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EFFECTS OF PRE-HARVEST METHYL JASMONATE TREATMENT ON POST-HARVEST FRUIT QUALITY OF JAPANESE PLUMS

Emine Kucuker [1*†], Burhan Ozturk [2*†]

[1]Department of Horticulture, Faculty of Agriculture, University of Gaziosmanpaşa, 60240, Tokat-Turkey, [2]Department of Horticulture, Faculty of Agriculture, University of Ordu, 52200, Ordu-Turkey.
[*]Correspondence to: Emine Kucuker, e-mail: emine2346@gmail.com; Burhan Ozturk, e-mail: burhanozturk55@gmail.com
[†] Emine Kucuker and Burhan Ozturk contributed equally to this work

Abstract

Background: Plum fruits constitute a good source of natural antioxidant substances. Particularly, plums contain large amounts of phenolic compounds and flavonoids having natural antioxidant activity which is effective in human diet. The aim of this study was to evaluate the effects of pre-harvest MeJA treatment on the fruit quality and bioactive compounds of three different Japanese plums under storage conditions.
Materials and Methods: The effects of pre-harvest methyl jasmonate treatment (MeJA) on weight loss, color characteristics (L^*, C^* and h°), firmness, soluble solids content (SSC), titratable acidity (TA), total phenolics (TP) and total antioxidant activity (TAA) of 'Black Beauty', 'Black Amber' and 'Fortune' plum fruits during the cold storage (at 0±0.5 °C and 90±5% RH) were investigated in this study.
Results: MeJA did not have significant effects on the weight loss (%) of 'Black Amber' and 'Fortune' fruits, whereas it was effective in delaying the weight loss of 'Black Beauty' at the end of storage. The color characteristics of all plum cultivars were not significantly affected by MeJA at the end of storage. In all plum cultivars, the SSC increased, while TA significantly ($P<0.05$) decreased during storage. TP and TAA of 'Black Amber' and 'Fortune' fruits significantly increased during the cold storage. MeJA treatments increased fruit firmness, TP and TAA (according to FRAP) of 'Fortune' plums at the end of storage.
Conclusion: The scientific results about the effects of pre-harvest MeJA treatments on the cold storage of Japanese plums may contribute significant helps to improve plum storage durations and quality characteristics.

Keywords: Color, firmness, total phenolic, total antioxidant, weight loss.

Introduction

Plums have a post-harvest cold storage life of 2-8 weeks. Excessive softening of fruit flesh is the basic factor shortening the storage and shelf life of plums. Preservation of fruit firmness also provides the preservation of taste, flavor and fruit texture and consequently increases plum consumption (Crisosto et al., 2004). Softening in fruit flesh decreases the market life and value of the fruit and limits the fruits to closer markets.

There are several methods to prolong the storage life and to preserve the fruit quality. One of them is to apply plant growth regulators before and after harvest. Aminoethoxyvinylglicine (AVG), polyamines (putrescine), 1-methylcyclopropene (1-MCP) and jasmonates (MeJA) are the most common growth regulators used for extending post-harvest storage life of horticultural crops (Jobling et al., 2003; Khan and Singh, 2007; Khan et al., 2007; Khan and Singh, 2010).

Methyl jasmonate (MeJA), a natural plant growth regulator, is a phytohormone with ubiquitous distribution among plants. Depending upon the plant species, cultivar, stage of development and climacteric stage, it modulates many physiological events in higher plants, such as defense responses, flowering, plant growth and development, senescence, fruit ripening, ethylene, anthocyanin and carotenoid synthesis (Fan et al., 1998; Rudell et al., 2002; Rohwer and Erwin, 2008; Carvalho et al., 2011; Zapata et al., 2014).

Jasmonic acid and its methyl ester, methyl jasmonate, function as a basic signaling compound in metabolic reactions of plants (Rudell et al., 2002; Rohwer and Erwin, 2008). Researchers (Rudell et al., 2002; Larrondo et al., 2003; Saniewski et al., 2004; Jin et al., 2009; Gong et al., 2013) reported that MeJA stimulated secondary metabolites in grapevine, strawberry, apple, plum, peach and mango fruits. It was also reported that MeJA increased anthocyanin accumulation in apples and strawberries, and β-carotene accumulation in tomato (Rudell et al., 2005; Moreno et al., 2010). Khan and Singh (2007) reported that post-harvest exogenous MeJA applications to 'Black Amber', 'Amber Jewel' and Angelino plums positively affected the bioactive compounds of plum fruits during ripening period.

The aim of this study was to evaluate the effects of pre-harvest 2240 mg L^{-1} MeJA treatment on weight loss, color characteristics, fruit firmness, SSC, titratable acidity, total phenolics and total antioxidant activity of three different Japanese plums under storage conditions at 0 °C.

Materials and Methods

Plant material

Five-years old uniform Japanese plum trees (*Prunus salicina* Lindell cvs. 'Black Beauty', 'Black Amber' and 'Fortune') grafted on Myrobalan (*Prunus ceresifera* Ehrh.) rootstock from Horticultural Research Center of Gaziosmanpaşa University (40° 20' 02.19"N latitude, 36° 28' 30.11"E longitude and 623 m above sea level, Tokat, Turkey) were selected as the plant material of the study.

Experimental design

Experimental design was randomized complete block with three blocks, each of having two trees. For each plum cultivar, 6 trees were selected and trees were grouped with 2 trees per block based on proximity in orchard and crop load for each plum cultivar. Methyl jasmonate dose was applied to one tree in each block and the other tree of the block was considered as control. Experimental trees were planted in north-south direction with 4 x 4 m spacing. Trees were trained in modified-leader system.

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MeJA (Sigma-Aldrich, Taufkirchen, Germany) was applied 2 weeks before the estimated harvest date at a dose of 2240 mg L^{-1}. MeJA dose was selected based on previous studies carried out under field conditions. Only water (with pH 6.48) was used in control treatment trees. All spray solutions contained 'Triton X-100' **as** surfactant [(0.077%, v/v), Alfa Aesar, Karslruhe, Germany]. Treatments were applied to runoff with a low pressure hand sprayer as fruit and foliar sprays. Volume of solution is significant to have the maximum impact of MeJA over the fruit and foliar. Therefore, amount of solution to be applied was calculated by using the equation developed by researchers (Anonymous, 2011) and 1.500 mL solution was sprayed to each tree. Shape (conical or spherical), height and row spacing were taken into consideration to calculate the amount of solution. MeJA was sprayed over trees early in the morning of a day without wind and precipitation.

Fruit quality assessment

The plum fruits were harvested at the firm-ripe stage. 'Black Beauty' plums were harvested on July 15, 'Black Amber' on July 25 and 'Fortune' on August 4, 2011. Plums with [with soluble solids content of 10%, 9% and 11% and fruit firmness of 35 N, 50 N and 55 N respectively for 'Black Beauty', 'Black Amber' and 'Fortune'] uniform of shape, color and size and free from visual symptoms of any disease or blemishes were harvested at the estimated harvest date.

Thirty fruits were randomly harvested from each tree in each block for each treatment at the estimated harvest date of each plum cultivar. Of these fruits, twenty were used to determine the fruit quality characteristics (fruit firmness, SSC and TA) and ten fruits were used to determine total phenolics (TP) and total antioxidant activity (TAA). All fruit quality characteristics and bioactive compounds were replicated three times. In order to determine fruit quality parameters and bioactive compounds during the cold storage, 120 fruits from each tree in each block for each treatment were harvested at the estimated harvest dates of each plum cultivar. The harvested plums were immediately placed into cardboard boxes in single rows and transferred to the cold storage at 0±0.5 °C temperature and 90±5% relative humidity (RH) within an hour. Fruits were stored in cold storage for 4 weeks. For each analysis period, 30 fruits were selected and 20 of them were used to determine the fruit quality characteristics (fruit firmness, SSC and TA) and 10 were used to determine bioactive compounds (phenolic and antioxidant activity). Bioactive compounds were only investigated in fruit flesh. The fruits were analyzed on 0, 7^{th}, 14^{th}, 21^{st}, and 28^{th} days of storage.

