Pak. J. Agri. Sci., Vol. 53(4), 893-900; 2016
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/16.2226
http://www.pakjas.com.pk

EFFECTS OF AMINOETHOXYVINYLGLYCINE AND NAPHTHALENEACETIC ACID ON ETHYLENE BIOSYNTHESIS, PRE-HARVEST FRUIT DROP AND FRUIT QUALITY OF APPLE

Yakup Ozkan[1], Burhan Ozturk[2,*] and Kenan Yıldız[3]

[1]Suleyman Demirel University, Faculty of Agriculture, Department of Horticulture, Isparta, Turkey; [2]Ordu University, Faculty of Agriculture, Department of Horticulture, Ordu, Turkey; [3]Gaziosmanpaşa University, Faculty of Agriculture, Department of Horticulture, Tokat, Turkey.
[*]Corresponding author's e-mail: burhanozturk55@gmail.com

Cultural control of pre-harvest drop has relied upon plant growth regulators. To investigate the effects of plant growth regulators on pre-harvest drop and fruit quality, 150, 300 and 600 mg L^{-1} aminoethoxyvinylglycine (AVG) and 20 mg L^{-1} NAA were sprayed to 'Red Chief' apple trees at 4 week before anticipated harvest date. Untreated trees were kept as control. Results revealed that all AVG treatments increased the fruit removal force and significantly delayed pre-harvest drop and fruit maturity. Pre-harvest drop generally was unaffected by NAA. Internal ethylene concentration decreased with increasing AVG concentrations. Fruits treated with 150, 300 and 600 mg L^{-1} AVG showed increased fruit firmness and titratable acidity and reduced soluble solids content. Red colour development and starch degradation were retarded by all AVG treatments. Fruits treated with AVG (300 and 600 mg L^{-1}) had lower fruit mass, fruit width and fruit length. The effect of NAA on all quality parameters was similar to the control treatment. AVG treatments decreased pre-harvest drop by fifty percent relatively to control.
Keywords: Colour, firmness, fruit removal force, *Malus x domestica*, starch index

INTRODUCTION

Drop of fruits with insufficient size, maturity and colour formation causes serious economic losses in apple orchards. Fruits sometimes are harvested before the usual harvest season to reduce the drop rates, but such early harvests also decrease the storage duration and market value of the fruits. A yield loss is evident since the fruits are harvested at insufficient sizes. Early-harvested fruits are also sold at low prices since they haven't reached desired size and colour. Several researches indicated that pre-harvest drops in apple might be significantly reduced by plant growth regulators (Byers, 1998; Amarante *et al.,* 2002; Greene, 2002; WookJae *et al.,* 2006; Yuan and Carbaugh, 2007). Auxins play an important role in fruit abscission. NAA (naphthalene acetic acid) is a synthetic auxin and is known with its retarding effect on pre-harvest drops of apples (Marini *et al.,* 1993). However, NAA has a limited use and does not always yield desired outcomes based on fruit species and the temperatures in application period (Greene *et al.,* 1987). Single and repeated application of NAA 3 or/and 1 week before anticipated harvest may also reduce fruit flesh firmness of apples (Yuan and Carbaugh, 2007).

Ethylene is a growth regulator effective in fruit ripening and abscission. Increased ethylene production stimulates fruit maturity and the synthesis of enzymes such as polygalacturonase degrading cell walls in abscission zone (Brown, 1997; Bonghi *et al.,* 2000). Internal ethylene inhibiting materials may hinder fruit ripening and pre-harvest drops. Aminoethoxyvinylglycine (AVG) treatments 1-4 weeks before the harvest inhibited ethylene synthesis in apples (Amarante *et al.,* 2002; Schupp and Greene, 2004; WookJae *et al.,* 2006; Yuan and Carbaugh, 2007). A natural ethylene inhibitor, AVG, is considered as an alternative of NAA and it was reported that pre-harvest AVG treatments retarded fruit ripening and prevented pre-harvest drops (Byers, 1998; Greene, 2002). AVG and NAA were found to be effective in controlling pre-harvest drops of various apple species (Byers, 1998; Greene, 2005; Yuan and Carbaugh, 2007). Fruit flesh softening in NAA treatments are not observed in AVG treatments and even increase in fruit firmness is observed with AVG treatments (Wargo *et al.,* 2004; Yuan and Li, 2008).

