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EFFECT OF AMINOETHOXYVINYLGLYCINE (AVG) ON THE QUALITY OF JAPANESE PLUM (*Prunus salicina* Lindell cv. Fortune) FRUITS

Emine Kucuker[1], Burhan Ozturk[2], Kenan Yildiz[1], Yakup Ozkan[3]

[1]Gaziosmanpasa University, 60240, Tokat, Turkey

[2]Ordu University, 52200, Ordu, Turkey

[3]Suleyman Demirel University, 32000, Isparta, Turkey

Abstract. The role of pre-harvest aminoethoxyvinylglycine (AVG) treatments on bioactive compounds, fruit ripening and quality of Japanese plum fruits (*Prunus salicina* Lindell cv. 'Fortune') were investigated in this study. Whole trees were sprayed once with an aqueous solution containing AVG (0, 100 and 200 mg L^{-1}) two weeks before the anticipated commercial harvest. Compared to control treatment, AVG applications retarded fruit ripening and peel red color formation of fortune plum fruits. Respiration rate and ethylene production in fruit were decreased by AVG applications. Respiration rate and ethylene production in control fruit were 57% and 60% higher than those in 200 mg L^{-1} AVG-treated fruit at the last harvest date respectively. The total phenolics and total antioxidant activity were significantly reduced by AVG treatments. Antioxidant activities of fruits treated at the date with AVG were approximate 2 fold higher than those of control fruits at the last harvest date. The chlorogenic acid, caffeic acid, rutin and kaempferol contents decreased with both AVG concentrations at all harvest dates.

Key words: antioxidant, color, ethylene, firmness, AVG, phenolics

INTRODUCTION

Plums are classified as either climacteric or non-climacteric [Valero et al. 2003]. Ethylene production impels various ripening-related processes in plums such as color development, flavor, softening, senescence and aroma volatiles, physico-mechanical and biochemical changes. Ethylene production stimulates especially fruit ripening, decreases shelf-life and ultimately results in losses in fruit quality parameters like firmness, and flavor [Sing and Khan 2010].

Corresponding author: Emine Kucuker, Department of Horticulture, Faculty of Agriculture, Gaziosmanpasa University, 60240, Tokat, Turkey, e-mail: emine2346@gmail.com

Control and management of ripening process are the significant issues in prevention of quality losses in fresh plums. Therefore, various strategies are developed to inhibit or retard physico-mechanical and biochemical changes able to result in post-harvest quality losses. Exogenous calcium and polyamines [Serrano et al. 2003], AVG [Jobling et al. 2003], 1-methylcyclopropen [Luo et al. 2009], methyl jasmonate [Ozturk et al. 2013], heat treatment [Serrano et al. 2004] and synthetic auxins [Stern et al. 2007] like treatments are among such strategies.

AVG (aminoethoxyvinylglycine) is an ethylene inhibitor and sold commercially under the brand of 'ReTain'. It is a human and environment-friendly organic product for apple, pear, peach, plum and nectarine in several countries. It suppresses and retards ethylene production even at very low doses. Effects of AVG vary based on development and growth stage of fruit, concentration, volume and time of application, fruit variety and environmental conditions [Jobling et al. 2003, Ozturk et al. 2012b]. It was reported in previous studies that pre-harvest AVG treatments retarded ethylene production, prevented pre-harvest fruit drops, retarded fruit ripening and thus allowed the producers to extend the harvest period over a longer time period and therefore to have savings in labor costs [Jobling et al. 2003]. AVG treatments also preserved post-harvest fruit firmness and thus extended the shelf lives of fruits [Ozturk et al. 2012a].

There are several studies about the effects of AVG treatments on ripening of various fruits; however, there is limited information available about the impacts of pre-harvest AVG treatments on ripening and bioactive compounds of plum fruits. The aim of this study was to elucidate the impacts of pre-harvest AVG application on color characteristics, fruit weight, geometric mean diameter, flesh firmness, soluble solids content, titratable acidity, ethylene production, respiration rate, total antioxidant activity, total phenolics and individual phenolics of 'Fortune' plums during fruit ripening.

MATERIAL AND METHODS

Plant materials

Five-year old uniform Japanese plum trees (*Prunus salicina* Lindell cv. 'Fortune') grafted on Myrobalan (*Prunus ceresifera* Ehrh.) rootstock at Research Station of Horticulture Department of Gaziosmanpaşa University Agricultural Faculty (40°20'02.19''N latitude, 36° 28'30.11''E longitude and 623 m altitude) in the Middle Black Sea Region of Turkey were selected for the experiments. The trees were planted at 4 × 4 m spacing and trained by modified leader system.