Fifty fruits from each tree in each block of every treatment were stored in cardboard boxes in single rows at the estimated harvest date of each plum cultivar to evaluate change of weight loss (%) and color characteristics (L^*, C^* and h°) of each plum cultivar during the cold storage.

Physico-mechanical properties

Fruit weights were determined by using a digital balance (±0.01 g) (Radvag PS 4500/C/1, Poland). Weight loss was determined by taking the difference between the initial and final weights of each replicate and expressed as percent. Chromatic analyses were conducted in accordance with the CIE (Commission Internationale de l'Eclairage) system of 1976. The color characteristics (L^*, a^* and b^*) of plums were determined with a chromameter (Minolta, model CR–400, Tokyo, Japan). Values of L^*, a^* and b^* were used to define a three-dimensional color space and interpreted as follows: L^* indicates lightness, with values ranging from 0 (completely opaque or 'black') to 100 (completely transparent or 'white'); a positive a^* value indicates redness on the hue circle ($-a^*$ =greenness) and a positive b^* value indicates yellowness ($-b^*$ =blueness). The hue angle (h^o) expresses the color nuance and values are defined as follows: red-purple: 0°; yellow: 90°; bluish green: 180°; blue: 270°. The chroma (C^*) is a measure of chromaticity, which defines the purity or saturation of the color. The chroma value was calculated with the formula $C^* = (a^{*2}+b^{*2})^{1/2}$, and the hue angle with $h° = \tan^{-1} b^*/a^*$ (McGuire, 1992). The fruit skin was cut at two different points (on cheek) over the equatorial part of the fruit and the fruit firmness was measured by using Effegi penetrometer (model FT–327; MoCormick Fruit Tech, Yakima, WA) with 7.9 mm tip. The measurement values were expressed as Newton (N).

Biochemical characteristics

In each analysis time, 20 fruits were used for each replication. Fruits were divided into 4 groups, each of with 5 fruits, and 4 different measurements were obtained from each replication. The SSC of a homogenate obtained from five fruits was determined with a digital refractometer (model PAL-1, McCormick Fruit Tech., and Yakima, Wash), and expressed as % soluble solids. Titratable acidity (TA, g malic acid 100 g^{-1}) was determined with 10 mL juice diluted in 10 mL distilled water, which was titrated with 0.1 N NaOH to a pH of 8.2.

A total of ten fruits were homogenized and placed into 5 different tubes each of having two fruits and five different measurements were taken in each replication. The fruit samples were kept in 50 mL tubes at -20 °C for biochemical analysis. Samples were thawed at room temperature (≈ 21 °C) and homogenized in a food grade blender. The resultant slurry was centrifuged (12000 g) for 30 min at 4 °C to separate the juice from the pulp. The freshly obtained juice materials were diluted with distilled water, divided into multiple sample aliquots, and refrozen at -20 °C until used in phenolics and antioxidant assay procedures.

Total phenolics: A portion of 300 µL from each sample was diluted with 4.3 mL distilled water and 100 µL Folin-Ciocalteu reagent were added. After an interval of 3 min, 20% Na_2CO_3 was added to 300 µL portions, and the mixture was vortexed and incubated for 30 min. Absorbances were then read on a UV-VIS (PerkinElmer, Lambda–1050 spectrophotomer, CA, USA) spectrophotomer at 760 nm. Gallic acid was used as the standard. The results were expressed as mg of gallic acid equivalent per gram of fresh weight (fw) (mg GAE g^{-1} fw), (Beyhan et al., 2010).

$ABTS^+$ radical scavenging activity: 2 mM of $ABTS^+$ (2.2''-azino-bis (3-ethyl benzothiazoline-6-sulfonic acid) diammonium salt) and 2.45 mM of $K_2S_2O_8$ solutions were prepared by 0.1 M of PO_4^{-3} buffer solution (pH 7.4). The $ABTS^+$ and $K_2S_2O_8$ solutions were mixed in (1:2) ABTS-$K_2S_2O_8$ and incubated for 6 h in dark. The absorbance of the mixture was read at 734 nm and it was diluted with PO_4^{-3} buffer if the value was greater than 0.75. Finally, 20 µL samples were taken out of the mixture into tubes, 1 mL of $ABTS^+$ - $K_2S_2O_8$ solution was added to each tube and buffer solution was added to make the total sample volume 4 mL. Following vortexing, they were incubated for 30 min and absorbances were read at 734 nm. The results were expressed as µmol Trolox equivalents (TE) per gram of fw (µmol TE g^{-1} fw) (Pellegrini et al., 1999).

Ferric ions (Fe^{+3}) reducing antioxidant power assay (FRAP): Portions of 120 µL were taken from the samples, 0.2 M of phosphate buffer (PO_4^{-3}) (pH 6.6) was added to obtain a volume of 1.25 mL and then 1.25 mL of 1% potassium ferricyanide ($K_3Fe(CN)_6$) solution was added. After vortexing, they were incubated at 50 °C. Afterwards, 1.25 mL of 10% TCA (trichloro acetic acid) and 0.25 mL of 0.1% $FeCl_3$ were added to the samples. The absorbances of the resultant solution were read on an UV-VIS spectrometer at 700 nm. The results were expressed as µmol TE g^{-1} fw (Benzie and Strain, 1996).

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Statistical analysis

The normality of the data was confirmed by the Kolmogorov-Smirnov test and the homogeneity of variances by the Levene's test. The data sets were analyzed with three-way ANOVA by using SAS Version 9.3 (SAS Institute Inc., Cary, NC, USA) software. Duncan multiple range test was used to compare treatments when ANOVA showed significant differences among means. The level of significance was determined at 5%.

