Effect of postharvest oxalic acid treatment on ethylene production, quality parameters, and antioxidant potential of peach fruit during cold storage

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Abstract

The effects of postharvest oxalic acid (OA) treatment on ethylene production, fruit quality, bioactive compounds and antioxidant activity of peach fruit, were examined. Fruits were treated with oxalic acid immediately after harvest and stored at 1° C and 90% relative humidity for 28 days. The oxalic acid treated peach fruit exhibited significantly lower levels of ethylene production, pH, total soluble solids and weight loss and higher levels of firmness and titratable acidity than control. Also, OA treated fruit exhibited significantly higher total antioxidant capacity, which resulted from higher total phenols and flavonoids accumulation. During storage, activity of peroxidase, catalase, and superoxide dismutase enzymes increased in both control and treated peaches, and peroxidase and superoxide dismutase activities in OA treated fruit were significantly greater than those in control. But, there was no significant difference in catalase activity between OA treated and control fruit. Results suggested that OA treatments could be a promising strategy to delay softening and enhance the phenolic content and antioxidant activity of peaches.

Key words: antioxidant enzymes; oxalic acid; phenol; *Prunus persica* L.; postharvest; quality attributes

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Introduction

Peach (*Prunus persica* L.) is one of the most important horticultural crops in the world because of its attractive taste and nutritive value (Nunes, 2008). Different varieties of peaches contain highly variable concentrations of ascorbic acid, carotenoids, and phenolic compounds which are good sources of antioxidants (Gil et al., 2002; Tomas-barberan et al., 2001). Peach fruit is highly perishable and deteriorates quickly during storage (Nunes, 2008). Rapid ripening of peach fruit at marketing temperatures and the concomitant increase in their susceptibility to decay by postharvest pathogens limits their life after harvest to five days or less (Tonini and Tura, 1998).

Postharvest strategies such as heat, intermittent warming, gamma irradiation, and treatment with chemicals such as aminoethoxyvinylglycine, 1-methylcyclopropene, calcium chloride, nitric oxide, salicylic acid, and methyl jasmonate have been presumed to extend

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the shelf life and quality of peaches (Cao et al., 2010; Zhu et al., 2010; Hussain et al., 2010; Hayama et al., 2008; Manganaris et al., 2007). In recent years, application of exogenous oxalic acid (OA), as an organic acid, at non-toxic concentrations has received much attention to extend the storage life of fruits and vegetables (Zheng et al., 2007a). It is the most effective anti-browning molecule on apple, banana, and litchi pericarp (Huang et al., 2013; Saengnil et al., 2006). It has been reported that exogenous OA markedly delayed ripening and softening of fruits such as peach (Zheng et al., 2007b), mango (Zheng et al., 2007a), plum (Wu et al., 2011), jujube (Wang et al., 2009) and sweet cherry (Valero et al., 2011).

The physiological effects of OA in decreasing ethylene production have been demonstrated in plum fruit during storage (Wu et al., 2011). Wang et al. (2009) found that reduced ethylene production in jujube fruit under OA treatment might be attributed to the reduced 1-aminocyclopropane-1-carboxylic acid synthase (ACS) activity. Whereas, Zheng et al. (2005) showed that the effect of OA in decreasing fruit decay incidence might be attributed to the delay of fruit ripening in mango fruit. Also, OA inhibits the progress of *Alternaria* rot in pear fruit during storage associated with an increase in phenyl alanine ammonia-lyase (PAL), polyphenoloxidase (PPO), and peroxidase (POX) enzymes activities (Tian et al., 2006). Antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase, glutathione reductase (GR), and antioxidant molecules such as vitamins C and E, flavonoids, and anthocyanins have been found to play crucial role in protecting the cells from the deleterious effects of reactive oxygen species (Hodges et al., 2004). Postharvest application of OA increased activity of antioxidant enzymes (superoxide dismutase, catalase, peroxidase, and ascorbate peroxidase) in peach fruit (Zheng et al., 2007b). Deng et al. (2015) treated muskmelons with OA and reported that OA treatments increased the activities of peroxidase, polyphenoloxidase, phenylalanine ammonia-lyase, superoxide dismutase, and promoted the accumulation of total phenolic, flavonoid, and lignin. Ruiz-Jimenez et al. (2014) reported that the artichokes treated with postharvest 1 mM oxalic acid delayed the deterioration process during storage by retarding weight loss, softening, color changes, and chlorophyll degradation. The aim of this study was to evaluate the effects of oxalic acid treatments on ethylene production, flesh firmness, titratable acidity, total soluble solids, pH, weight loss, total flavonoids, aphenolic contents, total antioxidant capacity assayed by DPPH, and FRAP and antioxidant enzymes such as superoxide dismutase, catalase, and peroxidase activities of peach fruit during cold storage.