The experiment was laid out in a randomized complete-block design with three replicates. In the study, 9 trees with homogeneous fruit load were selected and trees were grouped into 3 blocks with 3 trees per block based on proximity in orchard and crop load. Each AVG dose (0, 100 and 200 mg L^{-1}) was applied to a tree in each block and one tree in each block was selected as the control treatment (with 0 mg L^{-1} AVG).

Uniform trees were sprayed with an aqueous solution containing different concentrations (0, 100 and 200 mgL^{-1}) of 'ReTain' (containing 150 mg aminoethoxyvinylglycine g^{-1} – ValentBioScience Corp., USA) and 'Sylgard 309' surfactant (0.05%, v v^{-1} – Dow-Corning, Canada) as a surfactant till run-off with a low pressure hand sprayer two week

before the anticipated commercial harvest date (21 July, 2011). Only solution containing 'Sylgard 309' was applied in control (0 mg L^{-1} AVG) trees. The anticipated commercial harvest date (4th of August 2011) was determined based on the number of days after full bloom (115 days for 'Fortune'). Spray treatments were conducted during favorable weather conditions where rainfall was not forecasted for the following 24 h. AVG doses were selected based on previous studies carried out under field conditions [Jobling et al. 2003]. Standard cultural practices (pruning, thinning, fertilization and irrigation) were carried out during the experiment.

The fruits were analyzed at one week before anticipated commercial harvest, at anticipated commercial harvest and at one week after anticipated commercial harvest for all quality characteristics. Fifty fruits from each tree in each block were randomly harvested from the whole canopy on 28th of July, 4th and 11th of August 2011. Plums with uniform shape, color and size and free from visual symptoms of any disease or blemishes were harvested. Harvested fruits were immediately transported to laboratory to determine the quality parameters.

Color characteristics

Fifty fruits from each tree were used to determine the color characteristics (*L**, *a*, b** chroma *(C*) and* hue angle *(h°)*). Changes in fruit color characteristics were measured at opposite sides of each fruit with a colorimeter (Minolta, CR-400, Tokyo, Japan). Chromatic analyses were conducted in accordance with the CIE (Commission Internationale de l'Eclairage) system of 1976. 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 $h° = \tan^{-1} b^*/a^*$.

Fruit weight, geometric mean diameter and flesh firmness

Fifty fruits from each tree were used to determine the fruit weight and geometric mean diameter. Fruit weight (g) was measured with a digital balance (±0.01 g) (Radwag PS 4500/C/1, Radom, Poland). Fruit length (L), width (W) and thickness (T) were measured with a digital caliper (±0.01 mm) (Model No CD-6CSX, Mitutoyo, Tokyo, Japan). Geometric mean diameter (D_g) was determined by using the relationship [$D_g = (LWT)^{1/3}$] described by Mohsenin [1970]. Twenty fruits from each treatment were used to determine the flesh firmness. The fruit skin was cut at two different points (on the cheeks) along the equatorial part of the fruit and the firmness was measured by using an Effegi penetrometer (model FT–327; MoCormick Fruit Tech, Yakima, WA) with a 7.9 mm penetrating tip. The flesh firmness was expressed in newton (N).

Ethylene production and respiration rate

To determine ethylene production and respiration rate, 30 fruits were selected among 50 fruits harvested from each tree and three measurements were obtained from each tree. For ethylene production, 10 fruits per chamber were sealed in a 1 L air-tight chamber fitted with a rubber septum for 1 h at 20 ±1°C and 90% relative humidity (RH), and then a 1 mL gas sample was collected into a syringe. Each sample was injected into a gas chromatograph (Clarus 500, PerkinElmer, Shelton, CN, USA) equipped with a flame ionization detector and an alumina column. For respiration rate, 10 fruits per chamber were sealed in a 1 L air-tight chamber fitted with a rubber septum for 1 h at 20 ±1°C and 90% RH, and then the chamber was connected to an infrared gas analyzer (Horiba PIR-2000R, Horiba Instruments Inc., Irvine, CA, USA). The respiration rate was determined by measuring the amount of carbon dioxide (CO_2) produced by the plum fruits. Results were expressed as μmol kg^{-1} h^{-1} for ethylene production and mmol CO_2 kg^{-1} h^{-1} for respiration rate.

Soluble solids content (SSC) and titratable acidity

A sample of juice was taken from one piece of each of ten fruits per tree, and 4 different measurements were obtained from each tree (replication). SSC was determined with a digital refractometer (PAL-1, McCormick Fruit Tech., Yakima, Wash). For titratable acidity (TA), 10 ml of extract was taken from each sample, 10 ml of distilled water was added and the value corresponding to consumed sodium hydroxide (NaOH) during the titration with 0.1 mol L^{-1} sodium hydroxide to increase the pH of samples to 8.1 was expressed in malic acid (g malic acid 100 mL^{-1}).