Results and Discussion

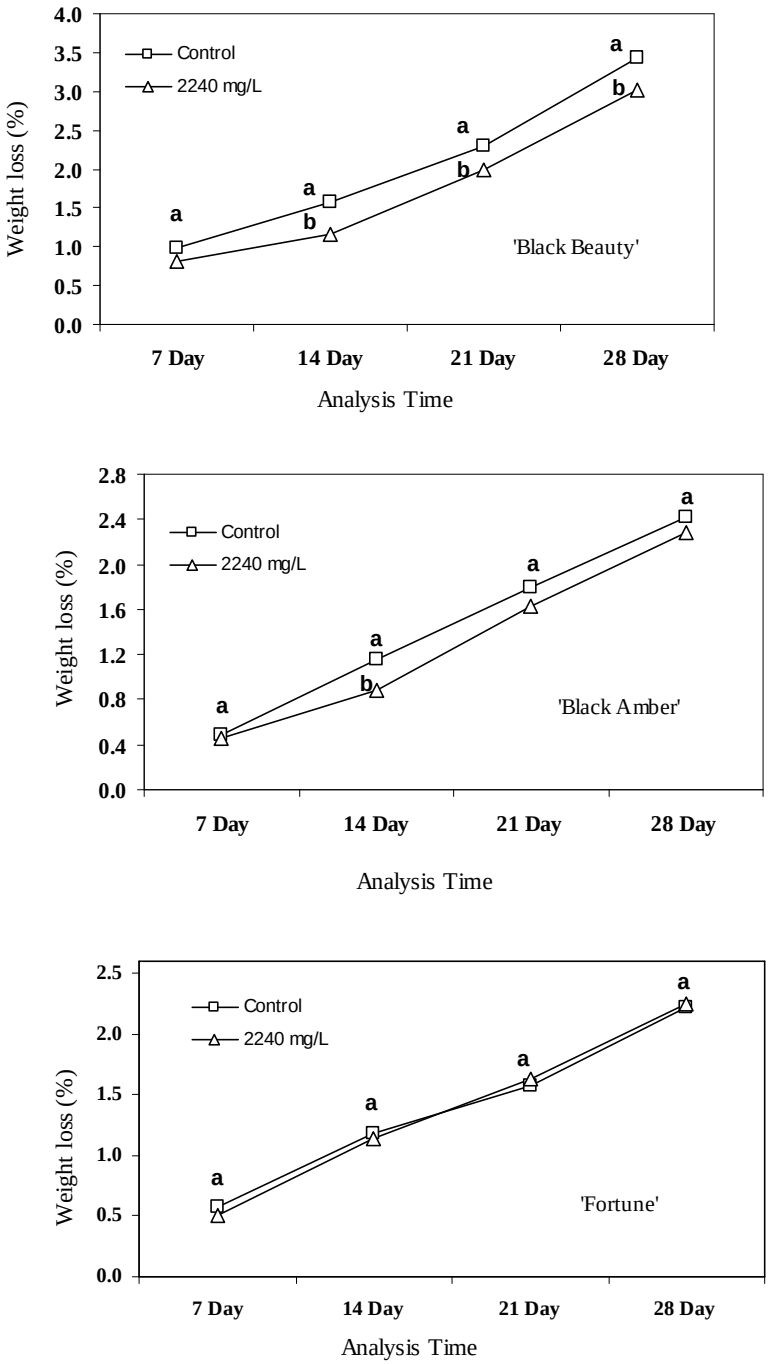

Figure 1: Changes in weight loss (%) of 'Black Beauty', 'Black Amber' and 'Fortune' plums treated with MeJA, after cold storage at 0 °C for 7, 14, 21 and 28 days. Each value is mean of 150 fruits (50 fruits x three replications). Values followed by different letter in each period time are significantly different ($p<0.05$).

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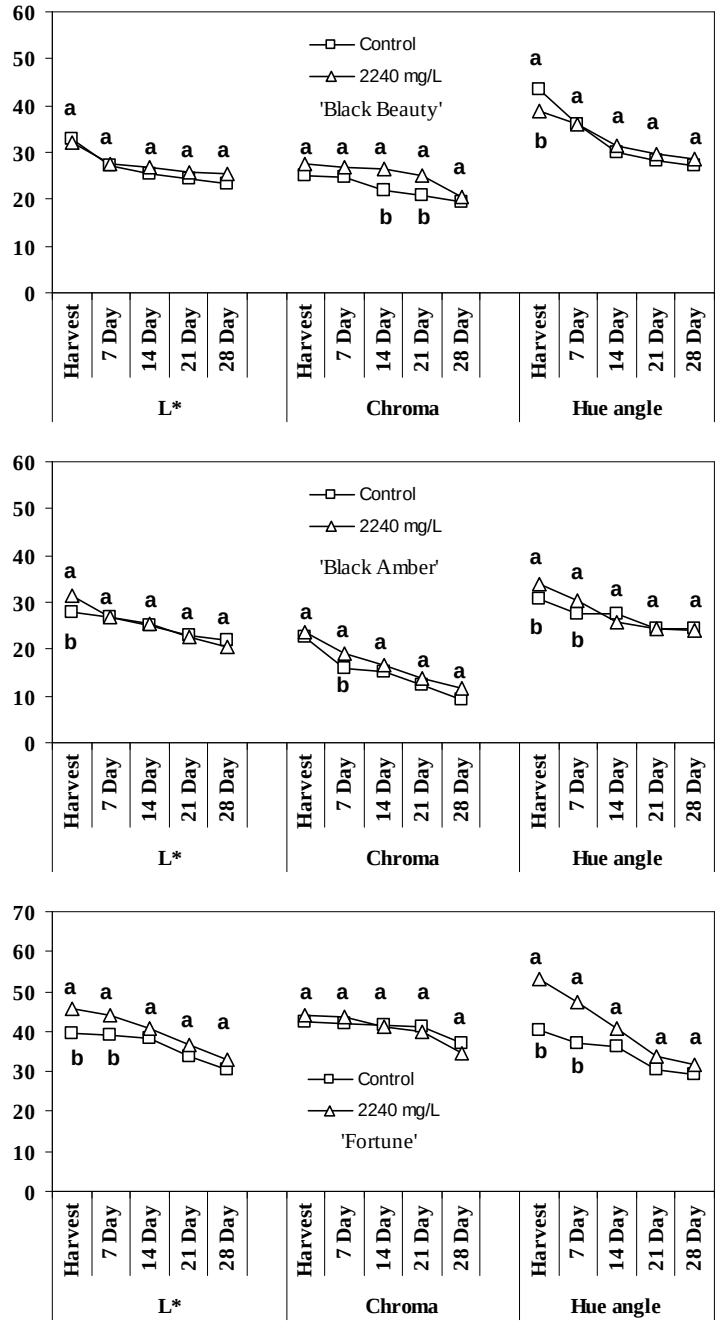

Figure 2: The effect of MeJA on color characteristics (L*, C* and h°) of 'Black Beauty', 'Black Amber' and 'Fortune' plums at the time of harvest and after cold storage at 0 °C for 7, 14, 21 and 28 days. Each value is mean of 150 fruits (50 fruits x three replications). Values followed by different letter in each period time are significantly different (P<0.05).

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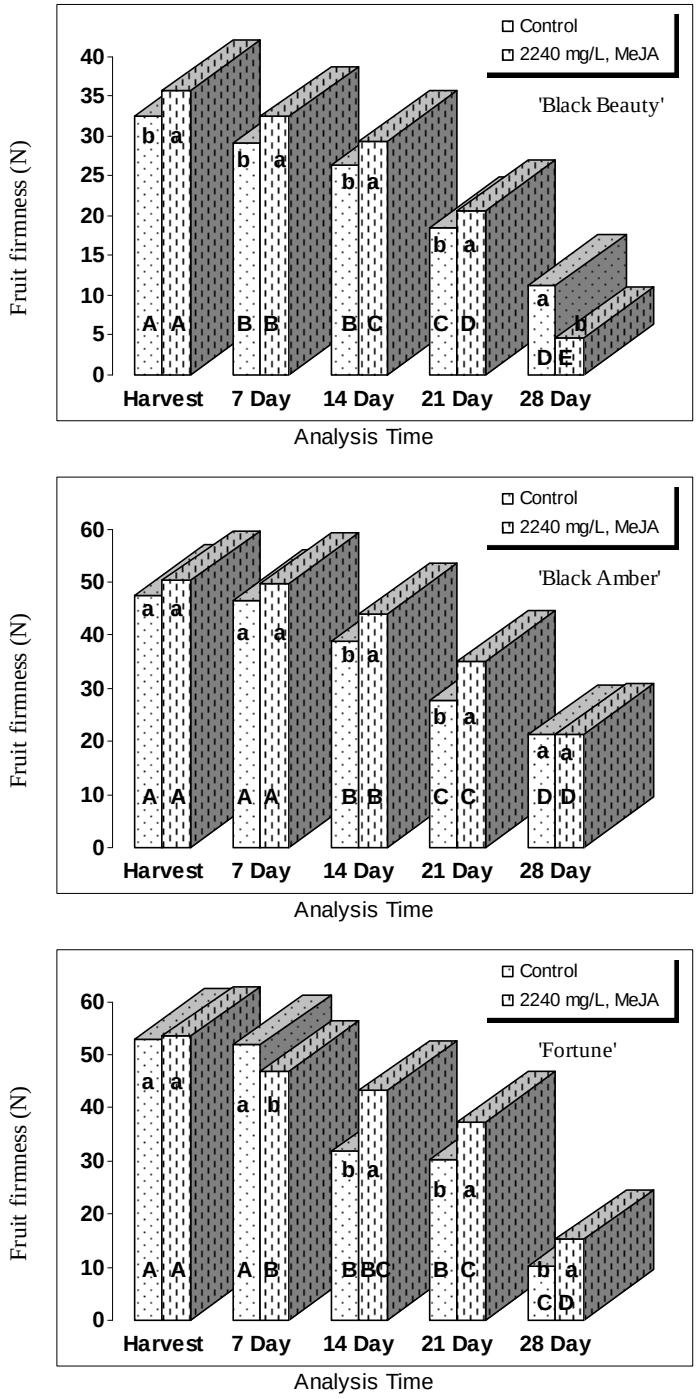

Figure 3: The effects of MeJA on fruit firmness of 'Black Beauty', 'Black Amber' and 'Fortune' plums at the time of harvest and after cold storage at 0 °C for 7, 14, 21 and 28 days. n=60 for fruit firmness (twenty fruits x three replications). Values followed by different lower-case letter in each period time are significantly different. Values followed by different capital letters for each treatment indicate significant differences among analysis times ($P<0.05$).