Materials and Methods

Peach fruit (*Prunns persica* L. cv. Anjiry maleki) was harvested from a commercial orchard in Azarbayzan, Iran. The fruit was then transported to the laboratory and were divided into twelve groups of 40 peaches each. The peaches were dipped in distilled water (control) or in 1, 3 and 5 mM OA for 5 min. The treated peaches were then air-dried for approximately 60 min and stored at 1° C and 90% relative humidity for 28 days. At 7-day intervals, 5 peaches from each replicate were sampled, stored for a further 24 h at 20° C, and subjected to physicochemical analysis.

Quality attributes

Flesh firmness was measured using Effegi penetrometer (FT 011, Fujihira Industry Co. Ltd., Tokyo, Japan) with an 8 mm diameter flat probe. The pH values of solutions were monitored with a pH meter (HI221, Hanna, USA) (Zheng et al., 2007b). Total soluble solids (TSS) were determined using a digital refractometer (Atago Co., Tokyo, Japan). Total acidity (TA) was determined by titrating 10 ml of juice to pH 8.2 using 0.1 M NaOH and the results were expressed as gram of malic acid equivalent per 100 g of FW (Valero et al., 2011).

Weight loss

Weight loss was determined in each replication and was recorded initially and weekly during storage. Weight loss was calculated as $(W_0 - W_f)/ W_0 \times 100$, W_0 being the initial sample

weight and W_f the final sample weight. Results are reported as percentage weight loss.

Ethylene synthesis

Ethylene evolution was measured by placing two peaches in a one-liter glass jar hermetically sealed with a rubber stopper for 1 h at room temperature. One ml of the holder atmosphere was withdrawn with a gas syringe, and injected into gas chromatographs (Shimadzu, 14A, Japan), fitted with a flame ionization detector and an activated alumina column. The amount of ethylene was estimated by comparing it with an ethylene curve. The results were expressed in micro liters of ethylene released per kilogram of fruit per hour ($\mu L\ kg^{-1}h^{-1}$) (Hayama et al., 2008).

Assay of enzymes activities

Extraction of enzymes

Three-grams of flesh samples from 5 fruit in each treatment were homogenized in 9 ml sodium phosphate buffer (100 mM, pH 7) containing 0.2% of polyvinylpolypyrrolidone (PVPP) for determination of antioxidant enzymes activity. After centrifugation, at 14,000 g for 20 min at 4°C, the supernatant was used for the determination of the activities of Superoxide dismutase, Peroxidase and Catalase.

Superoxide dismutase assay

Superoxide dismutase (SOD) activity was determined by the method of Winterbourn et al. (1976) with some modifications. The assay mixture contained 50 mM sodium phosphate buffer (pH 7.8), 15 mM methionine, 80 µM nitroblue tetrazolium, 0.1 mM EDTA, 2 µM riboflavin, and 0.1 ml of enzyme extract. The mixture in tubes was placed 50 cm under four 15 W fluorescent lamps at room temperature for 15 min. One unit of SOD was defined as the amount of enzyme required to induce 50% inhibition of nitroblue tetrazolium reduction as measured at 560 nm, compared with control samples without enzyme aliquot.

Peroxidase assay

Peroxidase (POX) activity was assayed according to the method of Ghamsari et al. (2007). The assay mixture contained 3 ml of 0.1 M citrate-phosphate-borate buffer system (pH 7.0), 50 µl of 480mM guaiacol, 50 µl of 96 mM H_2O_2, and 50 µl of the extract. The increase in absorbance at 470 nm was recorded spectrophotometrically for 6 min. Activity of POX was calculated as enzyme protein required for the formation of one µM tetraguaiacol per min.

