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ORIGINAL ARTICLE

Effects of salicylic acid and putrescine on storability, quality attributes and antioxidant activity of plum cv. 'Santa Rosa'

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Abstract Plum fruit has a short shelf life with a rapid deterioration in quality after harvest. The primary goal of this study is to investigate and compare the effect of putrescine and salicylic acid on quality properties and antioxidant activity of plum during storage. The plum fruits (cv. 'Santa Rosa') were harvested at the mature ripe stage, and dipped in different concentrations of putrescine (1, 2, 3 and 4 mmol/L) and salicylic acid (1, 2, 3 and 4 mmol/L), as well as distilled water (control) for 5 min. The fruits were then packed in boxes with polyethylene covers and stored at 4 °C with 95 % relative humidity for 25 days. A factorial trial based on completely randomized block design with 4 replications was carried out. The weight loss, fruit firmness, total soluble solids, titratable acidity, pH, maturity index, ascorbic acid, total phenolics and antioxidant activity at 0, 5, 10, 15, 20 and 25 days after harvest were recorded. During the storage period, the weight loss, total soluble solids, pH and maturity index increased significantly while the fruit firmness, titratable acidity, ascorbic acid, total phenolics and antioxidant activity decreased significantly ($P<0.05$) for all treatments. Statistically significant differences were observed between different treatments (putrescine, salicylic acid and control) in all measured parameters. The data showed that the weight loss and softening of the plum fruits were decreased significantly by the use of putrescine and salicylic acid. Also, exogenous treatments of putrescine and salicylic acid are found to be effective in maintaining titratable acidity, ascorbic acid, total phenolics and antioxidant activity in plum fruits during storage at 4 °C. It was concluded that postharvest treatment of plum fruit with putrescine and salicylic acid were effective on delaying the ripening processes and can be used commercially to extend the shelf life of plum fruit with acceptable fruit quality.

Keywords *Prunus salicina* · Postharvest · Properties · Shelf life · Ascorbic acid · Total phenolics

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Introduction

Plums belong to the Rosaceae family and are one of the most important stone fruits (Manganaris et al. 2007). The two distinct types of ripening behaviour have been observed for plums; 'Beauty', 'Gulfruby', 'Santa Rosa' and 'Black Star' cultivars have typical climacteric fruits ripening patterns, in contrast to 'Shiro', 'Rubyred' and 'Golden Japan' which exhibit a suppressed-climacteric phenotype (Serrano et al. 2003; Díaz-Mula et al. 2009). The plum has been of recent interest for its nutritional, antioxidant activity and its consumers increased considerably. In this sense, plum is known to contain considerable vitamins (A, C and E), anthocyanins and other phenolic compounds and carotenoids (Stacewicz-Sapuntzakis et al. 2001). These parameters may supply important information to the consumer in terms of recognizing a more nutritional fruit.

Postharvest decay is the major factor limiting the extension of storage life of many fresh fruits. Plum has a short shelf life and its quality deteriorates rapidly after harvest (Perez-Vicente et al. 2002). Little research has been done on improving the quality properties and shelf life of plum fruit. Recent works studied low temperature storage and application of putrescine (Khan et al. 2008), postharvest treatments whit polyamines (Perez-Vicente et al. 2002), calcium and heat (Serrano et al. 2004), 1-methylcyclopropene (1-MCP) (Menniti et al. 2006) and salicylic acid (Luo et al. 2011).

Recently, there is an increasing interest in the use of natural compounds for maintenance of fruit quality and extension of

shelf life. Salicylic acid (SA), a widely distributed compound in plants, belongs to a group of phenolic compounds. Salicylic acid could be considered as an endogenous plant growth regulator involved in the regulation of physiological processes and disease resistance mechanisms (Luo et al. 2011). Numerous authors have reported the possible ameliorative effects of exogenously applied salicylic acid in banana (Stacewicz-Sapuntzakis et al. 2001), kiwifruit (Zhang et al. 2003), sweet cherry (Qin et al. 2003), navel orange (Huang et al. 2008) plum (Luo et al. 2011) and apple (Kazemi et al. 2011).

Polyamines (PAs) are a group of natural compounds with low molecular weight and aliphatic nitrogen structure, present in all living organisms. The major forms of polyamines including spermidine (triamine), spermine (tetramine) and putrescine, (diamine) are found in every plant cell (Galston and Sawhney 1990). Polyamines have been found to play a key role in many physiological processes such as cell growth and development and response to environmental stresses. Polyamines were also shown to maintain flesh firmness in apples (Kramer et al. 1989, 1991; Wang et al. 1993), strawberries (Ponappa et al. 1993), tomatoes (Law et al. 1991), lemon (Valero et al. 1998a, b, c), peach (Bregoli et al. 2004) and plum (Serrano et al. 2003). The treatment with exogenous polyamines has been reported to delay colour changes, reduce mechanical damage and chilling injury susceptibility and increase shelf life in both climacteric and non-climacteric fruits (Serrano et al. 1996; Martinez-Romero et al. 2002; Perez-Vicente et al. 2002).

Salicylic acid and polyamine treatments have the potential for commercial control of quality properties and increase shelf life of harvested fruit. However, little information exists on the use of salicylic acid and putrescine to preserve plum fruits quality during storage. Therefore, the aim of this research is to study the effects of postharvest application of salicylic acid and putrescine in plum cultivar ‘Santa Rosa’, specially changes in quality properties and antioxidant activity during storage.