Bioactive compounds

For bioactive compounds, 10 fruits were selected from each tree (replication). Then these fruits were sliced with a sharp no serrated knife, and placed into 5 different tubes (two fruits per tube) and stored at -20°C for biochemical analyses. Samples were thawed at room temperature (≈21°C) and homogenized in a food-grade blender. The resultant slurry was centrifuged (12000 g) at 4°C for 30 min to separate the juice from the pulp. The freshly obtained juice was 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 reagents 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 Lambda-1050 spectrophotometer; Perkin-Elmer, Irvine, CA, USA) spectrophotometer at 760 nm. Gallic acid was used as the standard. The results were expressed as grams (g) of Gallic acid equivalents (GAE) per kilogram of fresh weight (fw) (g GAE kg^{-1} fw) [Beyhan et al. 2010].

Total antioxidant activity: the ABTS and FRAP assay

For the $ABTS^+$ 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 mmol Trolox equivalents (TE) per kilogram of fw (mmol TE kg^{-1} fw) [Pellegrini et al. 1999].

For the FRAP (ferric ions (Fe^{+3}) reducing antioxidant power assay), 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 mmol Trolox equivalents (TE) per kilogram of fw (mmol TE kg^{-1} fw) [Benzie and Strain 1996].

The FRAP assay measures the ferric to ferrous reduction in presence of antioxidants. The FRAP assay does not, however, measure the thiol group containing antioxidants. The TEAC (ABST) assay is based on the principle of inhibition radical cation production by antioxidants in the sample. The concentration of antioxidant in the sample is inversely proportional to the absorbance of the radical cation produced by 2.2''-azino-bis (3-ethyl benzothiazoline-6-sulfonic acid) diammonium.

Individual phenolics

Preparation of sample and standard solutions. All crude fruit samples were homogenized and 1000 mg slurry was accurately weighed and extracted with (5 mL) methanol in test tube for 6 h. After filtration through a syringe type filter (Chromtech, 13 mm, 0.22 µm), the filtrate was injected into the HPLC system for analysis. The results were expressed as mg kg^{-1}.

Accurately weighed solid portions of each standard were dissolved in methanol to prepare stock solutions. Working solutions were obtained by diluting the stock solutions with methanol. The final mixed standard solution contained 100 µg mL^{-1} of each standard.

Instrumentation and conditions. High performance liquid chromatography (HPLC, Perkin-Elmer Series 200; Perkin-Elmer, Norwalk, CT, USA) system equipped with a quaternary solvent delivery system (Series 200, analytical pump) and UV detector (Series 200, UV/Vis detector) was used at 280 nm. The analytes were separated on a Phenomenex Kromasil (Phenomenex, Torrance, CA, USA) 100A C18 (250 mm × 4.60 mm, 5 µm) column. The column temperature was maintained at 26°C by using a water bath (Wisebath, WB-22, and Daihan Scientific, Seoul, Korea). The mobile phase consisted of acetonitrile (A) and water containing 2.5% formic acid (B). The

following gradient conditions were used: initial 0–3 min, held at A–B (5:95, v/v), 3–8 min, linear change from A–B (5:95, v/v) to A–B (10:90, v/v); 8–13 min, linear change from A–B (10:90, v/v) to A–B (15:85, v/v); and 13–15 min, isocratic elution A–B (15–85, v/v); 15–22 min, linear change from A–B (15:85, v/v) to A–B (25:75, v/v); 22–37 min, linear change from A–B (25:75, v/v) to A–B (50:50, v/v); 37–40 min, isocratic elution A–B (100–0, v/v). The mobile phase flow rate was set at 1 mL min^{-1} and the injection volume was 20 μL.

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 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 set as 5%.

RESULTS

Compared to control treatments, AVG treatments significantly increased *L** and hue angle values of fruits harvested at 4 and 11th of August. The highest L* (41.95) and hue angle values (39.13) at the last harvest date were observed in 200 mg L^{-1} AVG treatment. Chroma values of fruits treated with 100 or 200 mg L^{-1} AVG were lower than those of control fruits at first harvest time (28 July). On the other hand, at last harvest time (11 August), there was not a significant difference between control and AVG treatment for chroma value (tab. 1).

