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Effect of pre- and post-harvest salicylic acid treatments on quality and antioxidant properties of 'Red Delicious' apples during cold storage

M. Hadian-Deljou, M. Esna-Ashari*, H. Sarikhani
Department of Horticultural Sciences, Bu-Ali Sina University, Hamedan, Iran.

Key words: anthocyanin, firmness, phenolic compound, soluble solid content, weight loss.

Abstract: Salicylic acid is a natural phenolic compound known as a plant hormone having positive effect on storage life and quality of fruits. This study aimed to investigate the effects of pre- and post-harvest application of salicylic acid on antioxidant properties and quality of 'Red Delicious' apples during 193 days cold (0±0.5°C) storage. Both pre- and post-harvest salicylic acid treatments did not affect soluble solid content, titratable acidity and fruit firmness, with the exception of 1 mM at pre-harvest application for titratable acidity. Fruit juice pH was reduced in all fruits at the end of storage, while it was not quite uniform during storage. Although there was no significant difference between the concentrations of salicylic acid in terms of fruit weight loss, but the highest amount of weight loss was observed in post-harvest treatments. Salicylic acid application increased total phenolics and antioxidant activity at the earlier stages of storage showing the highest capacity with 2 mM followed by 1 and 4 mM salicylic acid concentrations, while 1 mM concentration belonged to the highest antioxidant capacity at the end of storage. Anthocyanin content showed a gradual increase during storage until day 60, then decreased right afterwards. The highest amounts of anthocyanin were obtained from the concentrations of 1 and 2 mM salicylic acid in pre-harvest treatments, while 4 mM treatment was not encouraging. Overall, salicylic acid treatments could increase apple storage life and quality for a short period of time only.

1. Introduction

Apple (*Malus domestica* Borkh) is one of the most important horticultural crops considered as the third major fruit in the world (Garming, 2014). The main proportion (½ million tons) of apple production in Iran is used for fresh consumption (Iranian Ministry of Agriculture, 2016), while some problems such as tissue softening during storage, tissue browning due to physical damages at post-harvest handling, high water loss and some physiological disorders such as bitter pit, water core, scald and internal browning are the most dominant post-harvest restriction factors (Esna-Ashari and Zokaee Khosroshahi, 2011). Generally, quality apple must be mature, firm, crispy and juicy with a good flavor composition and free from mechanical damage, physiological disorders, and pathological diseases (Baldwin, 2002). However, reducing consumer acceptance or nutritional value usually happens in the period after harvesting. Apples contain several health-promoting compounds functioning as antioxidants, or modulators of enzyme activity. Peel of red apples contains higher antioxidant than their flesh. Meanwhile, Drougoudi *et al*. (2008) discovered a positive correlation between phenolic content and antioxidant capacity in both flesh and peel of apple. Color is also another important factor regarding fruit evaluation. There is a close correlation between color and overall quality of fruits (Ritenour and Khemira, 2007).

Salicylic acid (SA) is a natural compound that functions as plant growth regulator. SA carries a high potential of controlling post-harvest losses of horticultural crops. It has been discovered that the SA is associated with a delay in fruit ripening, (Srivastava and Dwivedi, 2000; Zhang *et al*., 2003; Mo *et al*., 2008), induction of disease resistance (Shafiee *et al*., 2010), increasing antioxidant and phenolic compounds (Peng and Jiang, 2006; Geransayeh *et al*., 2015), maintenance of post-harvest quality (Srivastava and Dwivedi, 2000; Zhang *et al*., 2003; Wang *et al*., 2006; Mo *et al*., 2008; Harindra *et al*.,

(*) Corresponding author: m.esnaashari@basu.ac.ir
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2015) and increasing storage life of horticultural crops. Hence, SA is suggested to be utilized in post-harvest handling of fruits and vegetables (Peng and Jiang, 2006) which necessitates further investigation into know-how of its application. Wen *et al*. (2008) found that treatment of grape berries with SA could induce an increase in phenylpropanoid and phenylalanine ammonia-lyase (PAL). Qin *et al*. (2003) reported a significant increase in polyphenoloxidase, PAL and β-1, 3-glucanase activity in cherries fruit through SA treatment. Exogenous application of SA on tomato green mature fruits has shown a delay in biosynthesis of some biochemicals including carotenoids, lycopene, ascorbic acid, total phenolics, free amino acids and γ-amino butyric acid that led to increase in the keeping quality of fruits (Kant *et al*., 2016). Pre-treatment of SA combined with lower storage temperature could provide a useful means of maintaining beneficial antioxidant activity during storage of navel orange (Huang *et al*., 2008). Exogenous application of SA enabled grape leaves to maintain relatively higher activities of antioxidant enzymes under normal temperature, heat, or cold stress. The effect of SA on alleviating chilling injury of peaches during cold storage may be attributed to its ability to induce antioxidant systems (Wang *et al*., 2006). The aim of this study was to maintain apple quality through the application of SA controlling physiological damages as well as investigating content of phenolic compounds, anthocyanin and antioxidant activity of fruits during cold storage.