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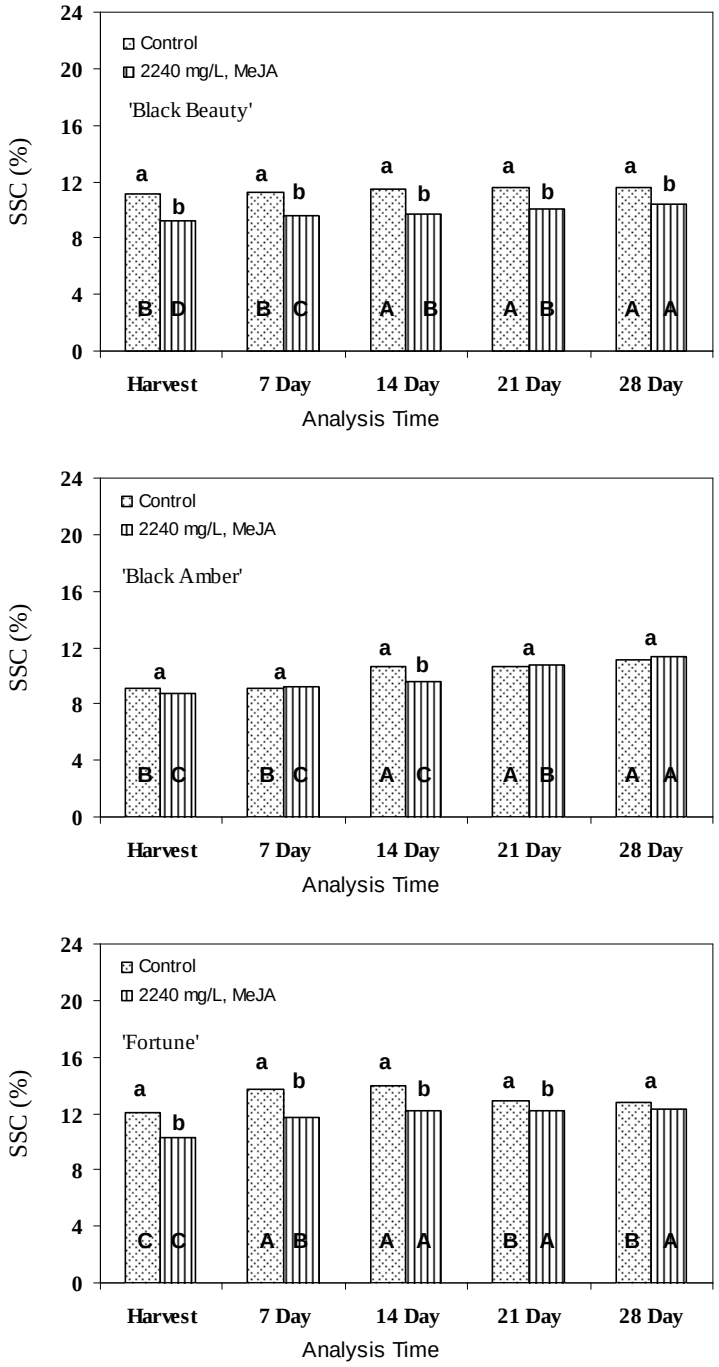

Figure 4: The effects of MeJA on SSC of 'Black Beauty', 'Black Amber' and 'Fortune' plums at the time of harvest and after cold storage at 0 °C for 7, 14, 21 and 28 days.. n= 12 for SSC (three replications x four different measurements for each replicate). Values followed by different lower-case letter in each period time are significantly different. Values followed by different capital letters for each treatment indicate significant differences among analysis times ($P<0.05$).

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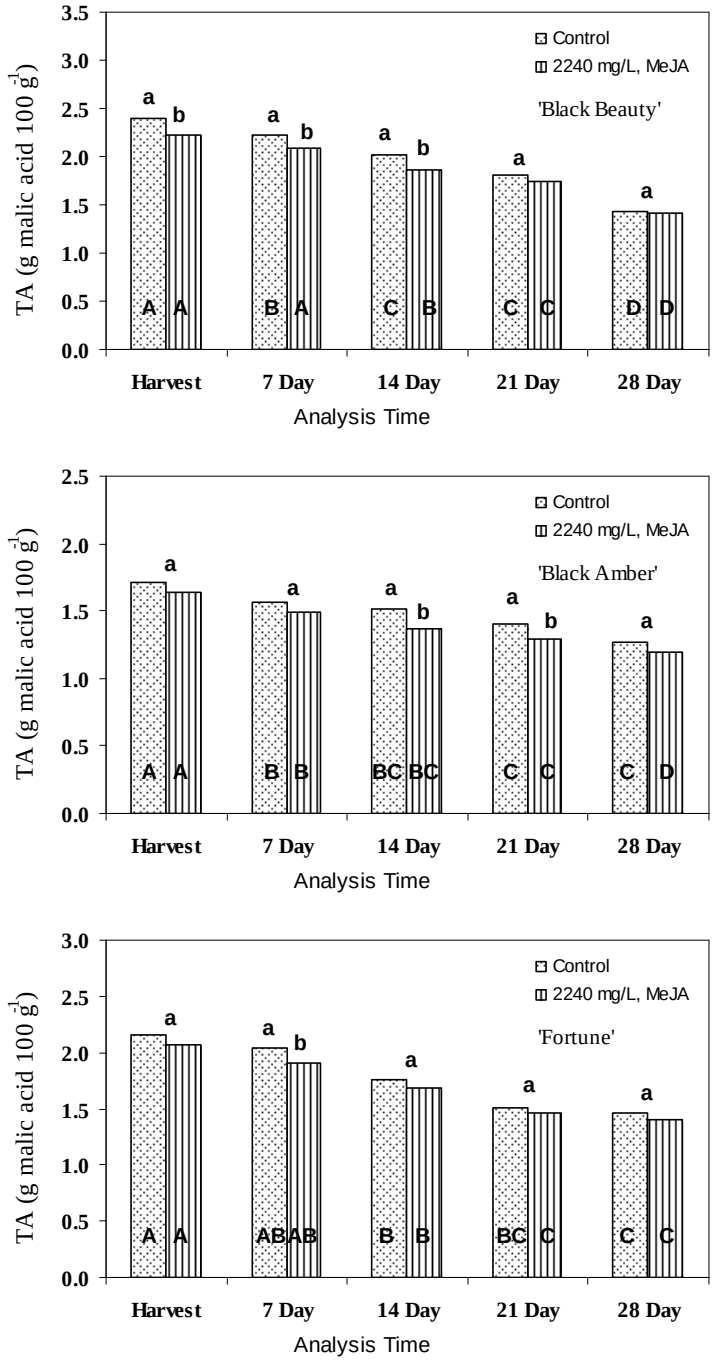

Figure 5: The effects of MeJA on titratable acidity (TA) of 'Black Beauty', 'Black Amber' and 'Fortune' plums at the time of harvest and after cold storage at 0 °C for 7, 14, 21 and 28 days. n= 12 for TA (three replications x four different measurements for each replicate). Values followed by different lower-case letter in each period time are significantly different. Values followed by different capital letters for each treatment indicate significant differences among analysis times ($P<0.05$).