Table 1. Effects of pre-harvest AVG treatments on color characteristics (*L**, chroma and hue angle) of 'Fortune' plums picked at different harvest dates

Treatments		Harvest date		
		28 July	4 August	11 August
*L**	0 mg L^{-1}, AVG	42.21 a	39.04 b	34.56 b
	100 mg L^{-1}, AVG	43.17 a	41.86 a	40.19 a
	200 mg L^{-1}, AVG	43.35 a	42.09 a	41.95 a
Chroma	0 mg L^{-1}, AVG	37.62 a	35.68 a	36.45 a
	100 mg L^{-1}, AVG	34.74 b	34.05 ab	37.56 a
	200 mg L^{-1}, AVG	33.13 b	33.10 b	37.99 a
Hue angle	0 mg L^{-1}, AVG	45.36 a	35.92 b	30.95 b
	100 mg L^{-1}, AVG	46.04 a	41.18 a	36.76 a
	200 mg L^{-1}, AVG	47.39 a	44.13 a	39.13 a

n = 300 for color characteristics (L*, chroma and hue angle – three replications × fifty fruits × two different measurements for each fruit). The differences between mean values shown on the same column with same letter are not significant according to Duncan's Multiple Range test at $P < 0.05$

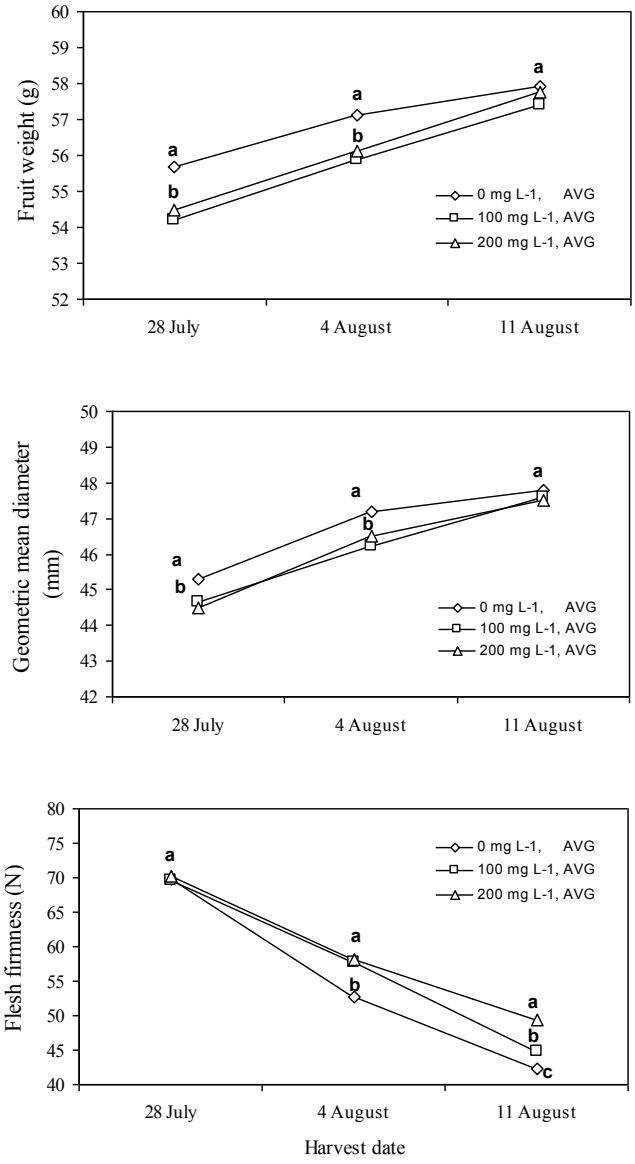

Fig. 1. Effects of pre-harvest AVG treatments on fruit weight, geometric mean diameter and fruit firmness of 'Fortune' plums picked at different harvest dates. n = 150 for the fruit weight and geometric mean diameter (three replications × fifty fruits); n = 120 for the flesh firmness (three replications × twenty fruits × two different measurements for each fruit). The differences among the treatments indicated with the same letter vertically are not significant according to Duncan's Multiple Range test at $P < 0.05$