Turkey is an important apple producing country of the world and old orchards are mostly composed of 'Golden Delicious' and 'Starking Delicious' apples grafted on seedling rootstocks. Recently, 'Fuji', 'Gala', 'Braeburn' and 'Red Chief' apples, with high market value, grafted on dwarf or semi-dwarf rootstocks have been widespread. 'Red Chief' has medium-level pre-harvest drop rates, but the rates may reach to significant levels in some years. Although there are many studies about the delaying effect of AVG on ripening of apple fruit, it was reported that the magnitude of ripening delay in apple fruits was dependent on AVG concentration and cultivar (Bramlage *et al.*, 1980). Therefore, the present study was conducted to determine the effects of different AVG concentration applied 4 weeks before the anticipated harvest date on pre-harvest drops, internal ethylene synthesis and fruit quality parameters of 'Red Chief'/MM.106 apples.

MATERIALS AND METHODS

This study was conducted at Research Station of Gaziosmanpaşa University Agricultural Faculty located at 40° 20' 02.19"N latitude, 36° 28' 30.11"E longitude and 623 m above sea level, Tokat, in middle Black Sea region of Turkey. The minimum, mean and maximum temperatures are presented in Table 1 (Anonymous, 2012). Soil texture is clay loam consisting of 22% sand, 50% clay and 28% silt with 0.7% organic matter content. The soil pH is 8.16. Irrigations were carried out by using a drip irrigation system. Nutrition supply was maintained with synthetic fertilizers. In both experimental years, the trees were supplied with compound fertilizers containing macro and micro nutrients on April 1, May 1, June 1 and July 5 in four aliquots, respectively. A total of 15 g of N (nitrogen), 25 g of K_2O (60%, potassium oxide), 5 g of $NH_4H_2PO_4$ (monoammonium phosphate) and 25 g of K_2SO_4 (potassium sulphate) were supplied to each tree in each year. Additionally, 5 g calcium nitrate was supplied once in August 1. Any symptoms of nutritional deficiency were not observed in leaves or fruits during the growing season.

To determine the effects of AVG ['ReTain' (15% AVG); Valent BioSciences Crop, Libertyville, II] on pre-harvest drop and fruit quality, 6-year old 60 'Red Chief' apples (*Malus domestica* Borkh.) grafted on MM.106 rootstock, were selected based on proximity in orchard and crop load and grouped into six blocks of 10 trees each. Experiments were conducted in randomized complete block design with six replications. AVG was applied in three different concentrations (150, 300 and 600 mg L^{-1}) 4 weeks before the anticipated harvest time (28th of August in 2010 and on 12th of September in 2011). NAA at 20 mg L^{-1} was sprayed 4 and 2 week before the anticipated harvest (28th August, 11th of September in 2010 and on 12th-26th of September in 2011) as a positive control. Regulaid [0.1% v v^{-1} (Kalo Inc., Overland Park, KS66211)] was added into entire solutions as surfactant. Treatments were applied to runoff with a low pressure hand sprayer. All treatments were separated by at least one buffer tree.

For each treatment, one pair of trees was used in each block. One tree in each pair was designated to be the sample tree, from which fruits were collected for ethylene and quality analysis at pre-determined date. No fruit were harvested from second tree until normal harvest time and this served to follow the progression of fruit drop. Two trees in each block were not sprayed and served as control. Water (pH 6.48) + surfactant mixture was sprayed to control trees.

***Pre-harvest drop*:** To determine the pre-harvest drop, existing fruits under the experimental trees were completely removed before application of solutions. The dropped fruits under each tree were counted periodically and discarded twice a week from the beginning 30 days before anticipated harvest time to anticipated harvest. Then, fruits remaining on the trees were harvested and cumulative drop ratio was calculated and expressed as %.

Cumulative drop ratio (%) = (Total number of dropped fruits) / (Total number of fruits before application) x 100

***Internal ethylene concentration*:** To evaluate internal ethylene concentration, ten fruits per tree were randomly harvested on 26th of September and 3 and 10th of October 2011. A 1-mL air sample from core cavity of each fruit was injected into a gas chromatograph equipped with an active alumina column and Flame Ionization Detector (Perkin Elmer-Clarus 500, USA), using the method of Bramlage *et al.* (1980). The resultant peaks were compared to that of 10 µL L^{-1} ethylene standard and the internal ethylene concentration was calculated.

To determine fruit removal force, fruit mass, fruit width, fruit length, colour characteristics (*L**, chroma and hue angle), flesh firmness, soluble solids content (SSC), titratable acidity (TA) and starch index, ten fruits were sampled randomly from the periphery of the trial trees at each sampling date (11th, 18th and 25th of September in 2010, and on 26th of September, 3rd and 10th of October in 2011).