2. Materials and Methods

Plant materials and salicylic acid treatments

Apples (*Malus domestica* Borkh cv. Red Delicious) were provided from a 20 years old orchard in Horticultural Research Center, Bu-Ali Sina University, Hamedan, Iran. This study was conducted as a factorial experiment based on a complete randomized block design with three replications. First stage of experiment launched on September when apples' green skin had just started to turn reddish. Four concentrations of SA including 0 (control), 1, 2 and 4 mM were sprayed on previously-selected trees, branches and fruits. SA concentrations were made by dissolving powdered SA (Merck, Germany) in hot water. In the second stage of experiment, non-treated fruits were first harvested according to the maturity index (starch test) using Cornell Starch-Iodine Chart in late September. Starch test is a standard method of determining apple maturity to estimate optimum harvest dates well before picking fruit (Blanpide and Silsby, 1992). The harvested fruits then dipped in the same concentrations of SA solution for approximately three minutes at room temperature (25±1ºC). Previously-treated apples were also harvested at this time. In this experiment, 15 apple fruit were used in each replicate for a totally of 45 fruit for each treatment. Two apples per each replicate were used for the measurments of all parameters (except for the weight loss) at any time of determination (totally 6 times). Three remaining apples from each replicate were kept to weigh at any time of determination for the evaluation of weight loss. For the packaging of the samples, each group of five apples was packed in a cubic plastic container with two small pores (2.5 mm in diameter) in each side, and stored at 0±0.5°C with 90% relative humidity and kept up to 193 days. Measurements of all parameters started at the beginning of the storage and then continued until the day of 90 with 30 days intervals. Two other measurements were taken 157 and 193 days of storage.

Soluble solid content, titratable acidity and juice pH

Apple juice was first prepared using a domestic electric apple juice maker available in the local shops. Soluble solid content (SSC) was determined by measuring refractive index of the juice with a handhold refractometer (N1, Atago Co., Tokyo, Japan) at room temperature (25±1°C) and the results were expressed as °Brix. Titratable acidity (TA) was measured by titration with a calibrated titrator using a solution of the juice and water (2/10 ratio) with 0.1 N NaOH to pH 8.2±0.1 and converted to malic acid percentage.

Fruit juice pH was determined using an Aqualitic digital pH meter (model AL10 pH) with a gel electrode.

Fruit firmness and weight loss

Firmness values of each individual apple were measured at three points of their equatorial region after which the peel was removed by using a manual penetrometer (FDK; Wagner Instruments, Greenwich, CT, USA) with a 2 mm diameter flat probe (Zhang *et al*., 2009).

Total phenolic content

Total phenolic content (TPC) of treated fruits were determined through a slightly modified version of Folin-Ciocalteu's method as suggested by Slinkard and Singleton (1977). Chlorogenic acid was used as standard phenolic compound. Extraction was performed by homogenizing 0.5 g flesh tissue powder in 3 ml of 85% MeOH and the extract was filtered with

No.1 Whatman filter paper. Sample extract (300 µl) was mixed with 1500 µl of Folin-Ciocalteu’s reagent. After 5 min, 1200 µL of sodium carbonate solution (7.0%, w/v) was added, and the mixture vortexed and allowed to stand at room temperature (25±1°C) in the dark for 90 min. The absorbance was read at 765 nm in a UV/vis spectrophotometer (Carry 100, Varian Analytical Instruments, Walnut Creek, CA, USA), and the total phenolic concentration was calculated from a calibration curve, using chlorogenic acid as the standard. Results were expressed as mg L^{-1} chlorogenic acid equivalents.

Total anthocyanin content

For the assessment of anthocyanin contents of the apples, only their peels were used through applying a pH differential protocol (Giusti and Wrolstad, 2003). The absorbance was measured at 510 and 700 nm with a UV/vis spectrophotometer (Carry 100, Varian Analytical Instruments, Walnut Creek, CA, USA). Anthocyanin content was then calculated using the following equation and expressed as mg cyanidin 3-galactoside equivalent per gram of fresh weight.

$$\text{mg Cya-3-gal /g FW} = [(A_{510} - A_{700})_{pH1} - (A_{510-}\ A_{700})_{pH4.5}]\times MW\times F\times 1000/\varepsilon\times d$$

where: A= absorbance, MW= molecular weight of cyanidin 3-galactoside = 445.2 [g/mol], F= dilution factor = 10, d= cell pathlengths [cm], ε= molar absorbance of cyanidin 3-galactoside = 34300 [L/mol×cm] and 1000= Factor for mg.