Catalase assay

Catalase (CAT) activity was assayed in a reaction solution composed of 50 mM citrate-phosphate-borate buffer, pH 7.0, to which 26 µl of 11.8 mM H_2O_2 and 50 µl of extracts were added. Decomposition of H_2O_2 was followed by a decrease in absorbance at 240 nm for 6 min. One unit of CAT was defined as the amount of enzyme that decomposes 1 µM of H_2O_2 per minute (Tayfi-Nasrabadi, 2008).

The protein content was measured according to the dye-binding method of Bradford (1976) using bovine serum albumin (BSA) as the standard protein. The specific activity of the enzymes was expressed as units per milligram protein.

DPPH radical scavenging activity

The DPPH scavenging activity of peach extracts was measured according to the method of Dehghan and Khoshkam (2012) with some modifications. Fruit extract (50 µL) was added to 1.95 ml of DPPH solution (0.1 mM in methanol). The mixture was shaken vigorously and kept in the dark at room temperature for 30 min. Absorbance of the mixture (As) was measured at 517 nm in a UV–visible spectrophotometer (T-60, PG Instrument UK). As a control, the absorbance of the blank solution of DPPH (2 ml) was also determined at 517 nm (Ac). The percentage of DPPH radical scavenging activity (RSA %) was calculated according to the following equation:

$$\mathrm{RSA}\,\% = \frac{100\,(\mathrm{AC} - \mathrm{AS})}{\mathrm{AC}}$$

Ferric reducing antioxidant power (FRAP)

The reducing power of peach extracts was determined by evaluating the transformation of $Fe^{3+} \rightarrow Fe^{2+}$ according to the method of Benzie and Strain (1999) with some modifications. FRAP reagent was prepared freshly by mixing 2.5 ml of solutions tripyridyl-S-triazine (TPTZ) (10 mM, dissolved in 40 mM HCl) and $FeCl_3$ (20 mM) in 25 ml of acetate buffer (300 mM concentration and 3.6 pH), the light blue reagent contained Fe^{3+}-TPTZ that changed to dark blue after interaction with antioxidants, which is explained by the presence of Fe^{2+}–TPTZ in the reagent. The reaction mixture was allowed to stand for 4 min at room temperature, and after vigorous shaking, the absorbance of the resulting solution was measured at 593 nm in a UV–visible spectrophotometer. FRAP values for extracts were achieved by standard calibration curve obtained using different concentrations (0–500 µM/l) of $FeSO4.7H_2O$.

Extraction and assay of phenolic content

Peach pulp (1 g) was homogenized with 8 ml of methanol (80%) and extracted for 24 h in the dark. Then centrifuged at 12000 × g for 20 min at 4° C. The phenolic content of the extract was determined according to the Folin- Ciocalteu method as described by Singleton and Rossi (1965) with some modifications. Briefly, 0.1 ml of extract was transferred into a test tube and mixed with 2 ml of 2% Na_2CO_3 and allowed to stand for 2 min at room temperature. For each sample 0.1 ml of 50% (v/v) Folin-Ciocalteu reagent was added and the reaction mixture was mixed and allowed to stand for 30 min in the dark. After incubation, absorbance was read at 720 nm. The total phenolic compound contents (µg/100g FW) were expressed as gallic acid equivalent and determined from the established standard curve of gallic acid at different concentrations.

Extraction and assay of flavonoids content

One gram of fruit pulp was homogenized with 8 ml of methanol and extracted for 24 h in the dark. Then the homogenate was centrifuged at 12000 × g for 20 min at 4° C. The flavonoid content of the peach extract was determined using a colorimetric assay (Kaijv et al., 2006). The absorbance of the solution versus a blank at 510 nm was measured immediately. The results were expressed as µM of quercetin equivalents per 100 g FW.

Statistical Analysis

The experiment was performed using a factorial design with OA treatment and storage time as the two factors. Data for the analytical determinations were subjected to analysis of variance. Mean comparisons were performed using Duncan's Multiple Range Test (P = 0.05). All analyses were performed with SPSS software package Version 14.0 (SPSS Inc., Chicago, IL, USA).