Materials and methods

The ‘Santa Rosa’ plum cultivars harvested manually at commercial maturity stage at July 2011 from 14 years-old trees in Mashhad (Khorasan-e-Razavi province, Iran). The average temperature, the average rainfall and relative humidity in growing season (March to July) of 2011 were 28.6°C, 20 mm and 26 %, respectively. Soil texture was sand-loam, EC=4.1 (ds m^{-1}) and soil pH=7.2. The trees were spaced 6 and 3 m between and along the rows, respectively. Trees were grown under traditional irrigation and routine cultural practices suitable for commercial fruit production.

Fruits were transported by a ventilated car to the laboratory soon after harvest. Plums with defects (sunburns, cracks, cuts and bruises in peel) were discarded afterwards and fruits were selected in accordance with their colour and weight. The homogeneous fruits were randomized and divided into 10 lots of 160 fruit of perform treatments in 4 replicates (each replicate contained 20 individual fruit). The fruits were soaked in different concentrations of two materials including; putrescine (1, 2, 3 and 4 mmol/L) and salicylic acid (1, 2, 3 and 4 mmol/L), as well as distilled water (control) for 5 min. Treatments were performed by dipping fruits in 10 L of solution for 5 min, and then fruits were left to dry at room temperature and were packed in boxes with polyethylene cover and after stored at 4 °C and 95 % relative humidity (RH) for 25 days (Storage chamber: Electro Stell (ES), model E, Iran). After 0, 5, 10, 15, 20 and 25 days (5 day intervals), 3 fruits from each replication for each treatment (12 fruits) were sampled for analytical determinations. All reagents, solvents and standards were of analytical reagent grade.

Weight loss and firmness of fruit

Fruits were weighted individually at each sampling time with accuracy of±0.001 g. The weight loss was calculated as follows: weight loss (%)=[(A-B)/A]×100. Where A indicates the fruit weight at the time of harvest and B indicates the fruit weight after storage intervals. The same samples were evaluated for weight loss of the fruit each time at 5 day intervals until the end of the experiment. Fruit firmness was determined by a fruit pressure tester (8 mm diameter probe) on pared surfaces from opposite sides of each fruit and the results were expressed as Newtons (N).

Total soluble solids, titratable acidity, pH and maturity index

The total soluble solids (TSS) were assessed by using a digital refractrometer (Erma, Tokyo, calibrated using distilled water), and were expressed as degree °Brix at 21 °C. The titratable acidity (TA) was determined with a digital acidity (model GMK855, Korea) assay. Results were reported as g of malic acid per 100 g of fresh weight (g/100 g FW). The pH measurements were performed using a digital pH meter (model 601, Metrohm, Herisau, Switzerland) at 21 °C. Maturity index was calculated by dividing total soluble solids to titratable acidity.

Ascorbic acid and total phenolics

Ascorbic acid was estimated according to method described by Mazumdar and Magumdar (2003). Results were expressed as mg ascorbic acid per 100 g of fresh weight (mg/100 g FW). The total phenolics were determined by using Folin-Ciocalteu method (Singleton et al. 1999). 1 g of plum tissue was extracted with 10 ml methanol (85 %). 250 μL of this extract was dissolved in a 250 μL of sterile distilled water, and then samples were mixed with 2.5 mL of 10-fold-diluted Folin-

Ciocalteu reagent and 2 mL of 7.5 % sodium carbonate. The mixture was shaken for 1.5 to 2 h before the absorbance was measured by a UV–visible spectrophotometer (model 2010, Cecil Instr. Ltd., Cambridge, UK) at 765 nm. Gallic acid was used as a standard. The results were expressed as mg gallic acid equivalent in 100 g fresh weight (mg GAE/100 g FW).

Antioxidant activity

Antioxidant activity was determined by the DPPH (1,1-diphenyl-2- pycrylhydrazyl) method described by Ismail et al. (2009). Briefly, 1 g of apricot tissue was extracted with 10 mL methanol (85 %). 1 mL of this extracts were mixed with 2 mL of DPPH (0.15 mmol/L) in methanol. The mixtures were shaken vigorously and left to stand for 30 min (under dark condition). The control was prepared by adding 2 mL of DPPH to 1 mL methanol. Absorbance of the resulting solution was measured at 517 nm by a UV–visible spectrophotometer (model 2010, Cecil Instr. Ltd., Cambridge, UK). The antioxidant activity is expressed in the form of the percentage of free radical scavenging.

Statistical analysis

This experiment was conducted according to factorial based on completely randomized block design with 4 replicates. A two factor (ANOVA) was made for salicylic acid and putrescine to determine the effect of their concentrations and storage period on weight loss, fruit firmness, total soluble solids, titratable acidity, pH, maturity index, ascorbic acid, total phenolics and antioxidant activity. Data were analyzed by Statistical Analysis System (SAS) software Version 9.1 and differences among means were determined for significance at $P<0.05$ using Tukey's test.

Results and discussion

The results of ANOVA for dependent variables for storage period, concentration, and their interactions for two materials of putrescine (PUT) and salicylic acid (SA) are given in Table 1.