Total antioxidant activity

Antioxidant activity was estimated using the stable 1,1-diphenyl-2-picryl hydrazyl (DPPH) free radical (Arnous *et al*., 2001) with slight modifications. The absorbance was read at t = 0 and t = 30 min with a spectrophotometer (Carry 100, Varian Analytical Instruments, Walnut Creek, CA, USA).

For all the above assessments (except the anthocyanin measurement), the apple flesh was used.

Statistical analysis

Statistical analysis (analysis of variance) of the data was performed with SAS software (version 9.1, 2002-2003, SAS Institute Inc., Cary, NC, USA). Means were compared with Duncan’s Multiple Range Test. Differences at p=0.05 were considered as significant.

3. Results and Discussion

Soluble solids content, titratable acidity and juice pH

Soluble solids content increased gradually during storage with no significant differences between the treatments (Fig. 1). With pre-harvest application of 1 mM SA, TA slightly increased until the 60th day of storage, when reached its maximum value being significant with the other treatments, but decreased gradually afterwards (Fig. 2). Fruit juice pH was reduced in all fruits at the end of storage, while it was not quite uniform during storage (Table 1). SSC may increase during fruit ripening due to the action of sucrose-phosphate synthase, a key enzyme in sucrose biosynthesis. This enzyme is activated by ethylene and the ripening process itself during storage. Because organic acids are substrates of respiration, their levels decrease during ripening. Utilization of these compounds over post-harvest period is the main reason of increasing sweetness in originally

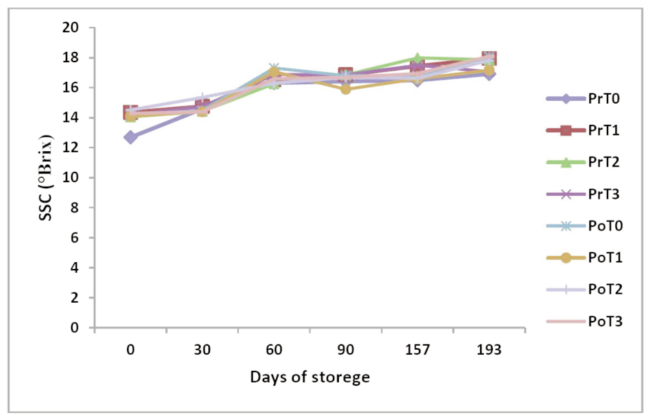

Fig. 1 - Effect of pre- and post-harvest salicylic acid treatments on SSC of ‘Red Delicious’ apples stored at 0±0.5°C for 193 days.
Comparison of the means was conducted through the Duncans’ Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

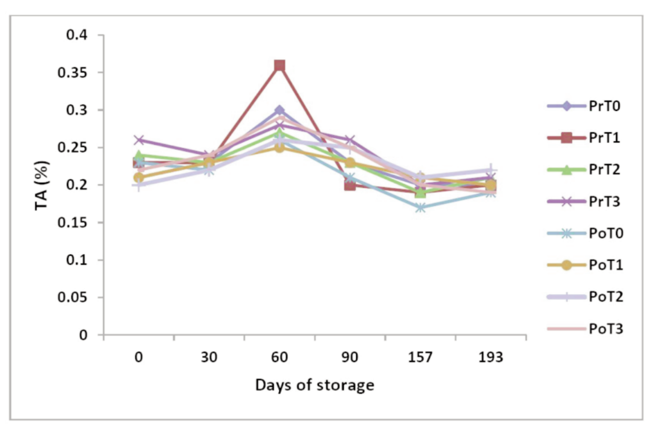

Fig. 2 - Effect of pre- and post-harvest salicylic acid treatments on TA of ‘Red Delicious’ apples stored at 0±0.5°C for 193 days.
Comparison of the means was conducted through the Duncans’ Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

Table 1 - Effect of pre- and post-harvest salicylic acid treatments on pH of 'Red Delicious' apples stored at 0±0.5°C for 193 days

Treatment	Days of storage					
	0	30	60	90	157	193
Pr	4.55 a	4.34 b	4.36 a	4.39 a	4.28 a	4.18 a
Po	4.56 a	4.54 a	4.34 a	4.43 a	4.31 a	4.10 b
T0	4.52 a	4.39 c	4.35 a	4.41 a	4.27 a	4.13 a
T1	4.54 a	4.42 bc	4.35 a	4.42 a	4.31 a	4.14 a
T2	4.58 a	4.49 a	4.33 a	4.39 a	4.28 a	4.13 a
T3	4.55 a	4.46 ab	4.37 a	4.42 a	4.33 a	4.15 a
PrT_0	4.53 a	4.30 d	4.34 a	4.36 a	4.26 a	4.15 abc
PrT_1	4.57 a	4.34 cd	4.36 a	4.41 a	4.30 a	4.25 a
PrT_2	4.52 a	4.36 cd	4.34 a	4.38 a	4.26 a	4.19 ab
PrT_3	4.59 a	4.37 c	4.40 a	4.40 a	4.32 a	4.15 abc
PoT_0	4.40 a	4.49 b	4.36 a	4.46 a	4.28 a	4.12 bc
PoT_1	4.53 a	4.50 b	4.34 a	4.43 a	4.32 a	4.03 c
PoT_2	4.46 a	4.62 a	4.32 a	4.40 a	4.31 a	4.08 bc
PoT_3	4.51 a	4.55 b	4.34 a	4.43 a	4.34 a	4.16 ab