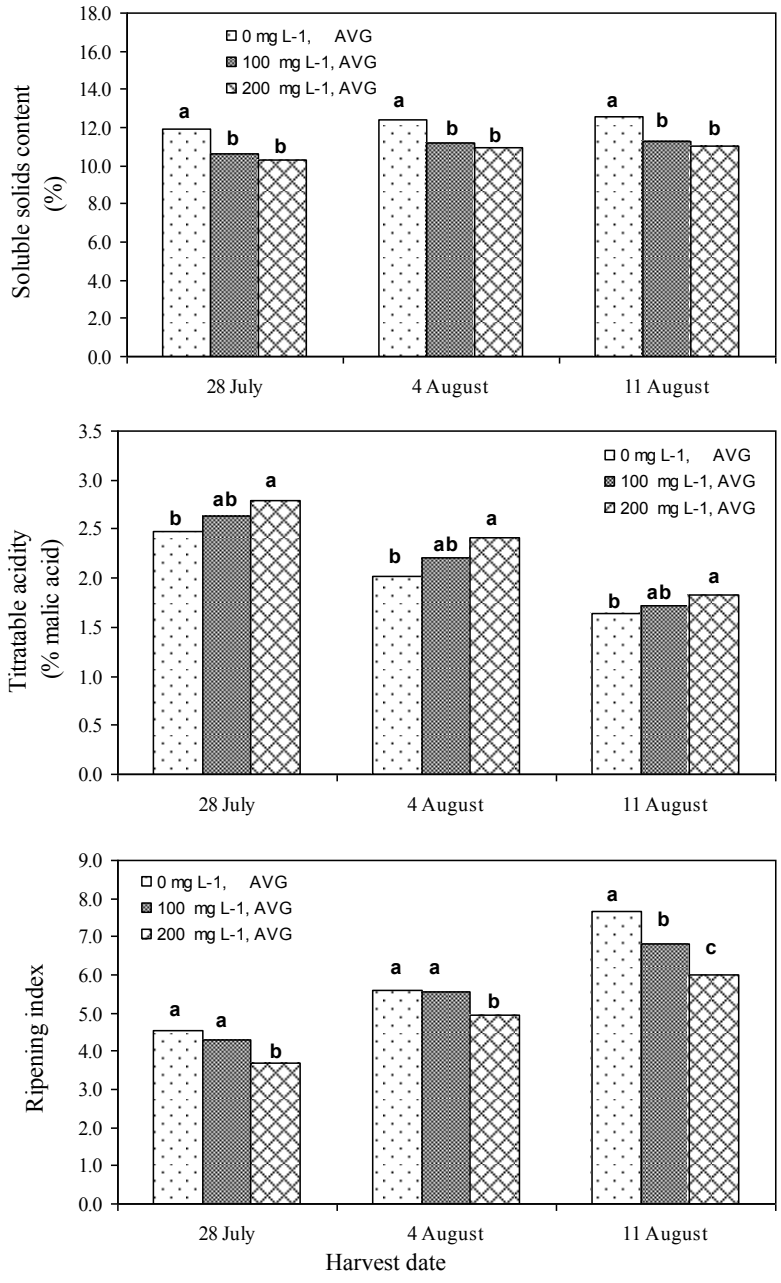

Fig. 2. Effects of pre-harvest AVG treatments on soluble solids content (SSC), titratable acidity and ripening index of 'Fortune' plums picked at different harvest dates. n = 12 for the SSC, titratable acidity and ripening index (three replications × four different measurements for each replication). The differences between mean values shown on the bars with same letter are not significant according to Duncan's Multiple Range test at $P < 0.05$

Fruit weight and geometric mean diameter were significantly decreased by both AVG treatments on 28th of July and 4th of August. On the other hand, fruit weight and geometric mean diameters were similar in all treatment at last harvest time (11 August) (fig. 1).

On 28th of July, fruit flesh firmness of all treatments was similar. Flesh firmness decreased with the progress of ripening. However, firmness was significantly preserved by both AVG concentrations at the subsequent date (4 and 11 August). At the last harvest (11th of August), flesh firmness of 200 mg L^{-1} AVG-treated fruits (49.41 N) was significantly higher than that of fruits of other treatments (fig. 1).