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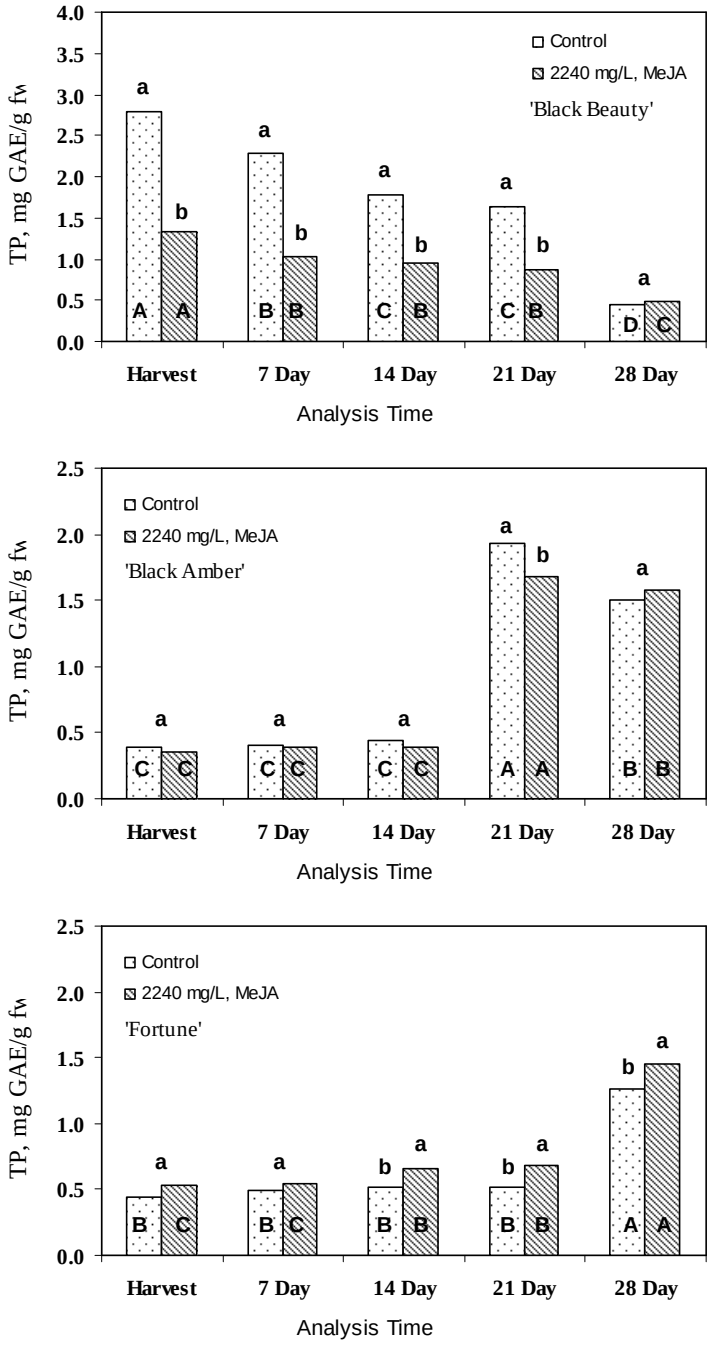

Figure 6 : The effects of MeJA on total phenolics (TP) of 'Black Beauty', 'Black Amber' and 'Fortune' plums at the time of harvest and after cold storage at 0 °C for 7, 14, 21 and 28 days. n= 15 for TP (three replications x five different measurements for each replications). Values followed by different lower-case letter in each period time are significantly different. Values followed by different capital letters for each treatment indicate significant differences among analysis times ($P<0.05$).

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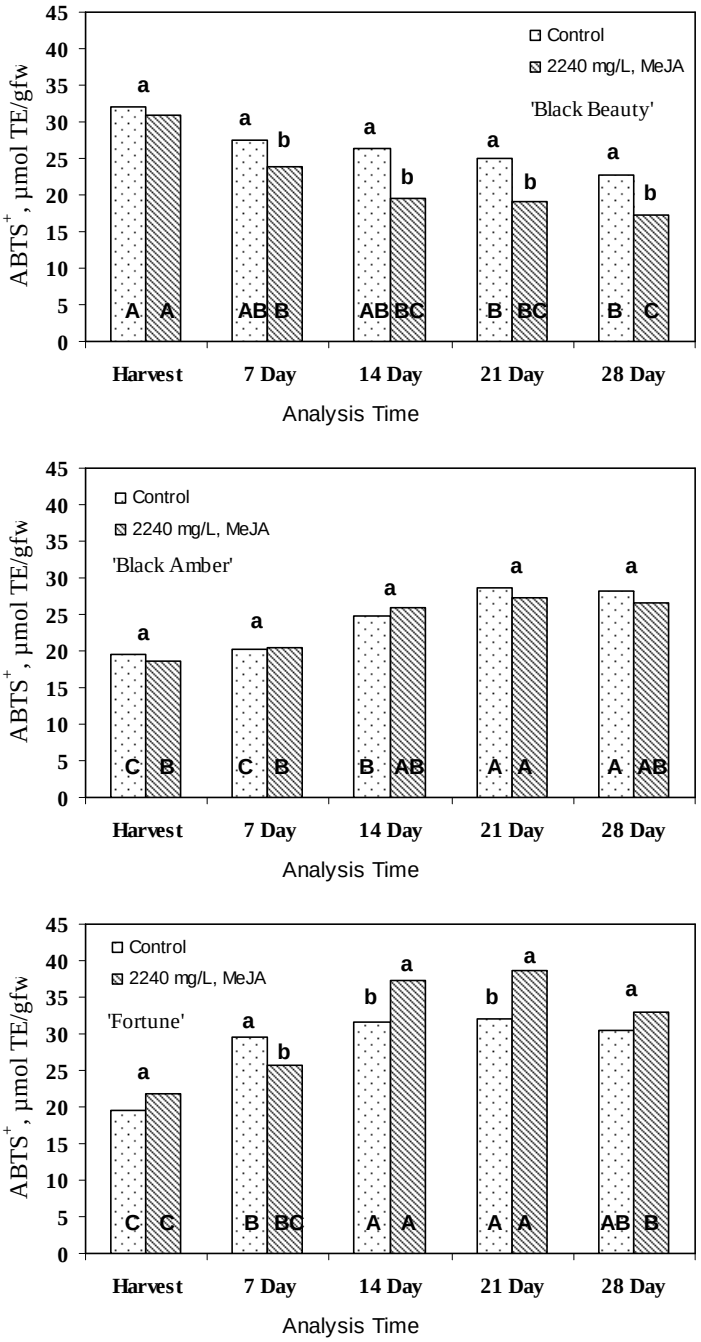

Figure 7: The effect of MeJA on total antioxidant activity [TAA, (According to $ABTS^{+}$)] of 'Black Beauty', 'Black Amber' And 'Fortune' plums at the time of harvest and after 7, 14, 21 and 28 days at 0 °C. n= 15 for TAA (three replications x five different measurements for each replications). Values followed by different lower-case letter in each period time are significantly different. Values followed by different capital letters for each treatment indicate significant differences among analysis times ($P<0.05$).