The same letters in any column show no significant difference between the data. Comparison of the means was conducted through the Duncans' Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

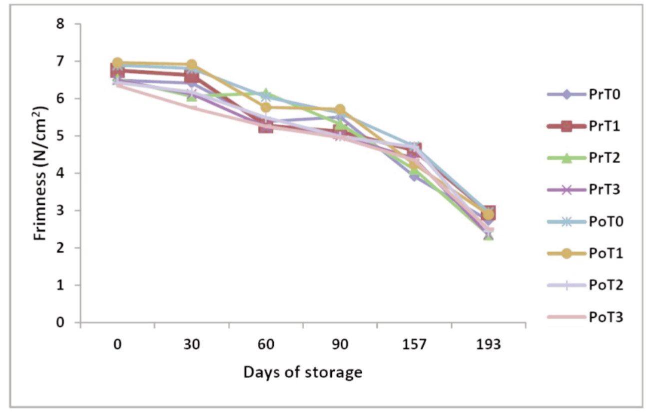

Fig. 3 - Effect of pre- and post-harvest salicylic acid treatments on firmness of 'Red Delicious' apples stored at 0±0.5°C for 193 days.
Comparison of the means was conducted through the Duncans' Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

high-sugar, high-acid apples or insipidity and blandness of fruit when sugar and acid concentrations are initially low (Jackson, 2003). Similar to our founding have been reported by Sayyari *et al*. (2011) in which SSC increased during storage in both control and treated fruits. As previously reported, in climacteric fruits such as apples, starch turns into sucrose during post-harvest storage. Mo *et al*. (2008) studies showed SSC in treated fruits to be lower than the control, suggesting that SA slowed starch degradation. This could be a possible reason why SSC increased in this study. However, dehydration of fruits during storage could be mentioned as another reason. Organic acids are consumed in the process of respiration during post-harvest storage. It could be concluded that, the apples' respiration rate in this study was possibly higher at the first two months of storage, and for this reason, the TA values were increased over this period, then lowered afterwards. Srivastava and Dwivedi (2000) stated that SA treatment has made TA fixed in banana. Similar results have been reported while investigating chestnut by Peng and Jiang (2006). As the contents of organic acids in fruit are mainly dependent to the activities of their synthetic and hydrolytic enzymes, SA treatment was probably regulated the activities of related enzymes (Ding *et al*., 2007).

Effects of salicylic acid on fruit softening

Fruits showed signs of softening during storage (Fig. 3). Firmness of apples was initially decreased in both control and SA-treated fruits, and then appeared rapidly. Similar results was found by Ding *et al*. (2007) and Sayyari *et al*. (2011) who reported that fruit firmness decreased during storage. A close relationship between the change at endogenous SA level and the rate of fruit ripening and softening in kiwifruit was observed by Zhang *et al*. (2003). Softening could be the result of turgor loss, starch degradation, and most importantly cell wall degradation associated with weakening intercellular cohesive forces (Jackson, 2003). SA decreases production of ethylene and inhibits activation of cell wall and membrane degrading enzymes such as polygalacturonase, lipoxygenase, cellulose and pectinemethylesterase resulting in the reduction of softening (Srivastava and Dwivedi, 2000; Zhang *et al*., 2003). Adding SA to the nutrient solution could induce firmness and delay the softening process in strawberry and apple fruits (Shafiee *et al*., 2010; Kazemi *et al*., 2011).

Effects of SA on weight loss

SA-treated fruits demonstrated controlled weight loss during initial stages of post-harvest. The lowest amount of weight loss was observed in 2 mM concentration of SA- pre-harvest-treated fruits. Higher concentrations of SA could induce fruit weight loss, but did not control it (Fig. 4). It was observed that the apples kept their quality until the 157 days of storage, so that they were still suitable to be transferred to the market, but they gradually started to show visible defects on the peel losing their quality afterwards. Therefore, we recommend our method to be suitable for the storage of Red Delicious apples for the period of five months.