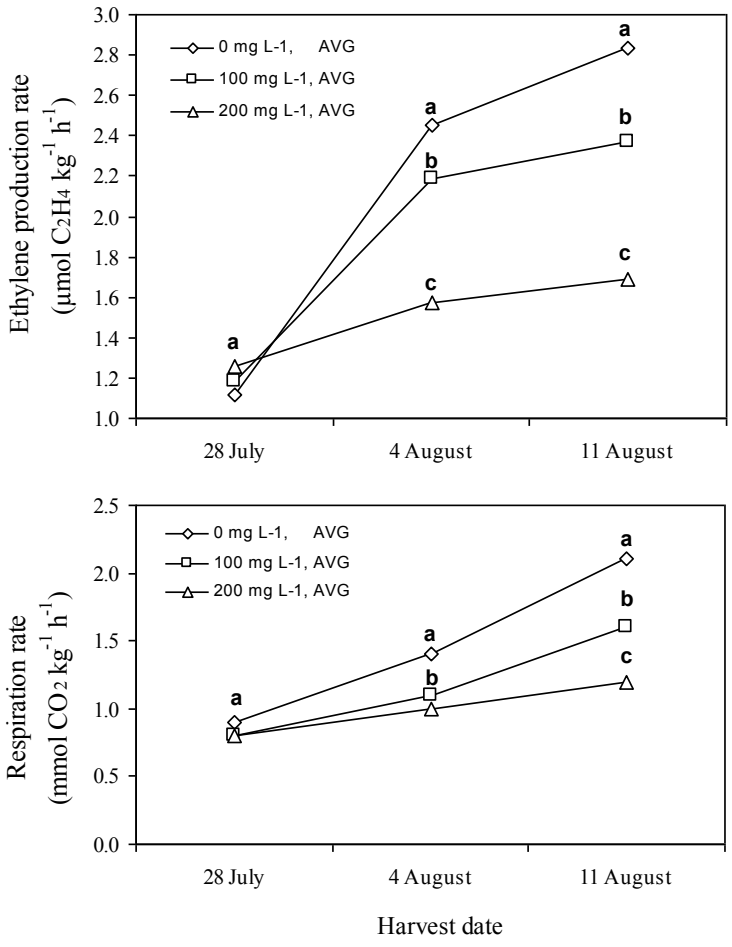

Fig. 3. Effects of pre-harvest AVG treatments on ethylene production rate and respiration of 'Fortune' plums picked at different harvest dates. n = 9 for the ethylene production rate and respiration rate (three replications × three different measurements for each replication). The differences among the treatments indicated with the same letter vertically are not significant according to Duncan's Multiple Range test at $P < 0.05$

AVG applications significantly decreased SSC values as compared to control at all harvest dates. While 100 mg L^{-1} AVG did not cause any significant change, 200 mg L^{-1} AVG significantly increased TA value at all harvest dates. Thus, ripening index were the lower in 200 mg L^{-1} AVG treatment in all three harvest dates when compared to control treatment. 100 mg L^{-1} AVG treatment was not significantly differs than control with respect to ripening index at the first two harvest date, but at the last harvest date, ripening index was lower in 100 mg L^{-1} AVG treatment (fig. 2).

Ethylene production and respiration rates increased with the progress of ripening. At the first harvest date (28 July), ethylene production and respiration rates did not differ between AVG-treated and control fruits. At the subsequent dates, ethylene production and respiration rate were significantly retarded by both AVG treatments. Ethylene production was especially even more suppressed by higher AVG concentration. On 11th of August, the lowest ethylene production and respiration rate were observed in 200 mg L^{-1} AVG treatment respectively with 1.69 μmol C_2H_4 kg^{-1} h^{-1} and 1.20 mmol CO_2 kg^{-1} h^{-1} (fig. 3).

Table 2. Effects of pre-harvest AVG treatments on bioactive compounds of 'Fortune' plums picked at different harvest dates

Treatments		Harvest date		
		28 July	4 August	11 August
Total phenolics (g GAE kg^{-1} fw)	0 mg L^{-1}, AVG	3.30 a	0.45 a	0.34 a
	100 mg L^{-1}, AVG	2.57 b	0.35 b	0.24 b
	200 mg L^{-1}, AVG	2.25 c	0.35 b	0.25 b
$ABTS^+$ (mmol TE kg^{-1} fw)	0 mg L^{-1}, AVG	28.10 a	19.50 a	12.80 a
	100 mg L^{-1}, AVG	24.32 b	17.10 b	7.10 b
	200 mg L^{-1}, AVG	22.99 c	17.23 b	7.23 b
FRAP (mmol TE kg^{-1} fw)	0 mg L^{-1}, AVG	13.56 a	10.83 a	2.89 a
	100 mg L^{-1}, AVG	11.96 b	9.47 b	1.39 b
	200 mg L^{-1}, AVG	5.99 c	8.14 b	1.08 b

n = 15 for total phenolics and total antioxidant activity (three replications × five different measurements for each replications). FRAP: Ferric reducing antioxidant power. ABTS: 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid. fw: fresh weight. The differences between mean values shown on the same column with same letter are not significant according to Duncan's Multiple Range test at $P < 0.05$

Compared to control fruits, total phenolics (TP) and total antioxidant activity (both according to ABTS and FRAP) of AVG-treated fruits were significantly lower at all harvest dates. Effects of high AVG concentration at the first harvest date were more distinctive than the effects of low AVG concentration (tab. 2).

Table 3. Effects of pre-harvest AVG treatments on individual phenolic compounds of 'Fortune' plums picked at different harvest dates