Weight loss

As shown in Fig. 1, the weight loss of the plum fruits increased progressively during storage at 4 °C, that the weight loss levels at the initial of the storage period were lower than the end ones for both materials (putrescine and salicylic acid). Results were in agreement with data reported by Serrano et al. (2003). Similar patterns of changes were reported for apricot (Ghasemnezhad et al. 2010). Significant differences ($p<0.05$) were revealed among the different treatments for fruit weight loss (Fig. 1). During the storage at 4 °C, treatments with various concentrations of putrecine and salicylic acid showed that the lower percentage of weight loss than those found in control ones. The higher the putrescine and salicylic acid concentrations applied, the greater the decrease in weight loss. The lowest of weight loss were observed in 4 mmol/L putrescine and 4 mmol/L salicylic acid treatments throughout storage (Fig. 1). Serrano et al. (2003) reported that the exogenous application of putrescine caused significantly less of weight loss of plum fruits during storage. It was previously showed that the weight loss of apple fruit significantly decreases in salicylic acid treatment in comparison to control treatment during storage (Díaz-Mula et al. 2009). The data indicates that among the presently tested treatments, salicylic acid treatments were found to be more effective in reducing weight loss in plum fruits in than the putrescine treatments.

Woods (1990) showed that the weight loss of fruit throughout storage period could be due to the water exchange between the atmosphere of internal and external, the transpiration rate being accelerated by cellular breakdown. The obtained results detected that the putrescine treatment decreased weight losses during storage, this effect might be due to modification of delay in the removal of epicuticular waxes which play an important role in water exchange through the skin, and thus lower weight loss would occur. Also, Zheng and Zhang (2004) reported that the salicylic acid caused reduction in rate of respiration and weight loss of fruit by closing stoma. With regard to the results, the salicylic acid and putrescine treatments showed significantly less of weight loss during storage; there being a negative correlation between concentrations of salicylic acid, putrescine and weight loss.

Fruit firmness

The results in this experiment showed that fruit flesh firmness decreased significantly during storage at 4 °C in both materials (putrescine and salicylic acid) (Fig. 2). The results were in agreement with the findings reported by Díaz-Mula et al. (2009) and Serrano et al. (2003). The differences between treatments were significant in fruit firmness (Fig. 2). The flesh firmness was affected by putrescine and salicylic acid treatments, since control fruits had significantly lower firmness during storage, while the highest levels were obtained with 4 mmol/L putrescine and 4 mmol/L salicylic acid treatments (Fig. 2). Serrano et al. (2003) also reported that the treated plum fruits with putrescine had the highest level of fruit firmness during storage. Similar data were also reported for apples (Wang et al. 1993), apricots (Martinez-Romero et al. 2002) and strawberry (Zokaee-Khosroshahi et al. 2007). Treatment with exogenous polyamines has been reported to maintain fruit firmness in bananas (Srivastava and Dwivedi 2000), kiwifruit (Aghdam et al. 2009) and sweet cherry (Valero et al. 2011) during storage. In relation to fruit firmness,

Table 1 ANOVA for dependent variables for storage period, concentration and their interactions for two materials of putrescine (PUT) and salicylic acid (SA)

Source	DF	Parameters								
		WL[a]	FF	pH	TSS	TA	MI	A	TPs	AA
PUT										
Storage period	5	3368.88[b]**	56.39**	9.62**	68.06**	0.55**	511.54**	89.56**	8335.01**	3099.98**
Concentration	4	322.66*	1.59**	0.99**	4.29**	0.03**	40.04**	9.82**	757.66**	496.75*
Storage period×concentration	20	120.85**	0.40**	0.22**	1.55**	0.008**	12.19**	2.34**	227.73*	123.24**
Error	60	11.32	0.06	0.04	0.47	0.002	1.84	0.33	44.16	17.98
Total	89									
SA										
Storage period	5	2997.25**	49.47**	9.04**	56.85**	0.46**	409.63**	67.01**	7783.13**	2463.23**
Concentration	4	313.19*	2.62**	1.04**	8.06**	0.05**	60.36*	16.44**	682.02**	759.35**
Storage period×concentration	20	102.08**	0.61**	0.24**	2.68**	0.01**	20.17**	4.24**	184.34*	176.04*
Error	60	9.30	0.06	0.03	0.16	0.003	2.01	0.32	24.515	18.03
Total	89									

[a] *WL* weight loss; *FF* fruit firmness; pH; *TSS* total soluble solids; *TA* titratable acidity; *MI* maturity index; *A* ascorbic acid; *TPs* total phenolics; *AA* antioxidant activity

[b] Sum of squares, **: significant at 0.01 level, *: significant at 0.05 level and *ns* not significant

salicylic acid treatments were more effective in than the putrescine treatments in maintaining fruit firmness.

Most fruits lose firmness and soften, with an acceleration of the ripening process, exhibiting a loss of quality during the storage period. The polyamines influence on firmness augmentation can be attributed to their capacity cross-link to pectic substances in the cell wall, resulting in rigidification that is detectable immediately after treatment (Abbott et al. 1989) and also as inhibition of the action of wall-degrading enzymes, such as pectinesterase, pectinmethylesterase and polygalacturonase, which reduces fruit softening during storage (Valero et al. 2002). Kazemi et al. (2011) reported that the effect of salicylic acid on the reduction of fruit softening can be attributed to ACO (1-aminocyclopropane-1-carboxylic acid oxidase) activity inhibitory, and therefore on ACC (1-aminocyclopropane-1-carboxylic acid) conversion to ethylene. In accordance with this hypothesis, the exogenously applied putrescine and salicylic acid went to cell walls to maintain high levels of fruit firmness and these high levels of firmness lead to increased shelf life.