Weight loss is caused by both dehydration and consumption of soluble solids during respiration. SA

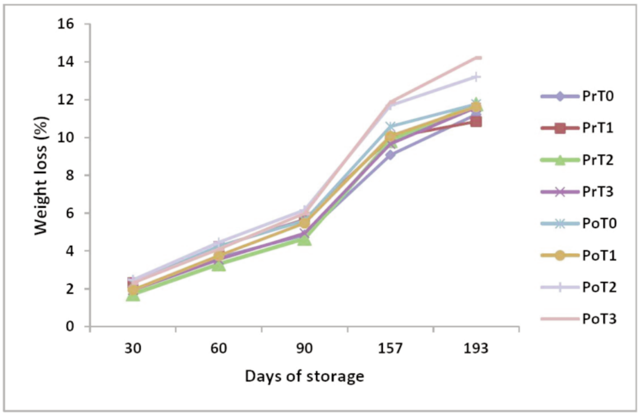

Fig. 4 - Effect of pre- and post-harvest salicylic acid treatments on weight loss of 'Red Delicious' apples stored at 0±0.5°C for 193 days.
Comparison of the means was conducted through the Duncans' Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

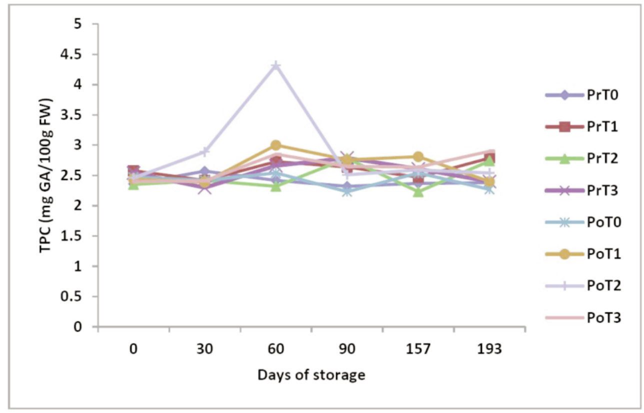

Fig. 5 - Effect of pre- and post-harvest salicylic acid treatments on TPC of 'Red Delicious' apples stored at 0±0.5°C for 193 days.
Comparison of the means was conducted through the Duncans' Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

could decrease water loss and respiration rate through controlling degradation of cell wall and reducing ethylene biosynthesis (Srivastava and Dwivedi, 2000), respectively. Jonagold apples immersed in SA have shown a significant decrease in weight loss during cold storage (Kazemi *et al.*, 2011). In pear fruits, ratio of weight loss has been decreased at 0.5 mM SA after 48 h of treatment (Imran *et al.*, 2007). Strawberries dipped in SA solution demonstrated less weight loss as well (Shafiee *et al.*, 2010). It seems that high concentrations of SA could induce aggregation of intoxicated materials such as certain polyphenols in later stages of storage, which is probably why plant tissues degrade followed by increasing weight loss. Further investigations are needed to clarify this.

Effects of salicylic acid on accumulation of phenolic compounds

Application of SA partially induced accumulation of phenolic compounds and these effects were significant only from the 60th day until the end of storage (Fig. 5). Since then, SA-treated fruits contained higher quantities of phenols than the control. These results are in agreement with the findings of Harindra *et al.* (2015) in grapes and Geransayeh *et al.* (2015) in strawberries. In contrast with the results of this work, Kant *et al.* (2016) reported a delay in the biosynthesis of total phenolics in tomato green mature fruits dipped in SA solution resulting in an increase in fruit quality that is possibly related to the different physiological status of tomato green mature fruits during storage. Apples contain many bioactive compounds including phenols. SA may act as modulator of phenylpropanoid metabolism leading probably to the accumulation of phenolics correlated with the induction of enzymes which are involved in general phenylpropanoid metabolism, e.g. PAL (Godoy-Hernandez and Loyola-Vargas, 1997). It has shown that PAL activity could be induced by SA elicitation in citrus (Lafuente *et al.*, 2001) and grapes (Chen *et al.*, 2006), which would result in the accumulation of plant secondary metabolites.

Effects of salicylic acid on anthocyanin content

Anthocyanin content of apples revealed an increasing trend until the 60th day of storage while decreased right afterwards (Table 2). Initially, effects

Table 2 - Effect of pre- and post-harvest salicylic acid treatments on anthocyanin content (mg/g FW) of 'Red Delicious' apples stored at 0±0.5°C for 193 days