***Fruit removal force*:** While the fruits were collected, fruit removal forces, the force required to remove fruit from shoot, were measured by using a dynamometer (Tronic HF-10, Taiwan).

***Fruit flesh firmness*:** Flesh firmness was measured on three sides of equatorial line of each fruit using a press-mounted Effegi penetrometer (FT 327; McCormick Fruit Tech, Torino, Italy) with an 11.1 mm tip.

***Colour characteristics*:** Chromatic analyses were conducted in accordance with the CIE (Commission Internationale de

Table 1. Temperature (maximum, mean and minimum, °C) data throughout the vegetation period at the experiment field in 2010-2011.

Temperature	June		July		August		September		October	
(ºC)	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Maximum	36.5	31.9	39.8	41.1	40.8	38.5	37.9	32	26.8	33.8
Mean	23.7	19.1	24.7	23.9	25.9	21.8	23.3	18.3	14.1	12.9
Minimum	13.2	9.6	14.5	12.7	13.8	11.6	11.9	6.9	3.7	1.3

l'Eclairage) system of 1976. The colour characteristics (L*, *a** and *b**) of apples were determined on sun-exposed side of each fruit with a chromameter (Minolta, model CR–400, Tokyo, Japan). Values of *L**, *a** and *b** were used to define a three-dimensional colour 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 colour 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 colour. 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).

***Fruit mass and fruit sizes*:** Fruit mass (g) were measured with a digital balance (±0.01 g) (Radvag PS 4500/C/1, Poland). Fruit width and fruit length were measured with a digital caliper (±0.01 mm) (Model No; CD-6CSX, Mitutoyo, Japan).

***Chemical characteristics*:** Starch-iodine tests of sliced fruits were carried out by using the Cornell Generic Starch-Iodine Index Chart, where 1 = 100% starch and 8 = 0% starch (Blanpied and Silsby, 1992). The soluble solids content (SSC) of a homogenate obtained from ten 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^{-1} mL) 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.

***Statistical analysis*:** A randomized complete block design was used. All statistical analyses were performed with SAS Version 9.1 (SAS Institute Inc., Cary, NC, USA). Data normality was confirmed by Kolmogorov-Smirnov test and the homogeneity of variances by the Levene's test. Data were analyzed by analysis of variance. Means were compared by Duncan's multiple range tests at a significance level of 0.05.

RESULTS

***Cumulative drop ratio (%)*:** There were not any significant differences between the treatments with regard to fruit drops in the first measurement date (28th of August 2010 and 12th of September 2011) of both years. However, at subsequent dates, all AVG concentrations significantly reduced cumulative drop rates compared to control and NAA application. Fruit drops of NAA-treated trees were similar to untreated trees. AVG was superior to NAA as a drop control agent. In 2010, while pre-harvest drop of control treatment on 25th of September was 49.88%, fruit drop of 150, 300 and 600 mg/L AVG treated trees were 30.5, 31.45 and 27.75%, respectively. A similar case was also observed in 2011. All three AVG concentrations have similar effects on fruit drop and the differences in the fruit drop between AVG doses used in this study were not found to be significant in both trial years (Table 2).

***Internal ethylene concentration*:** Internal ethylene concentration (IEC) of apples was not determined in 2010. Compared to control treatment, in 2011, all AVG treatments significantly decreased the IEC during the ripening. AVG treatments of 300 and 600 mg L^{-1} were found to be more effective than 150 mg L^{-1} AVG treatment in decreasing of IEC. In the last measurement date, IEC of 300 and 600 mgL^{-1} AVG treatments were as half as that of control treatment. On the other hand, NAA did not have any positive influences on IEC (Table 3).

***Fruit removal force*:** AVG had significant impacts on fruit removal forces at all harvest dates. Removal forces of AVG-treated fruits were significantly greater than those of NAA treated and control fruits. Removal forces of NAA-treated

Table 2. Effect of AVG concentrations and NAA on pre-harvest drop of 'Red Chief' apples.