Individual phenolics (mg kg^{-1})	Treatments	Harvest date		
		28 July	4 August	11 August
Chlorogenic acid (5-O-caffeoylquinic acid)	0 mg L^{-1}, AVG	7.10 a	3.30 a	1.56 a
	100 mg L^{-1}, AVG	4.39 b	2.37 b	1.44 b
	200 mg L^{-1}, AVG	3.19 c	1.92 c	1.28 c
Caffeic acid	0 mg L^{-1}, AVG	3.53 a	3.04 a	2.48 a
	100 mg L^{-1}, AVG	2.78 b	2.72 b	2.35 b
	200 mg L^{-1}, AVG	2.80 b	2.61 b	2.34 b
p-coumaric acid	0 mg L^{-1}, AVG	2.47 a	2.43 a	2.21 a
	100 mg L^{-1}, AVG	2.34 ab	2.31 ab	2.23 a
	200 mg L^{-1}, AVG	2.28 b	2.13 b	1.98 b
Rutin	0 mg L^{-1}, AVG	9.03 a	7.10 a	4.28 a
	100 mg L^{-1}, AVG	5.96 b	4.21 b	3.22 b
	200 mg L^{-1}, AVG	5.65 b	3.48 c	3.11 b
Ferulic acid	0 mg L^{-1}, AVG	8.68 a	8.26 a	2.94 a
	100 mg L^{-1}, AVG	8.60 a	7.23 b	2.76 b
	200 mg L^{-1}, AVG	5.83 b	5.62 c	2.20 c
Quercetin	0 mg L^{-1}, AVG	3.83 a	3.37 a	2.31 a
	100 mg L^{-1}, AVG	2.69 b	2.49 b	2.26 a
	200 mg L^{-1}, AVG	2.46 c	2.47 b	1.94 b
Naringenin	0 mg L^{-1}, AVG	1.88 a	1.75 a	1.42 a
	100 mg L^{-1}, AVG	1.77 b	1.59 b	1.44 a
	200 mg L^{-1}, AVG	1.86 a	1.57 b	1.43 a
Kaempferol	0 mg L^{-1}, AVG	4.32 a	3.23 a	2.88 a
	100 mg L^{-1}, AVG	3.50 b	3.12 b	2.79 b
	200 mg L^{-1}, AVG	3.56 b	3.01 c	2.65 c

n = 15 for individual phenolic compounds (three replications × five different measurements for each replications). The differences between mean values shown on the same column with same letter are not significant according to Duncan's Multiple Range test at $P < 0.05$

AVG treatments had significant impacts individual phenolics during the ripening process. At the first harvest date (28th of July), chlorogenic acid, caffeic acid, rutin, quercetin and kaempferol contents were the lower in both AVG treatment, *p*-coumaric acid and ferulic acid were decreased by 200 mg L^{-1} AVG treatment and naringenin was the lower in 100 mg L^{-1} AVG treatment as compared control treatment. On 4th of August, almost all of the individual phenolics were significantly decreased by AVG applications. Effects of 200 mg L^{-1} AVG concentration on decreases in chlorogenic acid, rutin, ferulic acid and kaempferol were more distinctive. At the last harvest date (11 August), chlorogenic acid, caffeic acid, rutin, ferulic acid and kaempferol was the lower in both AVG treratment, and *p*-coumaric acid and quercetin was the lower in 200 mg L^{-1} AVG treatment when compared control (tab. 3).

DISCUSSION

L* and hue angle values approaching 0 (zero) in fruits with red skin color indicate an increase in red coloration [Diaz-Mula et al. 2009]. Current findings revealed that AVG increased L* and hue angle in Fortune plum fruits, indicating a decrease red color formation in fruit peel. This result may be attributed to the decreased endogenous level of ethylene with AVG application. It was reported that per-harvest AVG treatment retarded ripening and accumulation of peel color pigments (anthocyanins and carotenoids) by inhibiting ethylene biosynthesis [Steffens et al. 2011]. Various other researchers reported similar results about red color development with AVG treatments in plums [Steffens et al. 2011, Ozturk et al. 2012], peaches [Amarante et al. 2005], apples [Whale et al. 2008] and pears [Clayton et al. 2000].

In the present study, fruit size at optimal harvest period was influenced by AVG treatments but delayed harvests eliminated such negative impacts. Similar results were also reported for cherries [Webster et al. 2006], peaches [Amarante et al. 2005] and plums [Ozturk et al. 2013]. Researchers [Greene 2005] reported that AVG did not directly affect the fruit size but increased fruit mass and mean diameter since it retards ripening and delays harvest and consequently fruits stay on the tree for longer times.

High ethylene production and respiration rates speed up the ripening process and consequently shorten the shelf life. Previous studies indicated that ethylene inhibitors (AVG, 1-MCP) might be used as a significant tool to retard the ripening process of both plums and other fruits since they retard ethylene production and decrease respiration rates [Jobling et al. 2003]. Compared to control fruits, current results revealed retarded ethylene production and respiration rates with AVG treatments. Retarded ethylene production and respiration rates with AVG treatments were also reported by different researchers [Jobling et al. 2003, Khan and Singh 2007, Ozturk et al. 2013] in plums. There are also other results reported about ethylene inhibition with AVG treatments [Rath et al. 2004, Torrigiani et al. 2004, Yildiz et al. 2012].