Treatment	Days of storage					
	0	30	60	90	157	193
Pr	5.57 a	7.39 a	12.41 a	9.15 a	4.91 a	2.54 a
Po	3.74 a	5.53 b	10.92 a	9.10 a	5.13 a	2.22 a
T0	5.75 a	6.32 ab	12.08 a	7.84 b	4.59 a	2.83 a
T_1	7.37 a	8.29 a	13.08 a	11.62 a	5.07 a	1.54 a
T_2	4.33 a	6.46 ab	11.63 a	10.02 ab	5.44 a	2.22 a
T_3	3.29 a	4.68 b	10.06 a	7.29 b	4.85 a	2.91 a
PrT_0	5.26 a	5.66 bc	12.50 a	7.65 b	4.04 a	2.88 ab
PrT_1	5.68 a	8.54 ab	15.39 a	12.98 a	5.24 a	1.35 b
PrT_2	7.56 a	10.13 a	12.02 a	9.43 ab	5.94 a	2.47 ab
PrT_3	4.46 a	5.38 bc	9.69 a	6.46 b	3.93 a	3.64 a
PoT_0	5.17 a	7.14 abc	11.53 a	8.00 b	5.14 a	2.79 ab
PoT_1	5.67 a	7.98 ab	10.78 a	10.27 ab	4.96 a	1.70 ab
PoT_2	2.75 a	3.52 c	11.23 a	10.74 ab	5.02 a	2.03 ab
PoT_3	2.10 a	3.97 c	10.43 a	7.96 b	5.54 a	2.36 ab

The same letters in any column show no significant difference between the data. Comparison of the means was conducted through the Duncans' Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

of SA on anthocyanin content were significant. The highest contents of anthocyanin were obtained in the concentrations of 1 and 2 mM at pre-harvest treatments with no significant differences between one and with 1mM of post-harvest treatment. Similar result has been reported by Jamali *et al*. (2013) who sprayed strawberry plants by SA together with nickel sulfate and found higher amounts of anthocyanin in strawberry fruits. Anthocyanins degrade by polyphenol oxidase during post-harvest, and this might be the main reason behind the reduction of anthocyanin compounds. The role of SA on anthocyanin production is unknown, one may hypothesize that SA could activate the key enzyme (Chalcone synthase) in the anthocyanin biosynthetic pathway (Godoy-Hernandez and Loyola-Vargas, 1997). Obinata *et al*. (2003) reported that SA could markedly increase the production of procyanidin in grape. Total anthocyanin has also been increased with storage period in both control and treated pomegranates (Sayyari *et al*., 2011). Our results agree with findings of Obinata *et al*. (2003) and Sayyari *et al*. (2011).

Effects of salicylic acid on antioxidant activity

Antioxidant activity increased in all treatments during storage (Table 3). Antioxidant activity was increased in SA-treated fruits, but this process was not uniform, i.e. changes antioxidant activity was not followed from fixed pattern during storage. Antioxidative potential of apple, however, is known to depend on the concentration and composition of phenolics. Numerous researchers have indicated that SA and its functional analogs have inhibitory effects on CAT and POD activities or serve as substrates for POD. Knorzer *et al*. (1999) reported, when applied exogenously at suitable concentrations, SA was found to enhance the efficiency of antioxidant system in plants. Imran *et al*. (2007) and Sayyari *et al*. (2011) found that SA have the capacity of increasing antioxidant, the result that confirms the present study. Kazemi *et al*. (2011) also observed the higher ascorbic acid (vitamin C) content as well as peroxidase and superoxide dismutase activities in apples treated with SA exogenously. SA is possibly effective through the activation of responsible genes for producing antioxidant compounds (Wang *et al*., 2006) and increasing activity of the antioxidant enzymes such as superoxide dismutase, peroxidase, catalase and ascorbate peroxidase (Mo *et al*., 2008).

Table 3 - Effect of pre- and post-harvest salicylic acid treatments on antioxidant activity (% of DPPH inhibition) of 'Red Delicious' apples stored at 0±0.5°C for 193 days

Treatment	Days of storage					
	0	30	60	90	157	193
Pr	60.20 a	74.34 a	62.00 b	73.67 b	78.67 a	82.18 a
Po	47.40 a	67.35 b	84.25 a	81.53 a	76.79 a	82.49 a
T_0	59.29 a	62.43 c	55.62 b	68.22 b	72.50 c	78.76 b
T_1	50.14 a	69.88 b	79.16 a	78.26 a	83.93 a	83.67 ab
T_2	61.03 a	81.16 a	81.52 a	81.93 a	79.84 ab	80.36 b
T_3	58.24 a	70.27 b	79.68 a	81.42 a	74.55 bc	86.33 a
PrT_0	58.46 a	70.85 cd	50.37 d	70.33 cd	82.55 a	63.54 c
PrT_1	61.94 a	68.59 d	68.09 b	73.09 bcd	84.57 a	77.94 b
PrT_2	56.35 a	78.56 b	60.33 c	75.35 bcd	81.73 a	87.23 a
PrT_3	60.13 a	77.82 bc	66.23 b	76.76 abcd	61.65 b	91.00 a
PoT_0	49.36 a	54.01 e	59.82 c	64.71 d	60.44 b	90.17 a
PoT_1	52.22 a	71.48 bcd	92.99 a	82.39 abc	83.29 a	87.49 a
PoT_2	63.47 a	86.35 a	92.12 a	88.52 a	78.25 a	71.20 bc
PoT_3	45.92 a	63.99 d	90.90 a	85.15 ab	84.87 a	78.54 b

The same letters in any column show no significant difference between the data. Comparison of the means was conducted through the Duncans' Multiple Range Test (P<0.05).
Pr= pre-harvest; Po= post-harvest; T0 to T3= control, 1, 2 and 4 mM SA treatment respectively.