Results

Ethylene production

Postharvest OA treatments exhibited significant (P≤0.01) suppression and delay in the ethylene production during storage at 1° C. Ethylene production steadily increased from the beginning of the experiments and peaked in control fruit after 3 weeks of the storage. But OA treated fruit did not show any climacteric rise in ethylene production after 4 weeks of the storage. Amongst treated peaches, OA at 5 mM was recorded with lowest ethylene production during storage period. At the end of storage, ethylene production levels were 29.4% lower than in 5 mM OA-treated peaches in control (Fig. I).

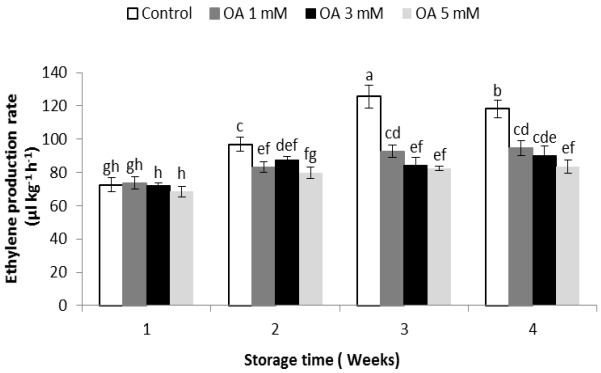

Fig. I. Effect of oxalic acid treatment (0, 1, 3, and 5 mM OA) on ethylene production of peach fruit stored at 1° C for 4 weeks; data shown are mean values ± SE (n = 3). Data followed by different letters are significantly different according to Duncan's multiple range test, P< 0.05.

Table 1
Effects of oxalic acid on firmness, weight loss, pH, total phenols (TP), and total flavonoids (TF) contents, peroxidase (POX), and Superoxide dismutase (SOD) activity in peach fruit during storage at 1˚C

Storage period (weeks)	Treatments	Firmness (N)	Weight loss (%)	pH	POX (U mg-1 protein)	SOD (U mg-1 protein)	TP (mg GAE/ 100gFW)	TF (µMQ/ 100gFW)
1	Control	19.9±1.5 a-d	2.7±0.2 ef	4.8±0.03 cde	7.4±0.6 f	35.6±1.4 h	34.4±1.2 i	9.4±1.3 f
	1 mM OA	21.1±2.8 abc	2.2±0.4 f	4.7±0.03 fg	9.4±0.8 ef	36.3±1.6 h	37.9±1.4 hi	7.6±1 f
	3 mM OA	22.2±1 ab	2.4±0.3 ef	4.6±0.06 gh	8.5±0.5 ef	35.9±1 h	32.8±2.3 hi	9.7±0.5 f
	5 mM OA	23.2±2.3 a	2.3±0.2 f	4.5±0.06 h	8.7±1.3 ef	38.3±1 h	42.2±1.2 gh	10.4±0.6 f
2	Control	13.5±1.6 f	4.7±0.5 cd	4.9±0.03 b-e	10.4±1 de	44.4±1.6 g	47.0±1.1 fg	17.7±1.4 e
	1 mM OA	17.6±2.2 de	3.6±0.7 de	4.8±0.06 def	10.9±0.8 de	49.9±1.4 ef	49.6±3.1 ef	20.8±1.2 cd
	3 mM OA	18.7±2.8 cd	4.2±0.4 cd	4.7±0.03 efg	12.6±1.2 cd	48.1±1.3 fg	54.4±2.2 de	20.8±1.1 cd
	5 mM OA	19.1±2.6 bcd	3.7±0.4 de	4.8±0.03 ef	14.7±1.1 bc	52.2±1.8 cdef	59.3±1.9 cd	24.0±0.1 c
3	Control	9.5±1.5 gh	5.5±0.4 bc	5.0±0.03 bc	14.7±0.7 bc	50.1±1.4 ef	56.2±0.8 d	19.7±0.7 de
	1 mM OA	14.2±2.1 ef	4.7±0.2 cd	5.0±0.03 bc	15.9±0.7 ab	54.9±2.3 bcd	63.1±1.8 bc	22.3±0.7 cd
	3 mM OA	15.2±0.5 ef	4.2±0.3 cd	4.9±0.03 bcd	18.0±0.9 a	54.2±1.1b-e	62.8±0.9 bc	23.8±0.9 c
	5 mM OA	17.2±1.8 de	4.7±0.5 cd	4.8±0.03 cde	16.5±1 ab	53.7±1.2 b-e	65.2±0.8 ab	29.8±0.4 b
4	Control	8.5±0.5 h	7.4±0.5 a	5.3±0.03 a	16.2±1.2 ab	51.3±1.2 def	54.9±2.4 de	23.4±1 c
	1 mM OA	12.0±2 fg	5.1±0.7 bc	5.0±0.06 b	16.7±1.1 ab	57.0±0.4 ab	64.6±1.6 abc	28.8±1.3 b
	3 mM OA	14.4±1.3 ef	5.5±0.4 bc	5.0±0.1 b	18.8±0.9 a	56.1±2.3 abc	66.1±1.6 ab	30.0±0.8 b
	5 mM OA	14.2±1.9 ef	6.3±0.4 ab	4.9±0.03 bc	18.9±0.8 a	59.6±0.9 a	69.2±2.2 a	37.1±1 a