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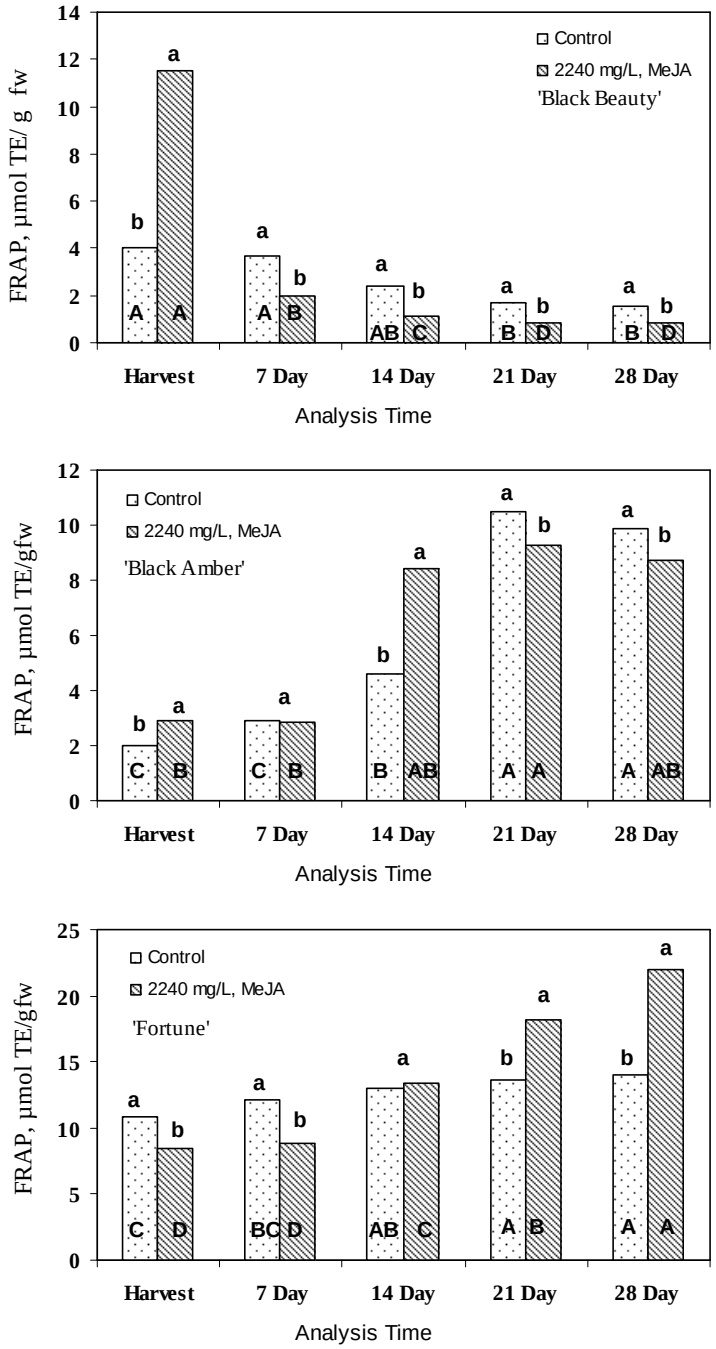

Figure 8: The effect of MeJA on total antioxidant activity [TAA, (According to FRAP)] of 'Black Beauty', 'Black Amber' And 'Fortune' plums at the time of harvest and after 7, 14, 21 and 28 days at 0 °C. n= 15 for TAA (three replications x five different measurements for each replications). Values followed by different lower-case letter in each period time are significantly different. Values followed by different capital letters for each treatment indicate significant differences among analysis times ($P<0.05$).

A weight loss was observed with treatments in all plum cultivars during the cold storage period. Compared to control treatment, MeJA significantly reduced the weight loss of 'Black Beauty' during the cold storage. However, no significant influence was observed in 'Black Amber' and 'Fortune' plums during the storage, except for 14th day of storage of 'Black Amber' plums (Figure 1).

Fruits, in general, have considerable resistance to moisture loss, as their water vapor pressure is lower than that of water at the same temperature because of dissolved substances, mostly sugars. The entire weight loss is not due to water loss alone. Ripening continues after the harvest in climacteric or non-climacteric plum cultivars (Singh and Khan, 2010; Paul et al., 2012). Respiration and ethylene production also go on during the cold storage and consequently pectines and hemicelluloses in cell walls are broken, structure and composition of carbohydrates of cell walls are altered and finally a weight loss is observed in the fruit. In the present study, weight loss in 'Black Beauty' plum significantly deceased with MeJA treatment. Severity of weight loss is usually related to storage conditions (temperature, relative humidity), pre-storage treatments (growth regulators), ripening level of fruits, plant nutrition, fruit type and cultivar (Valero et al., 2003; Casquero and Guerra, 2009; Krishna et al., 2012).

Color characteristics

The color characteristics (L^*, chroma and hue angle) of all plum cultivars decreased during the cold storage. Compared to control treatment, L^* values of MeJA-treated 'Fortune' plums were significantly higher at the harvest and 7th day of storage and values of 'Black Amber' plums were

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significantly higher only at the time of harvest. Chroma values of 'Black Beauty' plums were significantly higher on 14 and 21st days of storage and values of 'Black Amber' plums were significantly higher only on 7th day of storage. Hue angle values of MeJA-treated 'Black Amber' and 'Fortune' plums were significantly higher than the control at the time of harvest and on 7th day of storage and the values of 'Black Beauty' plums were significantly higher only at the time of harvest (Figure 2).

The color of plum fruit is mostly contributed by anthocyanins and total carotenoids. During the maturity and ripening of plum, anthocyanins and levels of total carotenoids increase in fruit skin (Singh and Khan, 2010). MeJA causes chlorophyll degradation and stimulates color pigments in unripe fruits (Khan and Singh 2007). A distinctive effect of MeJA treatment on coloration of plum cultivars was not observed in current study. But, positive impacts of MeJA treatments on fruit coloration were reported by Perez et al. (1997) in strawberries, by Rudell et al. (2005) in apples, by Janoudi and Flore (2003) in peaches and by Gonzalez-Aguilar et al. (2003) in papaya.

Fruit firmness

Flesh firmness of MeJA-treated 'Black Beauty', 'Black Amber' and 'Fortune' plums significantly decreased until the 28th day of cold storage. However, firmness values of MeJA-treated 'Black Beauty' fruits were significantly higher than control fruits at harvest and on 7, 14 and 21st days of storage, values of 'Black Amber' fruits were significantly higher on 14 and 21st days of storage and the values of 'Fortune' fruits were significantly higher on 14, 21 and 28th days of storage. On the other hand, firmness of 'Black Beauty' fruits on 28th day and 'Fortune' plums on 7th day were significantly lower than the control fruits (Figure 3).

Fruit firmness is the most significant quality parameter specifying the market value and shelf life of fruits. Producers are able to market their products for longer times and earn more by preserving fruit firmness in cold storages. Krishna et al. (2012) reported that fruit texture was preserved and cold storage life was prolonged with the application of growth regulators before the harvest and storage. Janoudi and Flore (2003) reported that MeJA increased fruit firmness in "Redhaven" peach. Altuntas et al. (2012) and Rudell et al. (2005) reported the similar results for apples. Gonzalez-Aguilar et al. (2003) reported that fruit firmness would not be affected negatively by MeJA treatment during the cold storage. It can be stated that the reason why MeJA dose yielded higher fruit firmness than control in the present study was due to the fact that MeJA had an effect on enzymes that cause softening of fruit flesh. Indeed, Fan et al. (1998) reported that, in relation to fruit firmness, polygalacturonase biosynthesis was inhibited by MeJA. Contrarily, Khan and Singh (2007) reported increasing endogenous ethylene levels and consequent faster ripening of fruits and increasing enzyme activities causing fruit softening with MeJA treatment in Japanese plums. In addition, Kondo et al. (2004) indicated different effects of jasmonates for different fruits and stated that such effects varied based on fruit ripening levels, applied growth regulators, fruit type and cultivar.