4. Conclusions

This study showed the effectiveness of pre- and post-harvest treatment of SA on the quality of 'Red Delicious' apples. Application of SA affected on juice pH and anthocyanin content until the middle of storage, maintaining phenolic compounds and increasing antioxidant activity. No significant difference between SA treatments was seen in terms of SSC, TA and fruit firmness. The lowest weight loss was observed on pre-harvest-SA treatment when sprayed, and the highest concentration of phenolic compounds was observed in post-harvest treatment when dipped. Anthocyanin content was also increased during storage up to 60 days, but by the day 90, it was gradually decreased until the end of storage when reached to the lower level. As a conclusion, treatment of 'Red Delicious' apples with SA could properly maintain the quality of fruits and increase their post-harvest life and antioxidant capacity for at least 2 months.

References

ARNOUS A., MAKRIS D.P., KEFALAS P., 2001 - *Effect of principal polyphenolic components in relation to antioxidant characteristics of aged red wines*. - J. Agric. Food Chem., 49: 5736-5742.

BALDWIN E., 2002 - *Fruit flavour, volatile metabolism and consumer perceptions*, pp. 89-106. - In: KNEEN M. (ed.) *Fruit quality and its biological basis*. CRC Press, Boca

Raton, FL, USA, pp. 320.
BLANPIDE G.D., SILSBY K.J., 1992 - *Predicting harvest date windows for apples*. - A Cornell Cooperative Extension Publication. Information Bulletin, 221: 1-18.
CHEN J.Y., WEN P.F., KONG W.F., PAN Q.H., ZHAN J.C., LI J.M., WAN S.B., HUANG W.D., 2006 - *Effect of salicylic acid on phenylpropanoids and phenylalanine ammonia-lyase in harvested grape berries*. - Post-harvest Biol. Technol., 40: 64-72.
DING Z.S., TIAN S.P., ZHENG X.L., ZHOU Z.W., XU Y., 2007 - *Responses of reactive oxygen metabolism and quality in mango fruit to exogenous oxalic acid or salicylic acid under chilling temperature stress*. - Plant Physiol., 130: 112-121.
DROUGOUDI P.D., MICHAILIDIS Z., PANTELIDIS G., 2008 - *Peel and flesh antioxidant content and harvest quality characteristics of seven apple cultivars*. - Scientia Hort., 115: 149-153.
ESNA-ASHARI M., ZOKAEE KHOSROSHAHI M.R., 2011 - *Post-harvest physiology and technolog*y. - Bu-Ali Sina University Press, pp. 658.
GARMING H., 2014 - *Apple*. - www.agribenchmark.org.
GERANSAYEH M., SEPAHVAND S., ABDOSSI V., 2015 - *Extending post-harvest longevity and improving quality of strawberry (*Fragaria ananasa *Duch cv.* Gaviota*) fruit by post-harvest salicylic acid treatment*. - J. Agric. Studies., 3(2): 17-36.
GIUSTI M.M., WROLSTAD R.E., 2003 - *Acylated anthocyanins from edible sources and their application in food systems*. - Bio. Eng. J., 14: 217-225.
GODOY-HERNANDEZ G., LOYOLA-VARGAS V.M., 1997 - *Effect of acetylsalicylic acid on secondary metabolism of* Catharanthus roseus *tumor suspension cultures*. - Plant Cell Reports., 16: 287-290.
HARINDRA CHAMPA W.A., GILL M.I.S., MAHAJAN B.V.C., ARORA N.K., 2015 - *Preharvest salicylic acid treatments to improve quality and post-harvest life of table grapes (*Vitis vinifera L.*) cv. Flame Seedless.* - J. Food Sci. Technol., 52(6): 3607-3616.
HUANG R.H., LIU J.H., LU Y.M., XIA R.X., 2008 - *Effect of salicylic acid on the antioxidant system in the pulp of 'Cara cara' navel orange (*Citrus sinensis *L. Osbeck) at different storage temperatures.* - Post-harvest Biol. Technol., 47: 168-175.
IMRAN H., YUXING Z., GUOQIANG D.U., GUOYING W., JIANGHONG Z., 2007 - *Effect of salicylic acid (SA) on delaying fruit senescence of Huang Kum pear*. - Front. Agric. China., 1(4): 456-459.
IRANIAN MINISTRY OF AGRICULTURE, 2016 - *Agricultural Statistics, 2016* - Iranian Ministry of Agriculture, Information Technology Centre, Iran.
JACKSON J.E., 2003 - *Biology of horticultural crops: Biology of apples and pears*. - Cambridge University Press, pp. 488.