Each value represents the mean ± SE (n = 3). Mean values in each column followed by the same lower-case letters are not statistically different by Duncan's multiple range test (p≤ 0.05).

Fruit firmness

As shown in Table 1, fruit firmness was significantly higher in treated fruit than control. Despite a consistent decrease in firmness of all treatments during the cold storage, still all OA concentrations helped in retaining higher firmness levels when compared with control. At the end of storage, the highest firmness (14.15 N) was observed in the 5 mM OA treatment and the lowest (8.48 N) was seen in control fruit.

Total soluble solids, titratable acidity and pH

The effects of OA treatment on TSS, TA and pH are shown in Table 2. During storage of control fruit, TSS and pH increased while TA decreased. These changes were significantly delayed in peaches treated with OA. Minimum TSS was observed in peach fruit treated with 5 mM OA (12.49%). The TA was higher in OA-treated fruit compared with controls, but there was not a significant difference between various treatments at P≤ 0.05. The interaction effects between treatments and storage period on pH values were found significant (P≤ 0.05). PH contents of the control fruit were higher than those of OA-applied fruit (Table 2).

Weight loss

Weight loss of peach fruit during storage is shown in Table 1. The rate of weight loss increased with the storage time and the minimum weight loss occurred in the OA treated fruit. There was no significant difference between various OA treatments at P≤0.05.

Antioxidant enzyme activities

During the storage POX and SOD activity increased in both control and treated peaches, but POX and SOD activities in OA-treated fruit were higher than those in control fruit (Table 1). POX and SOD activity in treated fruit with 5 mM OA was higher than that in control. CAT activity also gradually increased during storage, but no significant differences in CAT activity were observed between OA-treated and control peaches (Table 2).

Phenolic and flavonoids content

The phenolic content of control and OA-treated fruit increased during storage compared to the initial value. The application of OA led to a continuous increase in phenolic content until the end of the experiment, the values being higher for 5 mM OA-treated peaches followed by 3 and 1 mM OA-treated fruit (Table 1). Flavonoid contents in control and OA-treated fruits increased during cold storage. A significantly (P≤ 0.01) higher level of flavonoids was observed in OA-treated fruit from 2nd week of storage that continued till the end of experiment compared with the control (Table 1).

Antioxidant activity

The scavenging activity of control and treated peach fruit extracts, expressed as an inhibition percentage (IP) of DPPH radical is presented in Fig. (II). The data indicate a significant (P≤0.05) increase in IP in OA-treated fruits compared to the control. The IP of treated fruits increased significantly with increase in the treatment dose. Highest IP was recorded in fruits treated with 5 mM OA followed by those treated with 3 mM OA. The IP continued to increase during storage in all treatments and control, the increase being significantly (P≤0.05) higher in treated fruits. A similar pattern to that of DPPH radical scavenging activity was found in ferric reducing/antioxidant power (FRAP). Application of OA led to a continuous increase in FRAP until the end of the experiment, the values being higher for OA-treated fruits (Fig. III). DPPH scavenging activity was significantly correlated with flavonoid and phenolic contents, and the correlation coefficients were 0.843 and 0.881, respectively (all significant at P≤0.01).