Soluble solids content

SSC values of MeJA-treated 'Black Beauty' and 'Black Amber' fruits until 28th day of the cold storage and 'Fortune' plums until 14th day of storage significantly increased. SSC values of 'Black Beauty' fruits on entire analysis periods, 'Black Amber' fruits on 14th day and 'Fortune' fruits at harvest and on 7, 14 and 21st days of cold storage were significantly lower than the control fruits (Figure 4).

SSC values increase with increasing ripening levels. Ripened fruits usually have higher SSC levels than unripe ones. Kondo et al. (2001) reported accelerated ripening effects of MeJA treatments in fruits. In the present study, MeJA negatively affected SSC values of all plum cultivars during the storage period. Rudell et al. (2005) reported retarded conversion of starch into sugar in 'Fuji' apples with MeJA treatments. Possibly, MeJA might have hindered pectin and polygalactronase enzyme activities providing the formation of glucose, fructose and sucrose-like sugars increasing the SSC values. Or, SSC levels might have been weakened with MeJA treatment through faster ripening of fruits along the enzymatic pathway to ripening.

Titratable acidity

TA values of MeJA-treated 'Black Beauty' and 'Black Amber' fruits until 28th day of the cold storage and 'Fortune' plums until 21st day of storage significantly reduced. TA values of MeJA-treated 'Black Beauty' fruits at harvest and on 7 and 14th days of storage, values of 'Black Amber' plums on 14 and 21st days and values of 'Fortune' plums only on the 7th day of storage were significantly lower than the values of control fruits (Figure 5).

TA of the fruits is affected by the metabolism activity especially respiration rate which consumed organic acid, and thus the acidity decreases with increasing respiration rates. Since the fruits are living things that respires even after harvest from the tree and during the storage, organic acids are continued to be consumed and thus the acidity decreases (Jan et al., 2012).

Total phenolics (TP) and total antioxidant activity (TAA)

TP content of MeJA-treated 'Black Beauty' plums significantly decreased until 28th day of cold storage. On the other hand, TP values of 'Fortune' significantly increased until 28th day of storage. However, TP values of 'Black Amber' fruits significantly increased until 21st day, then significantly decreased on 28th day of cold storage. Compared to control treatment, significantly lower TP contents were observed in MeJA-treated 'Black Beauty' fruits at harvest and on 7, 14 and 21st days of cold storage, in 'Black Amber' plums only on 21st day of storage. Contrarily, 'Fortune' plums had significantly higher values than the control on 14, 21 and 28th days of cold storage (Figure 6).

According to $ABTS^{+}$ test, TAA values of MeJA-treated 'Black Beauty' fruits significantly decreased during the cold storage. On the other hand, there were significant increases in TAA values of MeJA-treated 'Black Amber' fruits until 21st day of storage and TAA values of 'Fortune' fruits until 14th day of storage. Compared to control treatment, significantly lower TAA values were observed in MeJA-treated 'Black Beauty' fruits during the cold storage and in 'Fortune' fruits on 7th day of storage. On the other hand, 'Fortune' fruits had significantly higher TAA values than the control on 14 and 21st day of storage (Figure 7).

According to FRAP test, while there were significant decreases in TAA values of MeJA-treated 'Black Beauty' fruits until 21st day of cold storage, there were significant increases in TAA values of 'Black Amber' fruits until 21st day of storage. TAA values of MeJA-treated 'Fortune' fruits also increased significantly during the cold storage. Compared to control treatment, significantly lower values were observed in TAA values of MeJA-treated 'Black Beauty' fruits on 7, 14, 21 and 28th days of storage, of 'Black Amber' fruits on 21 and 28th days of storage and of 'Fortune' fruits at harvest and on 7th day of cold storage. Contrarily, 'Black Beauty' fruits at harvest, 'Black Amber' fruits on 14th day and 'Fortune' fruits on 21 and 28th day had significantly higher TAA values than the control fruits(Figure 8).

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Plums are good source of naturally occurring bioactive compounds [phenolics (neo-chlorogenic acid, *p*-coumaroylquinic acid, chlorogenic acid and rutin) and antioxidants] (Singh and Khan, 2010). There are some changes in phenolics and antioxidant activity of plums during the ripening (Rohwer and Erwin, 2008; Diaz-Mula et al., 2009). Changes in chemical composition of fruits including phenolic and antioxidant compounds vary based on the variety, growth period, preferred root stock, nutrient contents, environmental conditions, cultural practices, ripening levels of fruits, time of harvest, post-harvest storage conditions and post-harvest fruit processing methods. Some plant growth regulators (methyl jasmonate, AVG, 1-MCP, polyamines and nitric oxide) applied before and after the harvest and other implementations (heat treatment, calcium, cold storage) may also change the total phenolics and antioxidant activity of fruits (Jobling et al., 2003; Khan et al., 2007; Singh and Khan, 2010; **Öztürk et al., 2013; Zapata et al., 2014**). Likewise, with regard to total phenolics and antioxidant activity, each plum cultivar of the present study had different values in each analysis periods. Different changes were observed in TP and TAA values of plum cultivars of the present study with MeJA treatments. Kondo et al. (2004) reported that jasmonates had a different effect on each fruit species and such an effect depended directly on fruit growth stage and the concentration of applied plant growth regulator. Khan and Singh (2007) reported that bioactive content of fruit could change with MeJA treatments. Therefore, MeJA should be studied in detail for different fruit species and varieties. Heridia and Cisneros-Zevallos (2009) reported increased phenolics content of strawberries with MeJA treatments. Diaz-Mula et al. (2009) found total phenolics content of different plum varieties as between **1310– 4370** mg GAE kg^{-1} fw. Puerta-Gomez and Cisneros- Zevallos (2011) recorded total phenolics and antioxidant activity of "Black Splendor" respectively as 400 mg 100 g^{-1} and 2.5 mg g^{-1} trolox.

Conclusions

In general, the weight and firmness losses of plum were significantly delayed with MeJA treatment during the cold storage. Any significant impacts of pre-harvest MeJA treatment on color characteristics of plum cultivars were not observed. MeJA treatment delayed ripening process. The effect of MeJA on phenolics and antioxidant activity were based on plum variety.

MeJA was proved to be beneficial in extending the cold storage life and preservation of the fruit quality. Future works should include a more detailed evaluation of key quality attributes such as aroma, bioactive compounds and enzymes, or should focus on traits relevant to quality preservation of plums or other fruits with pre-harvest MeJA treatment.

