play an important role in preserving fruit quality. Especially the combination of OA + MAP offered many advantages such as reducing weight loss, preserving phenolic content and better preserving fruit color and firmness. This application was also effective in controlling fruit metabolism by suppressing ethylene production. In line with these findings, it is suggested that the use of MAP and OA may be an effective method in commercial fruit storage and transportation processes. In addition, it was revealed that OA applications were effective in increasing phenolic content and antioxidant activity and that this treatment method was beneficial in terms of fruit protection.

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Authors' contributions
O T: Methodology, validation, resources, software, formal analysis, investigation visualization, E K: Methodology, validation, resources, software, formal analysis, investigation visualization, E A: Conceptualization, methodology, software, visualization, validation, investigation, writing - review & editing. D A: Resources, software, formal analysis, methodology, A S: Resources, software, formal analysis, methodology.

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Data availability
Data sharing is not applicable to this article as all new created data are already contained within this article.

Declarations

Ethics approval and consent to participate
Plant materials were taken from growers' field in Siirt provinces. Necessary permissions were obtained verbally from the breeders for the use of the material. There is no problem in terms of ethics. In this sense, researchers are responsible for any problems that may occur and provide assurance.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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