Table 2
Effects of oxalic acid on TSS, TA, and catalase activity in peach fruit during storage at 1° C

OA Treatment	TSS (%)	TA (g/100 g malic acid)	Catalase (U mg^{-1} protein)
Control	14.5± 0.97[a]	0.28± 0.03 [b]	19.9± 1.5 [a]
1 mM	14± 1.01[a]	0.31± 0.03 [a]	20.1± 1.4 [a]
3 mM	13.3± 0.59[ab]	0.32± 0.03[a]	21.2± 3.1[a]
5 mM	12.5± 1[b]	0.33± 0.02[a]	20.9± 1.9[a]

Each value represents the mean values ± SE (n = 3); mean values in each column followed by the same lower-case letters are not statistically different by Duncan's multiple range test (P≤0.05).

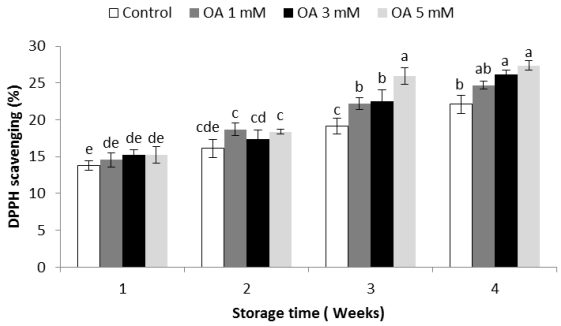

Fig II. Effect of oxalic acid on fruit DPPH scavenging activity of peach stored at 1° C; Data shown are mean values ± SE (n = 3). Data followed by different letters are significantly different according to Duncan's multiple range test, P≤ 0.05.

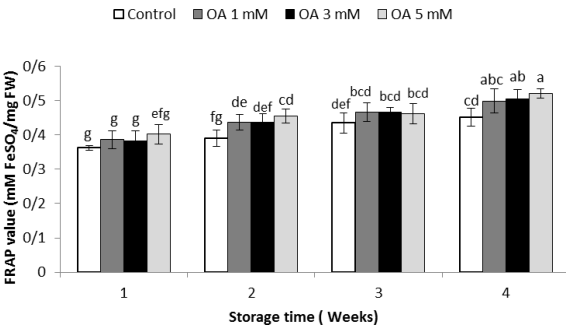

Fig 3. Effect of oxalic acid on fruit ferric reducing antioxidant power (FRAP) of peach stored at 1°C. Data shown are mean values ± SE (n = 3). Data followed by different letters are significantly different according to Duncan's multiple range test, P≤ 0.05.

Discussion

Peach is a climacteric fruit in which the increase in ethylene production occurs during storage. The ripening and senescence processes

of climacteric fruits were delayed through inhibition of the ethylene biosynthesis (Hayama et al., 2006). A reduction in ethylene production with postharvest OA application has also been reported in mango and plum (Razzaq et al., 2015; Wu et al., 2011). It may be argued that inhibition of the ethylene production with OA application occurs due to the inhibition of the activities of ethylene biosynthesis enzymes (Wang et al., 2009).

Firmness is an important factor that influences the consumer acceptability of fresh fruit. Peaches soften considerably during storage, which contributes greatly to its short postharvest life (Nunes, 2008). The role of OA in maintaining fruit firmness, delaying softening, and increasing shelf life has been reported in several crops such as peach, plum, cherry, and mango (Zheng et al., 2007b; Zheng et al., 2007a; Wu et al., 2011; Valero et al., 2011). Decreased fruit softening after OA treatment may be attributed to the reduction of the polygalacturonase and pectinmethylesterase enzymes activity that are beneficial in the inhibition of pectin solubilization and fruit softening (Wu et al., 2011).

The loss of the TA and the increase in TSS are commonly used to demonstrate the ripening stage of the fruits as well as to evaluate the fruit taste which is represented mainly by the balance between sweetness and acidity. OA delayed the ripening process in fruits such as peach (Zheng et al., 2007b), cherry (Valero et al., 2011), mango (Zheng et al., 2007a) and jujube (Wang et al., 2009). These results are in general agreement with those of Saengnil et al. (2006) who reported that oxalic acid-treated pericarps had the lowest pH in litchi fruit.