Treatments	Pre-harvest drop (% of total)				
	2010				
	28 Aug.	4 Sept.	11 Sept.	18 Sept.	25 Sept
Control	5.26 a	19.03 a	32.11 a	40.08 a	49.68 a
150 mgL^{-1} AVG	5.63 a	12.50 b	24.40 b	27.27 b	30.50 b
300 mgL^{-1} AVG	5.13 a	10.36 b	21.28 b	27.66 b	31.45 b
600 mgL^{-1} AVG	5.09 a	9.13 b	20.10 b	26.84 b	27.75 b
20 mgL^{-1} NAA	5.96 a	19.66 a	29.10 a	43.74 a	54.11 a
	2011				
	12 Sept.	19 Sept	26 Sept.	3 Oct.	10 Oct.
Control	4.61 a	19.84 a	22.68 a	34.97 a	48.65 a
150 mgL^{-1} AVG	4.23 a	13.49 b	16.13 b	26.76 b	29.58 b
300 mgL^{-1} AVG	5.91 a	11.19 b	15.75 b	24.20 b	26.75 b
600 mgL^{-1} AVG	4.31 a	10.24 b	15.89 b	22.78 b	24.20 b
20 mgL^{-1} NAA	5.12 a	21.23 a	21.78 a	38.37 a	51.89 a

Means in columns with the same letter do not differ according to Duncan's multiple range test at $P < 0.05$.

Table 3. Effect of different AVG concentrations and NAA on flesh firmness, fruit removal force and internal ethylene concentration (IEC) of 'Red Chief' apples.

Treatments	Fruit removal force (N)			IEC (mL L^{-1})			Flesh firmness (N)		
	2010								
	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.
Control	19.30 b	16.67 b	13.26 b	nd	nd	nd	76.01 b	71.87 b	69.32 b
150 mgL^{-1} AVG	27.29 a	21.17 a	16.65 a	nd	nd	nd	84.48 a	77.64 a	73.45 a
300 mgL^{-1} AVG	26.06 a	20.75 a	17.30 a	nd	nd	nd	83.28 a	76.41 a	73.29 a
600 mgL^{-1} AVG	26.39 a	22.65 a	18.84 a	nd	nd	nd	82.56 a	75.76 a	74.12 a
20 mgL^{-1} NAA	19.15 b	15.20 b	10.81 c	nd	nd	nd	78.81 b	70.59 b	65.39 c
	2011								
	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.
Control	22.42 b	17.86 b	10.33 b	40.78 a	54.71 a	66.56 a	78.77 b	76.45 b	70.36 b
150 mgL^{-1} AVG	26.04 a	22.96 a	16.51 a	27.43 b	32.09 b	44.46 b	82.30 a	81.70 a	78.31 a
300 mgL^{-1} AVG	27.27 a	23.15 a	16.30 a	24.77 b	30.71 b	34.00 c	84.04 a	82.83 a	77.30 a
600 mgL^{-1} AVG	28.76 a	23.82 a	19.07 a	25.27 b	27.12 b	31.48 c	85.20 a	83.75 a	79.81 a
20 mgL^{-1} NAA	21.79 b	16.81 b	9.90 b	36.60 a	44.23 a	60.67 a	78.33 b	75.52 b	72.01 b

nd; not determined, n = 60 (ten fruits × six replications) for fruit removal force, n = 60 (five fruits × six replications) for internal ethylene concentration (IEC), n = 180 (ten fruits × six replications × three measurements for each fruit) for flesh firmness. Means in columns with the same letter do not differ according to Duncan's multiple range test at $P < 0.05$.

Table 4. Effect of different AVG concentrations and NAA on colour characteristics (L*, chroma and hue angle) of 'Red Chief' apples.

Treatments	L*			Chroma			Hue angle		
	2010								
	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.
Control	45.44 b	40.62 b	38.32 b	33.42 a	33.26 a	33.07 a	42.53 b	41.97 b	36.72 b
150 mgL^{-1} AVG	48.51 a	45.60 a	43.28 a	34.12 a	33.49 a	32.86 a	46.54 a	44.85 a	39.16 a
300 mgL^{-1} AVG	47.53 a	45.77 a	43.59 a	34.06 a	33.61 a	33.83 a	46.80 a	44.59 a	39.69 a
600 mgL^{-1} AVG	49.40 a	45.38 a	44.26 a	34.58 a	33.21 a	34.57 a	47.38 a	44.41 a	40.27 a
20 mgL^{-1} NAA	45.99 b	42.01 b	37.00 b	34.54 a	33.51 a	32.70 a	41.12 b	39.56 b	34.67 b
	2011								
	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.
Control	39.75 b	36.11 b	33.67 b	29.95 a	28.51 a	27.44 a	41.55 b	37.06 b	34.67 b
150 mgL^{-1} AVG	42.42 a	38.72 a	36.98 a	30.67 a	29.42 a	28.81 a	47.85 a	42.26 a	38.58 a
300 mgL^{-1} AVG	41.32 a	38.18 a	37.20 a	30.46 a	29.18 a	27.52 a	48.52 a	43.93 a	39.85 a
600 mgL^{-1} AVG	42.38 a	39.26 a	37.14 a	31.50 a	29.77 a	28.43 a	47.93 a	43.89 a	39.56 a
20 mgL^{-1} NAA	38.56 b	35.25 b	32.94 b	30.50 a	28.48 a	27.21 a	42.25 b	38.74 b	32.19 b