Total soluble solids

According to the data shown in Fig. 3, the content of total soluble solids increased significantly during storage at 4 °C in both materials (putrescine and salicylic acid). Similar results were also reported by Díaz-Mula et al. (2009) and Serrano et al. (2003). There was a significant difference ($p<0.05$) between treatments in terms of their effects on levels of total soluble solids (Fig. 3). The concentration of total soluble solids was significantly affected by the exogenous application of both putrescine and salicylic acid treatments. During the

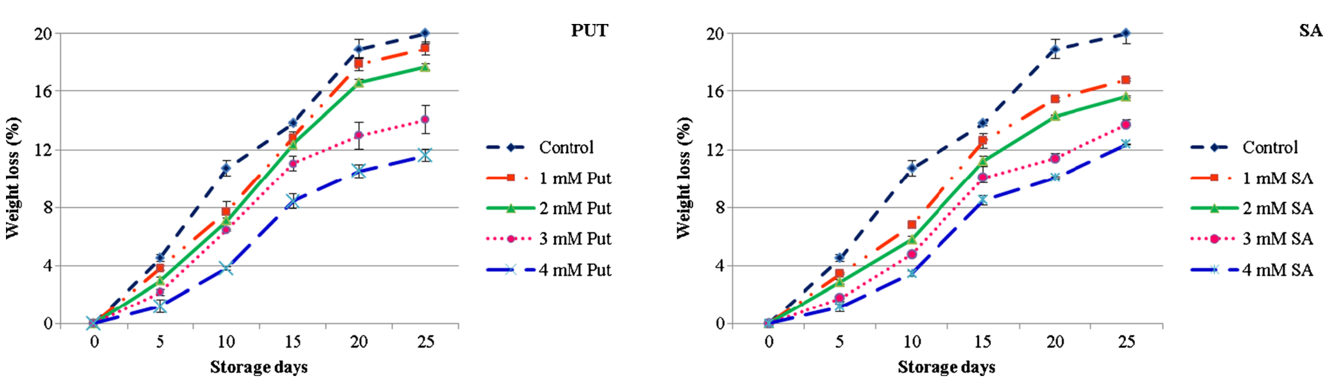

Fig. 1 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on weight loss of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications ± standard errors

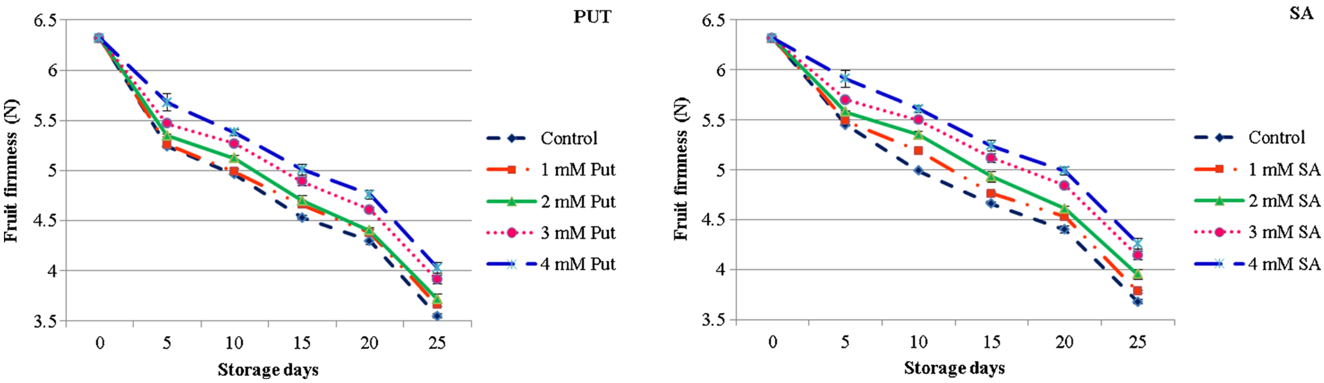

Fig. 2 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on fruit firmness of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications ± standard errors

storage, treatments of 4 mmol/L putrescine and 4 mmol/L salicylic acid had the lowest amount of total soluble solids and control treatment had the highest total soluble solids content (Fig. 3). This data was in agreement with the report of Kazemi et al. (2011) who proposed that the minimum total soluble solids were observed in 3 mmol/L salicylic acid and the highest total soluble solids were recorded in control apple fruit during storage. In another experiment, the effects of putrescine application on postharvest life and physiology of apricot fruit were investigated and the results showed that the putresince treatment (4 mmol/L) had the lowest content of total soluble solids and control treatment had the highest total soluble solids levels during storage (Zokaee-Khosroshahi and Esna-Ashari 2008). According to data, the treatment with salicylic acid was more effective in than the putrescine treatment to retard the total soluble solids change in relation to the control plum fruit.

The increase in total soluble solids content during storage was probably due to the concentrated juice content as a result of dehydration and hydrolysis of polysaccharides. The obtained results indicated that all treatments showed increases in content of total soluble solids, although the increases were significantly lower in treatments of putrescine and salicylic acid than in control treatment during the storage period. This effect of putrescine and salicylic acid can be attributed to low levels of the respiration rate, ethylene production and delay in ripening process.