JAMALI B., ESHGHI S., TAFFAZOLI E., 2013 - *Vegetative growth, yield, fruit quality and fruit and leaf composition of strawberry cv. 'Pajaro' as influenced by salicylic acid and nickel sprays*. - J. Plant Nut., 36: 1043-1055.
KANT K., ARORA A., SINGH V.P., 2016 - *Salicylic acid influences biochemical characteristics of harvested tomato (*Solanum lycopersicon *L.) during ripening*. - J. Plant Physiol., 21(1): 50-55.
KAZEMI M., ARAN M., ZAMANI S., 2011 - *Effect of salicylic acid treatment on quality characteristics of apple fruits during storage*. - Am. J. Plant Physiol., 6: 113-119.
KNORZER O.C., LEDERER B., DURNER J., BOGER P., 1999 - *Antioxidative defense activation in soybean cells*. - Physiol. Plant., 107: 294-302.
LAFUENTE M.T., ZACARIAS I., MARTINEZ-TELLEZ M.A., SANCHEZ-BALLESTA M.T., DUPILLE E., 2001 - *Phenylalanine ammonia-lyasa as related to ethylene in the development of chilling symptoms during cold storage of citrus fruits*. - J. Agric. Food Chem., 49: 6020-6025.
MO Y., GONG D., LIANG G., HAN R., XIE J., LI W., 2008 - *Enhanced preservation effects of sugar apple fruits by salicylic acid treatment during post-harvest storage*. - J. Sci. Food Agric., 88: 2693-2699.
OBINATA N., YAMAKAWA T., TAKAMIYA M., TANAKA N., ISHIMARU K., KODAMA T., 2003 - *Effects of salicylic acid on the production of procyanindin and anthocyanin in cultured grape cells*. - Plant Bio., 20(2): 105-111.
PENG L., JIANG Y., 2006 - *Exogenous salicylic acid inhibits browning of fresh-cut Chinese water chestnut*. - Food Chem., 94: 535-540.
QIN G.Z., TIAN S.P., XU Y., WAN Y.K., 2003 - *Enhancement of biocontrol efficacy of antagonistic yeasts by salicylic acid sweet cherry fruit*. - Physiol. Mol. Plant Pathology., 62: 147-154.
RITENOUR M., KHEMIRA H., 2007 - *Red color development of apple: A literature review*. - Washington State University, Tree Fruit research and Extension Centre, pp. 10.
SAYYARI M., BABALAR M., KALANTARI S., MARTINEZ-ROMERO D., GUILLEN F., SERRANO M., VALERO D., 2011 - *Vapour treatments with methyl salicylate or methyl jasmonate alleviated chilling injury and enhanced antioxidant potential during post-harvest storage of pomegranates*. - Food Chem., 124: 964-970.
SHAFIEE M., TAGHAVI T.S., BABALAR M., 2010 - *Addition of salicylic acid to nutrient solution combined with post-harvest treatments (hot water, salicylic acid, and calcium dipping) improved post-harvest fruit quality of strawberry*. - Scientia Hort., 124: 40-45.
SLINKARD K., SINGLETON V.L., 1977 - *Total phenol analyses: automation and comparison with manual methods*. - Am. J. Enol. Vitic., 28: 49-55.
SRIVASTAVA M.K., DWIVEDI U.N., 2000 - *Delay ripening of banana fruit by salicylic acid*. - Plant Sci., 158: 87-96.
WANG L., CHEN S., KONG W., LI S., ARCHBOLD D.D., 2006 - *Salicylic acid pretreatment alleviates chilling injury and affects the antioxidant system and heat shock proteins of peaches during cold storage*. - Post-harvest Biol.

Technol., 41: 244-251.
WEN P.F., CHEN J.Y., WAN S.B., KONG W.F., ZHANG P., WANG W., ZHAN J.C., PAN Q.H., HUANG W.D., 2008 - *Salicylic acid activates phenylalanine ammonia-lyase in grape berry in response to high temperature stress*. - J. Plant Growth Regu., 55: 1-10.
ZHANG H., WANG L., MA L., DONG Y., JIANG S., XU B., ZHENG X., 2009 - *Biocontrol of major post-harvest pathogens on apple using* Rhodotorula glutinis *and its effects on post-harvest quality parameters*. - Biol. Control., 48: 79-83.
ZHANG Y., CHEN K., CHEN Q., ZHANG S., REN Y., 2003 - *Effects of acetylsalicylic acid (ASA) and ethylene treatments on ripening and softening of post-harvest kiwifruit*. - Acta Botan. Sinica, 45(12): 1447-1452.
ZHANG Y., CHEN K., ZHANG S., FERGUSON I., 2003 - *The role of salicylic acid in post-harvest ripening of kiwifruit*. - Post-harvest Biol. Technol., 28: 67-74.