n = 60 (ten fruits × six replications) for colour characteristics (L*, chroma and hue angle). Means in columns with the same letter do not differ according to Duncan's multiple range test at $P < 0.05$.

apples were similar to untreated fruits in 2011. NAA caused significant decrease in fruit removal force on 25th of September of the first year (Table 3).

***Fruit flesh firmness*:** In both years, flesh firmness of AVG-treated fruits was found to be higher than those of NAA-treated and control fruits. NAA treatment reduced flesh firmness only on the 25th of September 2010 (Table 3).

***Colour characteristics*:** L* and hue angle values were significantly higher on fruits treated with AVG at all harvest dates of 2010 and 2011. The effect of NAA on L* and hue angle values was similar to control treatment at all harvest dates. Neither doses of AVG nor NAA significantly affected chroma values at any of the harvest dates (Table 4).

***Fruit mass and fruit sizes*:** AVG treatments of 300 and 600 mg L^{-1} significantly decreased fruit mass, width and length at all harvest dates of 2010 and 2011. In 2010, while the average fruit mass was 214.0 g in control treatment, it was measured as 205.5 g in 300 mgL^{-1} AVG treatment and 204.2 g in 600 mgL^{-1} AVG treatment in the last measurement date. Similar situation was observed in 2011. Compared to control treatment, NAA and 150 mg L^{-1} AVG treatments did not have any significant effects on fruit mass, width and length of apples (Table 5).

Table 5. Effect of different AVG concentrations and NAA on fruit mass, fruit width and fruit length of 'Red Chief' apples.

Treatments	Fruit mass (g)			Fruit width (mm)			Fruit length (mm)		
2010									
	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.
Control	183.5 a	186.1 a	214.0 a	74.42 a	75.30 a	78.70 a	62.85 a	63.78 a	65.63 a
150 mgL^{-1} AVG	181.7 a	185.6 a	211.1 a	74.27 a	75.44 a	77.67 a	61.53 a	62.97 a	65.19 a
300 mgL^{-1} AVG	176.9 b	181.4 b	205.4 b	72.06 b	73.82 b	75.09 b	59.45 b	60.64 b	62.61 b
600 mgL^{-1} AVG	177.0 b	181.7 b	204.2 b	72.53 b	73.57 b	75.11 b	59.63 b	60.82 b	62.15 b
20 mgL^{-1} NAA	181.7 a	184.2 a	213.7 a	73.99 a	75.45 a	78.96 a	61.21 a	62.86 a	65.63 a
2011									
	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.
Control	182.9 a	188.1 a	207.9 a	69.29 a	72.96 a	74.89 a	62.43 a	64.92 a	65.01 a
150 mgL^{-1} AVG	180.2 a	187.6 a	207.2 a	68.63 a	72.10 a	74.25 a	62.09 a	64.53 a	65.57 a
300 mgL^{-1} AVG	177.5 b	184.4 b	200.5 b	67.20 b	70.71 b	72.27 b	61.06 b	62.91 b	63.44 b
600 mgL^{-1} AVG	176.3 b	185.7 b	201.3 b	67.16 b	70.15 b	72.76 b	61.15 b	62.87 b	63.19 b
20 mgL^{-1} NAA	180.8 a	189.2 a	209.8 a	68.89 a	73.10 a	75.06 a	62.72 a	65.09 a	66.02 a

n = 60 (ten fruits × six replications) for fruit mass, fruit width and fruit length. Means in columns with the same letter do not differ according to Duncan's multiple range test at $P < 0.05$.

Table 6. Effect of different AVG concentrations and NAA on soluble solids content, titratable acidity and starch index of 'Red Chief' apples.