Titatable acidity

The data indicated that the content of titratable acidity decreased significantly during storage at 4 °C for both materials (putrescine and salicylic acid) (Fig. 4). Similar results were also reported by Díaz-Mula et al. (2009) and Serrano et al. (2003). As shown in Fig. 4, a variation in terms of titratable acidity level was observed among the treatments and the differences were statistically significant. The treated fruits with putrescine and salicylic acid had a significantly influence on the titratable acidity content. During the storage at 4 °C, the highest level of titratable acidity was detected in 4 mmol/L putrescine and 4 mmol/L salicylic acid treatments, while the lowest content was observed in control fruit (Fig. 4). Zokaee-Khosroshahi et al. (2007) also reported that strawberries treated with putrescine had the highest amount of titratable acidity during storage. Kazemi et al. (2011) proposed that the maximum titratable acidity were observed in 3 mmol/L salicylic acid and the minimum titratable acidity were recorded in control apple fruit during storage. With respect to the results, the treatments of salicylic acid were found to be more effective

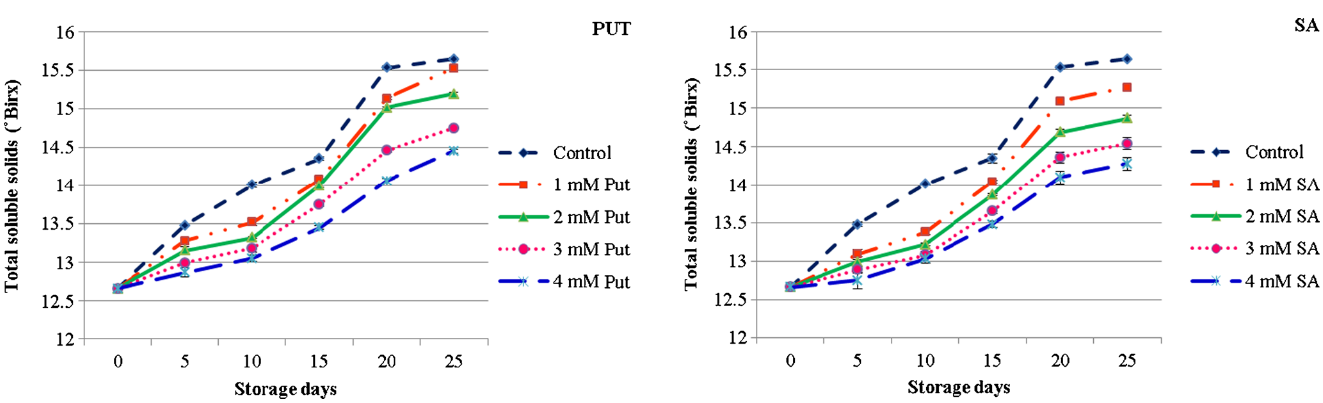

Fig. 3 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on total soluble solids of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications ± standard errors

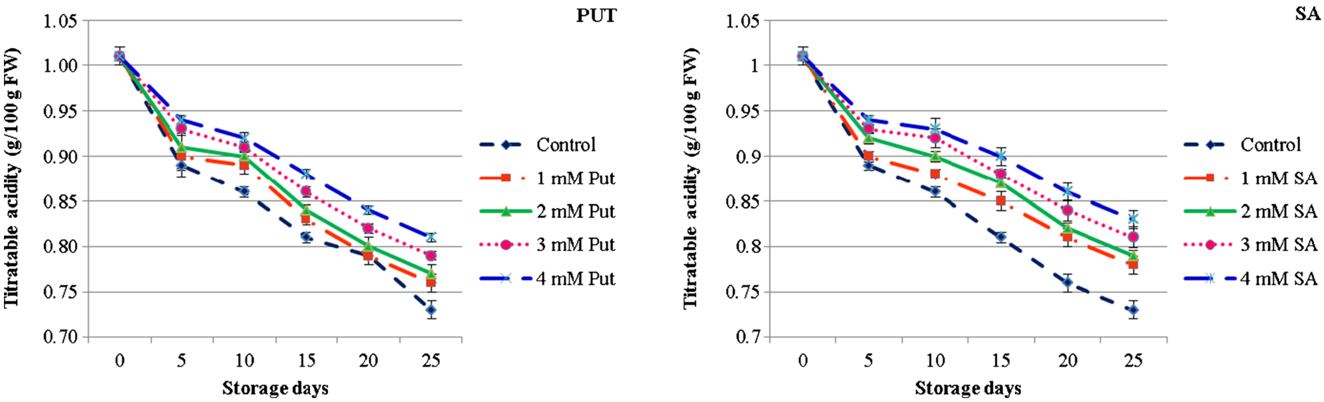

Fig. 4 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on titratable acidity of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications ± standard errors

in than the putrescine treatments in maintaining fruit firmness during storage.