Loss of water during storage is one of the main causes of deterioration, as it results in a peach with a shriveled and dry appearance (Nunes, 2008). Weight loss in fruit during storage is caused by water exchange between the internal and external atmosphere and cellular breakdown accelerates the transpiration rate in fruit (Woods, 1990). Thus, OA treatment might maintain membrane integrity and reduce ion leakage, as has been reported in peach fruit during storage at room temperature (Zheng et al., 2007b). Previously, pre-storage OA treatments reduced the weight loss in mango fruit during ripening at ambient conditions and in cold storage (Razzaq et al., 2015).

Oxidative stress is involved in the formation of ROS such as hydrogen peroxide and superoxide radicals in fruit cells. Various enzymes including POX, SOD, GR, and CAT are involved in the ROS scavenging in plants. Superoxide radicals are converted into hydrogen peroxide as a result of SOD activity, and H_2O_2 is further detoxified by CAT and/or POX to water and molecular oxygen (Ding et al., 2007). Our results suggested that OA treatments induced the activities of defense enzymes and then promoted protection of peach fruit.

Antioxidant enzymes are able to prevent oxidation processes by reacting with free radicals (Xing et al., 2011). Therefore, it is suggested that such effects of OA application on these antioxidant enzymes could result in a decrease in the ROS level as well as delaying the ripening process in peach fruits. It has been reported that peach fruits treated with OA exhibited higher antioxidant enzymes superoxide dismutase, catalase, peroxidase, and ascorbate peroxidase activities (Zheng et al., 2007b). Also, exogenous OA-treated mango fruit showed higher activities of superoxide dismutase, catalase, ascorbate peroxidase, and glutathione reductase (Ding et al., 2007).

Phenolics such as flavonoids and anthocyanins are beneficial antioxidants and are associated with a lowered risk of heart disease via their action toward low-density lipoproteins (Serrano et al., 2009). Tomas-barberan et al. (2001) reported that hydroxycinnamates along with flavonoids are the main constituents of total phenols in peaches. Increase in phenolic compounds was related to the development of the ripening process. However, other factors including the ripening stage at harvest, cultivar, season growth, and duration of storage time affected the change of total phenols during postharvest storage (Serrano et al., 2009; Valero et al., 2011). Imeh and Khokhar (2002) showed that in peaches 80% of phenols are in the conjugated form and then postharvest increases polyphenol contents because of enzymatic hydrolysis of bound polyphenols to extractable single phenolic acids during cold storage, thus enhancing the total phenols' status. Valero et al.

(2011) reported that total phenols increased in untreated sweet cherry fruits during the first 10 days of storage and then decreased, while in fruits treated with OA, these parameters increased continuously during storage time. Also, Zheng et al. (2012) showed that potassium oxalate treatment led to increased activity of peroxidase in both the peel and the flesh and polyphenol oxidase in the peel, and promoted phenolic content in the peel of mango fruit during storage at room temperature. The physiological effects of oxalate in increasing activities of peroxidase and polyphenoloxidase and elevating the phenolic level could be involved in induced resistance of mango fruit against postharvest disease.

The balance between ROS production and their removal by the antioxidant defense systems determines the rate of ripening and senescence processes, and therefore, the extension of the fruit shelf-life. Valero et al. (2011) reported that, continuous increases occurred in hydrophilic-total antioxidant activity for cherries treated with OA during storage. Also, banana and mango fruit treated with OA exhibited higher antioxidant capability with a lower production of reactive oxygen species at the late storage period (Huang et al., 2013; Razzaq et al., 2015). Early reports have demonstrated that OA has also a constructive effect on antioxidant enzymes. For example, increases in catalase, peroxidase, superoxide dismutase, and ascorbate peroxidase have been found in fruit such as peach, and mango after OA treatment, which enhanced their antioxidant activity.

Gil et al. (2002), studying peach and nectarine cultivars, found a correlation between antioxidant activity and phenolics. In the present study, peach fruit treated with OA exhibited significantly ($P \leq 0.01$) higher levels of phenolics compared to the control fruit, which suggests that OA may improve the antioxidant status of the fruit by positively affecting phenolic metabolism.

Conclusions

In conclusion, the experiment conducted here indicated that a postharvest application of OA positively affected antioxidant levels, antioxidant activity, and overall quality of peach fruit. Thus, OA has a potential application in postharvest treatment for delaying the ethylene production and the softening process, improving the functional properties and maintaining peach fruit quality during cold storage.

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