Fruit flesh firmness is the most significant quality parameter effecting shelf lives and market values of the fruits. The present findings revealed that AVG treatment retarded flesh softening occurred through the progress of ripening. Such an impact of AVG was due to ethylene suppression. AVG was reported to inhibit ethylene synthesis and retard fruit ripening of plums [Jobling et al. 2003], peaches [Amarante et al. 2005], nectarines [Rath et al. 2004] and apples [Greene 2005]. Khan and Singh [2007] reported that suppression of ethylene production through ethylene inhibitors (AVG, 1-MCP) decreased the level of flesh softening enzymes like exo-polygalacturonase, endo-polygalacturonase, pectin esterase and endo-1,4-β-D-glucanase. Similar findings about the effects of AVG on flesh firmness were also reported for 'Laetitia' plums [Steffens et al. 2011], 'Stark Red Gold' nectarines [Torrigiani et al. 2004] and 'Barlett' pears [Clayton et al. 2000].

Sugar contents of fruits increase and acidity levels decrease with the progress of ripening [Valero et al. 2012]. SSC and ripening index of AVG-treated fruits were lower and TA values were higher. These results corroborated that AVG treatments retarded fruit ripening of Fortune plum. Similar results were reported in previous studies. [Pinto et al. 2012, Greene 2005].

Plums are good source of naturally occurring bioactive compounds (phenolics – neo-chlorogenic acid, *p*-coumaroylquinic acid, chlorogenic acid and rutin – and antioxidants]. In the present study, AVG treatment decreased total phenolics and total antioxidant activity of Fortune plum fruits. This result contradict the assertion by Diaz-Mula et al. [2009] and Usenik et al. [2009] that AVG treatments increase total phenolics in plums, and supports the finding of Ozturk et al. [2012a, 2013] that AVG treatments decreased total phenolics and total antioxidant activity in plums and cherries. This discrepancy is likely due to environmental conditions, cultural practices, ripening levels of fruits, time of harvest, pre and post-harvest implementations and varietal differences between the studies.

Lombardi-Boccia et al. [2004] reported the presence of quercetin, ferulic acid, caffeic acid, coumaric acid and kaempferol in plums. Slimestad et al. [2009] reported the presence of rutin in plums. Kim et al. [2003] reported that chlorogenic acid and quercetin were abundant polyphenols in plums. In this study, chlorogenic acid, ferulic acid, rutin appeared as main individual phenol in Fortune plum fruits. Furthermore, it has been determined that Fortune plum fruits are important food source in respect to other individual phenol. In the present study examining the effects of AVG on fruit quality, pre-harvest application of AVG was found to decrease almost all individual phenol.

CONCLUSIONS

It was concluded in this study that ripening in "Fortune" plums progressed through ethylene production. AVG treatments retarded ethylene production and slowed down respiration mechanism. AVG treatments of the present study retarded ripening and slowed down peel color development and fruit flesh softening; decreased SSC values, total phenolics, individual phenolics and total antioxidant activity. AVG, a natural growth regulator, may then be considered as a promising tool to be used commercially to retard ripening and to prolong shelf lives of "Fortune" plums.

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WPŁYW AMINOTOKSYWINYLOGLICYNY (AVG) NA JAKOŚĆ OWOCÓW ŚLIWY JAPOŃSKIEJ (*Prunus salicina* Lindell cv. Fortune)

Streszczenie. Zbadano wpływ aminotoksywinyloglicyny (AVG) użytej przed zbiorem owoców śliwy japońskiej (*Prunus salicina* Lindell cv. 'Fortune') na ich składniki bioaktywne, dojrzewanie i jakość. Całe drzewa opryskano wodnym roztworem AVG (0, 100 i 200 mg l^{-1}) na dwa tygodnie przed spodziewanym zbiorem owoców. W porównaniu z wynikami z kombinacji kontrolnej, AVG opóźnił dojrzewanie owoców i wybarwienie ich skórki na czerwono. Preparat w stężeniu 200 mg·l^{-1} zastosowany w ostatni dzień zbioru spowodował także obniżenie intensywności oddychania owoców oraz wytwarzania przez nie etylenu (odpowiednio o 57 i 60% w porównaniu z owocami z kombinacji kontrolnej). Obniżyły się także całkowita zawartość fenoli i aktywność antyutleniająca. Ta ostatnia, w tym samym terminie użycia, była dwa razy wyższa niż u owoców z kombinacji kontrolnej. Zawartości kwasów chlorogenowego i kafeinowego, rutyny i kaempferolu obniżyły się przy zastosowaniu AVG w obu stężeniach i we wszystkich terminach zbioru owoców.

Słowa kluczowe: antyutleniacz, kolor, etylen, trwałość, AVG, fenole

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