The titratable acidity is an important factor in maintaining the quality of plum fruits, which is directly related to the organic acids content present in the fruit. Zokaee-Khosroshahi et al. (2007) and Ishaq et al. (2009) reported that the decrease of titratable acidity content could be due to consumption of organic acids in fruits during respiration. According to the results, the treatments of putrescine and salicylic acid showed significantly lower decrease in content of titratable acidity than control treatment during storage. In the present study it seems that putrescine and salicylic acid treatments did have any significant effect on respiration process which could result in reduction or delay of respiration and maintain titratable acidity content.

pH

The obtained results detected that the pH values increased significantly during storage at 4 °C, that the pH values at the initiation of the storage period were lower than at the end for both materials (putrescine and salicylic acid) (Fig. 5). Similar data were also reported for apricot and peach (Zokaee-Khosroshahi and Esna-Ashari 2008). A significant difference in the pH values were found among treatments during storage period (Fig. 5). The levels of pH was significantly affected by putrescine and salicylic acid treatments, since treated fruits with putrescine and salicylic acid had the lowest pH values during storage, while the highest was in control fruit (Fig. 5). In another experiment, the effects of putrescine on postharvest life and physiology of apricot and peach fruits were investigated and the results showed that the putresince treatments (4 mmol/L) had the lowest pH values and control treatment had the highest pH levels during storage (Zokaee-Khosroshahi and Esna-Ashari 2008). Also, the data indicated that the treatments of salicylic acid were more effective in than the putrescine treatments in change of pH values during storage.

During the storage, the all fruits showed increases in pH values, although the increases were significantly lower in treated fruits with putrescine and salicylic acid than in control fruit. This effect of putrescine and salicylic acid might be due to create a thin layer on the surface of fruit which delayed degradation process.

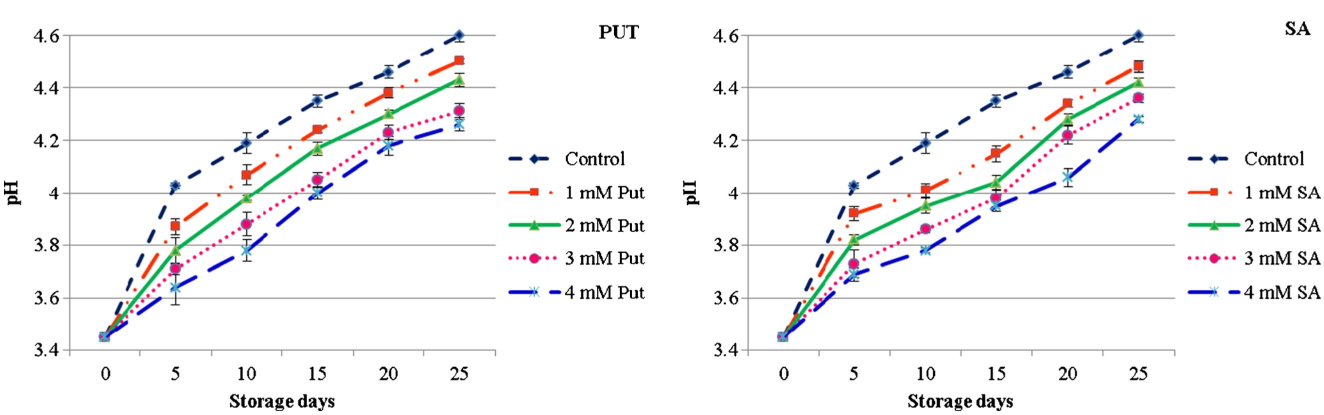

Fig. 5 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on pH of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications±standard errors

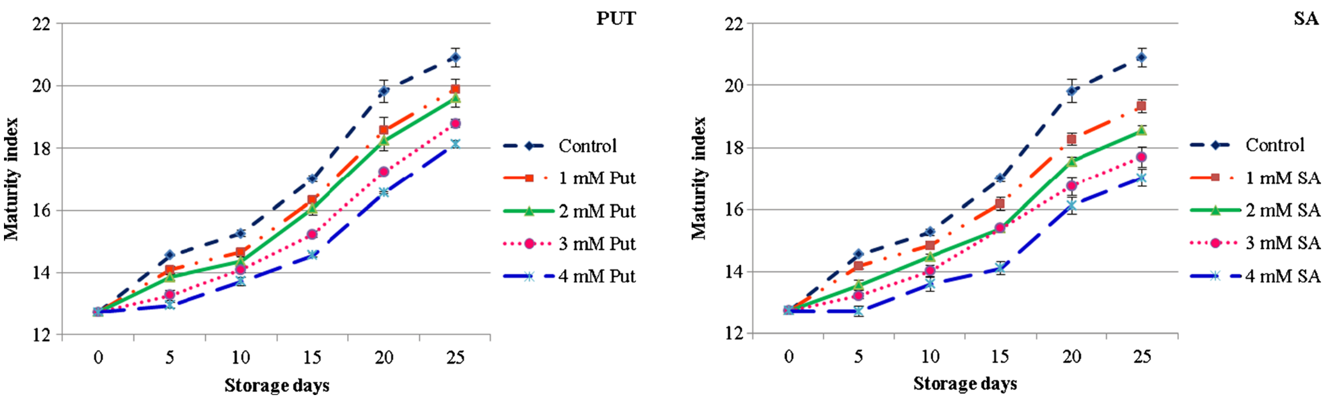

Fig. 6 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on maturity index of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications±standard errors

Maturity index

As shown in Fig. 6, significant increases in maturity index during storage at 4 °C were observed in both materials (putrescine and salicylic acid). The result of maturity index showed significant differences in relation to the treatments applied (Fig. 6). The treated fruit with putrecine and salicylic acid showed lower levels of maturity index in than those found in control ones. The highest amount of maturity index was observed for control treatment, while the lowest was in 4 mmol/L putrescine and 4 mmol/L salicylic acid treatments during storage (Fig. 6). Khan et al. (2008) also reported that the treated plum fruits (cv. 'Angelino') with putrescine had the lowest amount of maturity index during storage. The data in this experiment showed that the salicylic acid treatments were found to be more effective in reducing maturity index in plum fruits in than the putrescine treatments.