References

1. Altuntas, E., Ozturk, B., Ozkan, Y., and Yildiz, K. (2012). Physico-mechanical properties and color characteristics of apple as affected by methyl jasmonate treatments. International Journal of Food Engineering, 1: 1-16.
2. Anonymous (2011). Block-specific sprayer calibration worksheet. http://www.umass.edu/fruitadvisor/clements/trvcalculator.html#1 (Accessed to web: February 1, 2011).
3. Benzie, I.F.F., and Strain, J.J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. Analytical Biochemistry, 239: 70-76.
4. Beyhan, O., Elmastas, M., and Gedikli, F. (2010). Total phenolic compounds and antioxidant capacity of leaf, dry fruit and fresh fruit of Feijoa (*Acca sellowiana*, Myrtaceae). Journal of Medicinal Plants Research, 11: 1065-1072.
5. Carvalho, R.F., Piotto, F.A., Schmidt, D., Peters, L.P., Monteiro, C.C., and Azevedo, R.A. (2011). Seed priming with hormones does not alleviate induced oxidative stress in maize seedlings subjected to salt stress. Scientia Agricola, 68: 598-602.
6. Casquero, P.A., and Guerra, M. (2009). Harvest parameters to optimize storage life of European plum 'Oullins Gage'. International Journal of Food Science and Technology, 44: 2049-2054.
7. Crisosto, C.H., Garner, D., Crisosto, G.M., and Bowerman, E. (2004). Increasing 'Blackamber' plum (*Prunus salicina* L.) consumer acceptance. Postharvest Biology and Technology, 34: 237-244.
8. Diaz-Mula, H.M., Zapata, P.J., Guillen, F., Martinez-Romero, D., Castillo, S., Serrano, M., and Valero, D. (2009). Changes in hydrophilic and lipophilic antioxidant activity and related bioactive compounds during postharvest storage of yellow and purple plum cultivars. Postharvest Biology and Technology, 51: 354-363.
9. Fan, X., Mattheis, J.P., and Fellman, J.K.C. (1998). A role for jasmonates in climacteric fruit ripening. Planta, 204: 444-449.
10. Gong, D.Q., Gu, H., Zhang, L.B., Hong, K.Q., and Zhu, S.J. (2013). Effects of pretharvest methyl jasmonate spraying on disease resistance and postharvest quality of mango fruits. Acta Horticulturae Sinica, 40: 49-57.
11. Gonzalez-Aguilar, G.A., Buta, J.G., and Wang, C.Y. (2003). Methyl jasmonate and modified atmosphere packaging (MAP) reduce decay and maintain postharvest quality of papaya 'Sunrise'. Postharvest Biology and Technology, 28: 361-370.
12. Heridia, J.B., and Cisneros-Zevallos, L. (2009). The effects exogenous ethylene and methyl jasmonate on the accumulation of phenolic antioxidant in selected whole and wounded fresh produce. Food Chemistry, 115: 1500-1508.
13. Jan, I., Rab, A., and Sajid, M. (2012). Storage performance of apple cultivars harvested at different stages of maturity. The Journal of Animal and Plant Sciences, 22: 438-447.
14. Janoudi, A., and Flore, J.A. (2003). Effects of multiple applications of methyl jasmonate on fruit ripening, leaf gas exchange and vegetative growth in fruit trees. The Journal of Horticultural Science and Biotechnology, 78: 793-797.
15. Jin, P., Zheng, Y.H., Tang, S.S., Rui, H.J., and Wang, C.Y. (2009). Enhancing disease resistance in peach fruit with methyl jasmonate. Journal of the Science of Food and Agriculture, 89: 802-808.
16. Jobling, J., Pradhan, R., Morris, S.C., Mitchell, L., and Rath, A.C. (2003). The effect of ReTain plant growth regulator [aminoethoxyvinylglycine (AVG)] on the postharvest storage life of 'Tegan Blue' plums. Australian Journal of Experimental Agriculture, 43: 515-518.
17. Khan, A.S., and Singh, Z. (2007). Methyl jasmonate promotes fruit ripening and improves fruit quality in Japanese plum. The Journal of Horticultural Science and Biotechnology, 82: 695-706.
18. Khan, A.S., Singh, Z., and Abbasi, N.A. (2007). Pre-storage putrescine application suppresses ethylene biosynthesis and retards fruit softening during low temperature storage in 'Angelino' Plum. Postharvest Biology and Technology, 46: 36-46.
19. Khan, A.S., and Singh, Z. (2010). Pre-harvest application of putrescine influences Japanese plum fruit ripening and quality. Food Science and Technology International, 16: 53-64.
23. Kondo, S., Tsukada, N., Niimi, Y., and Seto, H. (2001). Interactions between jasmonates and abscisic acid in apple fruit, and stimulative effect of jasmonates on anthocyanin accumulation. Journal of the Japanese Society for Horticultural Science, 70: 546-552.

http://dx.doi.org/10.4314/ajtcam.v11i6.11
24. Kondo, S., Yazama, F., Sungcome, K., Kanlayanarat, S., and Seto, H. (2004). Changes in jasmonates of mangoes during development and storage after varying harvest times. Journal of the American Society for Horticultural Science, 129: 152-157.

25. Krishna, H., Das, B., Attri, B.L., Kumar, A., and Ahmed, N. (2012). Interaction between different pre and postharvest treatment on shelf life extension of 'Oregon Spur' apple. Fruits, 67: 31-40.

26. Larrondo, F., Gaudillere, J.P., Krisa, S., Decendi, A., Deffieux, G., and Merillon, J.M. (2003). Airborne methyl jasmonate induces stilbene accumulation in leaves and berries of grapevine plants. American Journal of Enology and Viticulture, 54: 63-66.

27. Mcguire, R.G. (1992). Reporting of objective color measurements. HortScience, 27: 1254-1255.

28. Moreno, F.D., Blanch, G.P., Flores, G., and Del Castillo, M.L.R. (2010). Development of a method based on on-line reversed phase liquid chromatography and gas chromatography coupled by means of an adsorption–adsorption interface for the analysis of selected chiral volatile compounds in methyl jasmonate treated strawberries. Journal of Chromatography A., 1217: 1083-1088.

29. Öztürk, B., Küçüker, E., Saraçoğlu, O., Yıldız, K., and Özkan, Y. (2013). Effect of plant growth regulators on fruit quality and biochemical content of '0900 Ziraat' sweet cherry cultivar. Journal of Tekirdag Agricultural Faculty, 10(3): 82-89.

30. Paul, V., Pandey, R., and Srivastava, G.C. (2012). The fading distinctions between classical patterns of ripening in climacteric and non-climacteric fruit and the ubiquity of ethylene-an overview. Journal of Food Science and Technology, 49: 1-21.

31. Pellegrini, N., Re, R., Yang, M., and Rice-Evans, C.A. (1999). Screening of dietary carotenoids and carotenoid-rich fruit extracts for antioxidant activities applying the 2,2'-azino-bis-3-ethylenebenzothiazoline-6-sulfonicacid radical cation decolorization assay. Methods in Enzymology, 299: 379-389.

32. Perez, A.G., Sanz, C., Olias, R., and Olias, M. (1997). Effect of methyl jasmonate on in vitro strawberry ripening. Journal of Agricultural and Food Chemistry, 45: 3733-3737.

33. Puerta-Gomez, A.F., and Cisneros-Zevallos, L. (2011). Postharvest studies beyond fresh market eating quality: Phytochemical antioxidant changes in peach and plum fruit during ripening and advanced senescence. Postharvest Biology and Technology, 60: 220-224.

34. Rohwer, C.L., and Erwin, J.E. (2008). Horticultural applications of jasmonates: a review. The Journal of Horticultural Science and Biotechnology, 83: 283-304.

35. Rudell, D.R., Mattinson, D.S., Mattheis, J.P., Wyllie, S.G., and Fellman, J.K. (2002). Investigations of aroma volatile biosynthesis under anoxic conditions and in different tissues of 'Redchief Delicious' apple fruit (Malus domestica Borkh.). Journal of Agricultural and Food Chemistry, 50: 2627-2632.

36. Rudell, D.R., Fellmann, J.K., and Mattheis, J.P. (2005). Preharvest application of methyl jasmonate to 'Fuji' apples enhances red coloration and affects fruit size, splitting, and bitter pit incidence. HortScience, 40: 1760-1762.

37. Saniewski, M., Miyamoto, K., and Ueda, J. (2004). Gum induction by methyl jasmonate in fruits, stems and petioles of Prunus domestica L. Acta Horticulturae, 636: 151-158.

38. Singh, Z., and Khan, A.S. (2010). Physiology of plum fruit ripening. Stewart Postharvest Review, 2: 3.

39. Valero, D., Martinez-Romero, A.D., Valverde, J.M., Guillen, F., and Serrano, M. (2003). Quality improvement and extension of shelf life by 1-methylcyclopropene in plum as affected by ripening stage at harvest. Innovative Food Science Emerging Technologies, 4: 339-348.

40. Zapata, P.J., Martinez-Espla, A., Guillen, F., Diaz-Mula, H.M., Martinez-Romero, D., Serrano, M., and Valero, D. (2014). Pre-harvest application of methyl jasmonate (MeJA) in two plum cultivars. 2. Improvement of fruit quality and antioxidant systems during postharvest storage. Postharvest Biology and Technology, 98: 115-122.