The maturity index (TSS/TA) is responsible for the taste and flavor of plum. The increase in maturity index content during storage was probably due to the increase total soluble solids content and decrease in titatable acidity levels. With respect to the data, the all treatments showed increases in content of maturity index, although the increases were significantly lower in treatments of putrescine and salicylic acid than in control treatment during the storage period. This effect might be due to the significant effect of putrescine and salicylic acid treatments on levels of titratable acidity and total soluble solids during storage.

Ascorbic acid

The levels of ascorbic acid decreased significantly during storage at 4 °C, that the content of ascorbic acid at the initial of the storage period was higher than the end ones just for both materials (putrescine and salicylic acid) (Fig. 7). Ishaq et al. (2009) reported also the ascorbic acid content in apricot fruit was reduced during storage. With regards to the observations, significant differences were found in relation to the ascorbic acid level (Fig. 7). Putrescine-treated and salicylic acid-treated plums had higher ascorbic acid levels than that of control during storage, e.g. the control treatments had the lower amount of ascorbic acid than the other treatments (Fig. 7). Kazemi et al. (2011) showed that the salicylic acid treatment had a significant influence on retaining ascorbic acid content in apple fruits storage duration. Also, among the presently tested treatments, salicylic acid treatment is found to be more

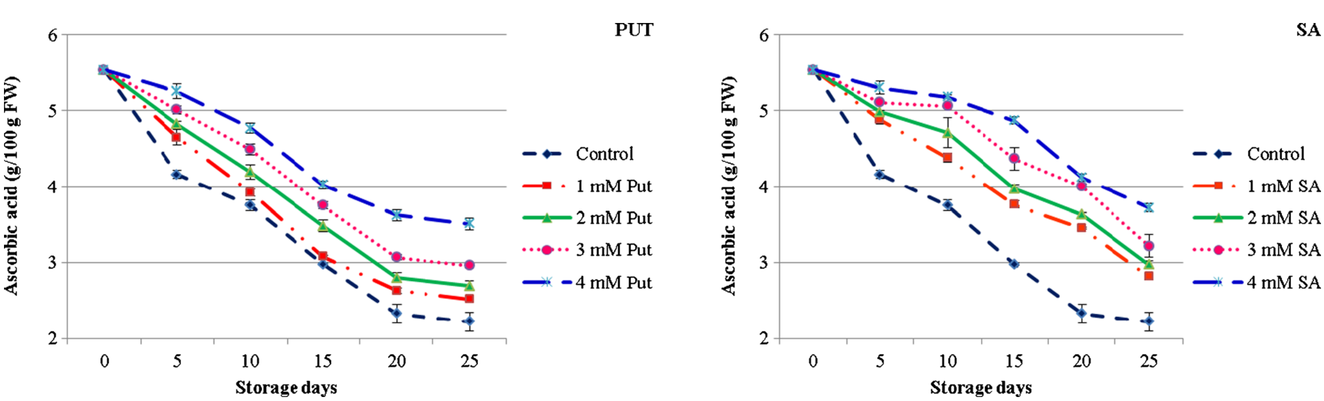

Fig. 7 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on ascorbic acid of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications±standard errors

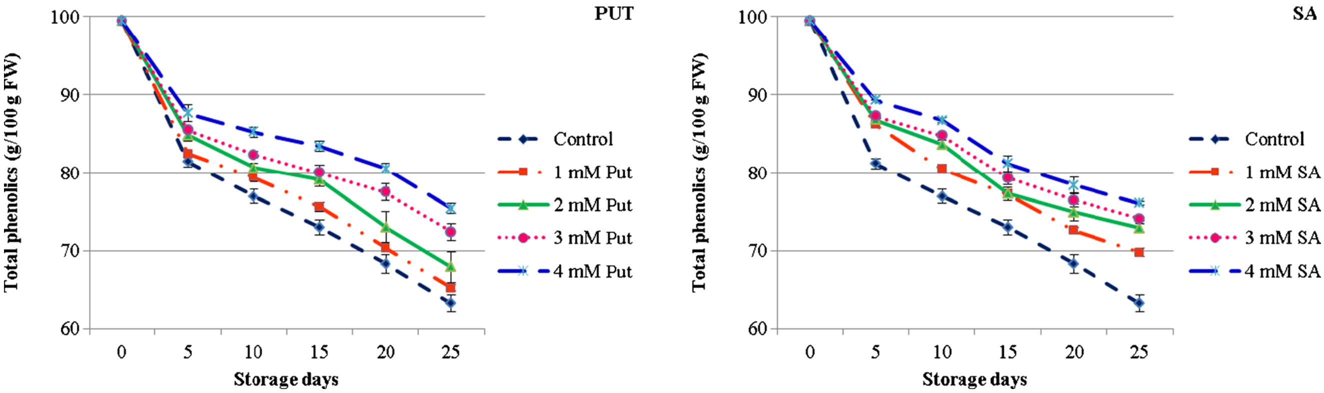

Fig. 8 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on total phenolics of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications ± standard errors

effective in maintaining ascorbic acid in plum fruits during storage in than putrescine treatments.

Ascorbic acid is an important nutrient quality factors, which is very sensitive to degradation due to its oxidation compared to other nutrients during storage. According to Ishaq et al. (2009) the decrease of ascorbic acid during storage could be due to the conversion of dehydroascobic to diketogulonic acid by oxidation. During the storage, all treatments showed decreases in content of ascorbic acid, although the decreases were significantly lower in treatments of putrescine and salicylic acid than in control treatment. The influence of putrescine and salicylic acid might be due to decreased or delayed ascorbate oxidase activity.

Total phenolics

At the beginning of the experiment the content of total phenolics was 99.43 (mg/100 g FW), that decreased significantly in both materials (putrescine and salicylic acid) during storage at 4 °C (Fig. 8). There were significant differences ($p<0.05$) between treatments in terms of their effects on total phenolics content during storage (Fig. 8). As shown in Fig. 8, 4 mmol/L putrescine and 4 mmol/L salicylic acid treatments had the highest total soluble solids and control treatment had the lowest levels of total phenolics. According to the results, salicylic acid treatments maintained higher total phenolics levels in treated plums in than the putrescine treatments.

Ghasemnezhad et al. (2010) reported that the decrease of total phenolic levels might be due to breakdown of cell structure in order to senescence phenomena during the storage period. According to the observations, although all the treatments showed decrease in content of total phenolics, the decrease were significantly lower in the cases of putrescine and salicylic acid compared to that of control treatment. The effect of putrescine and salicylic acid treatments on maintainance of total phenolics content plausibly may be attributed to delay in senescence process.

Antioxidant activity

The antioxidant activity decreased significantly during storage at 4 °C, that the antioxidant activity at the initial of the storage period was higher than the end ones just for both materials (putrescine and salicylic acid) (Fig. 9). A variation in terms of

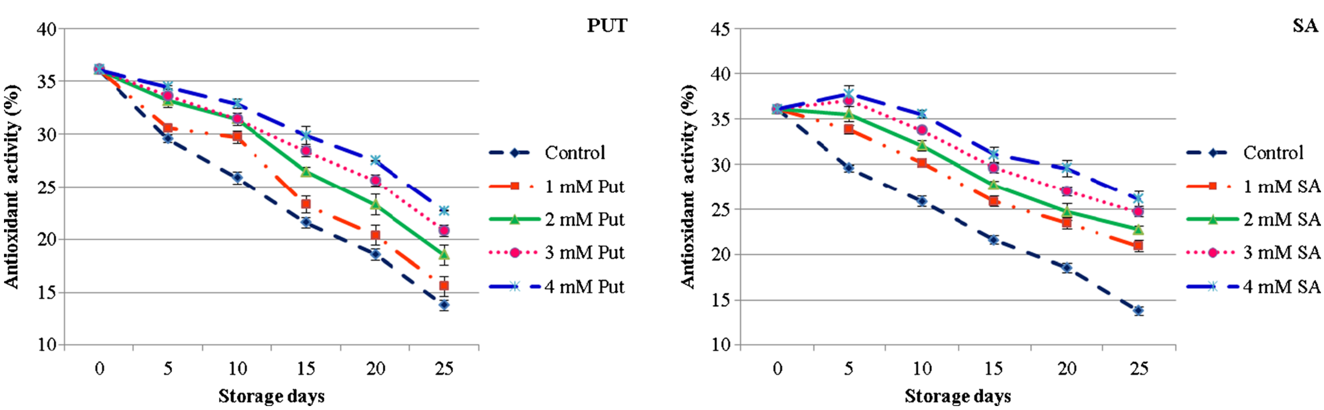

Fig. 9 Influence of putrescine (PUT) and salicylic acid (SA) concentrations (mM=mmol/L) on antioxidant activity of plum (cv. 'Santa Rosa') during storage at 4 °C. The results represent the means of 12 fruit in 4 replications ± standard errors

total soluble solids content was observed among the treatments and the differences were statistically significant (Fig. 9). The antioxidant activity was significantly higher in putrescine and salicylic acid treatments than in control-treated ones (Fig. 9). During the storage period, treated fruit with salicylic acid had higher antioxidant activity in than the putrescine treatment.

The results showed that the antioxidant activity declined along with decease of total phenolic and ascorbic acid contents. In previous researches, the positive correlation between antioxidant activity and total phenolics has been reported (Díaz-Mula et al. 2009; Ghasemnezhad et al. 2010). The treatments of putrescine and salicylic acid maintained antioxidant activity of the fruit significantly during storage. This effect of putrescine and salicylic acid treatment was probably due to maintain of total phenolics and ascorbic acid levels during storage.

Conclusion

This research showed the same behaviour in all measured factors during storage at 4 °C for both putrescine and salicylic acid. During the storage period, the typical changes related to quality loss of plum fruit occurred such as; weight loss, softening, decrease in titratable acidity, ascorbic acid, total phenolics and antioxidant activity and increase in both total soluble solids and pH. The results in this experiment revealed that the exogenous treatments of putrescine and salicylic acid are found to be effective in maintaining weight, firmness, titratable acidity, ascorbic acid, total phenolics and antioxidant activity in plum fruits during storage at 4 °C. Thus, the data suggest that treatments of putrescine and salicylic acid can be used commercially to extend the shelf life of plum fruit with acceptable fruit quality.

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