Treatments	Starch index [a]			Soluble solids content			Titratable acidity		
2010									
	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.	11 Sept.	18 Sept.	25 Sept.
Control	3.4 a	3.9 a	5.8 a	11.6 a	13.0 a	13.4 a	0.27 b	0.23 b	0.20 b
150 mgL^{-1} AVG	2.8 b	3.0 b	4.1 b	10.7 b	11.4 b	11.5 b	0.30 a	0.28 a	0.25 a
300 mgL^{-1} AVG	2.7 b	2.9 b	3.9 b	10.7 b	11.3 b	11.5 b	0.30 a	0.29 a	0.25 a
600 mgL^{-1} AVG	2.7 b	2.7 b	3.3 c	10.5 b	11.2 b	11.4 b	0.29 a	0.28 a	0.26 a
20 mgL^{-1} NAA	3.2 a	4.0 a	5.6 a	11.8 a	12.7 a	13.2 a	0.27 b	0.22 b	0.20 b
2011									
	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.	26 Sept.	3 Oct.	10 Oct.
Control	3.9 a	5.4 a	5.9 a	11.9 a	12.7 a	13.8 a	0.30 b	0.26 b	0.23 b
150 mgL^{-1} AVG	3.2 b	3.8 b	4.2 b	11.1 b	11.4 b	12.4 b	0.34 a	0.28 a	0.26 a
300 mgL^{-1} AVG	3.3 b	3.8 b	4.1 b	11.2 b	11.4 b	12.5 b	0.34 a	0.30 a	0.26 a
600 mgL^{-1} AVG	2.8 b	3.1 c	3.6 c	11.0 b	11.2 b	12.5 b	0.33 a	0.30 a	0.27 a
20 mgL^{-1} NAA	4.0 a	5.6 a	6.2 a	11.9 a	12.9 a	13.6 a	0.31 b	0.25 b	0.24 b

n = 60 (ten fruits × six replications) for starch index ([a] 1 = 100% starch and 8 = 0% starch), n = 6 replicates for soluble solids content and titratable acidity (apple samples were taken from each of ten fruits). Means in columns with the same letter do not differ according to Duncan's multiple range test at $P < 0.05$.

***Chemical characteristics*:** Starch degradation of apples was delayed with AVG treatments. Effect of 600 mg L^{-1} AVG treatment on starch degradation was more distinctive than the other AVG treatments at the last harvest date of 2010 and the last two harvest dates of 2011. Soluble solids content of AVG-treated fruits was found to be lower than those of NAA-treated and control fruits, whereas titratable acidity of AVG-treated fruits was found to be higher at all harvest dates of 2010 and 2011. The effect of NAA on chemical characteristics of apple fruits was similar with the control (Table 6).

DISCUSSION

Higher drop rates were observed in control trees of both years. Such a case may be resulted from higher temperatures during the ripening periods of both years (Table 1) (Greene *et al.*, 1987). Current results showed that AVG treatments significantly decreased pre-harvest drop of Red Chief apples. Similar results were observed by various researchers for different apple cultivars (Byers, 1998; Schupp and Greene, 2004; Wargo *et al.*, 2004). It was assumed that AVG controlled pre-harvest drops in apples by inhibiting internal ethylene synthesis (Greene and Schupp, 2004; Silverman *et* *al.,* 2004; Argenta *et al.,* 2006; Greene, 2006). The results of the current study support to those literature findings. In this study, all three AVG doses decreased significantly IEC of Red Chief apple. Previous studies also reported varying effects of AVG on pre-harvest drop rates based on implementation concentrations (Greene, 2002; Greene and Schupp, 2004; Schupp and Greene, 2004). Amarante *et al.* (2002) found that AVG at 125 and 250 mg L^{-1} was highly effective in decreasing fruit drop of Gala while it increased slightly fruit drop of Fuji. All three AVG doses used in this study decreased fruit drop of Red Chief apple by half compared to control.

NAA is commonly used by commercial growers to decrease pre-harvest drop of apples. Therefore, in present study, 20 mgL^{-1} NAA was used as a positive control. On the other hand, compared to control treatment, NAA treatments did not change drop rates in both years. NAA was reported to decrease pre-harvest drop rates but effects of this growth regulator varied based on variety and climate conditions (particularly daily temperatures) and desired results were not always observed (Greene *et al.,* 1987).

Fruit drop is mainly caused by reduced fruit removal force. Therefore, fruit removal forces were also measured in present study. Autio and Bramlage (1982) indicated significant increases in fruit removal force of apples with AVG treatments. Similarly, in current study, all AVG doses significantly increased removal forces compared to control treatment. Generally, NAA did not cause any significant change in removal force.

Increasing ethylene synthesis toward to maturity stimulates fruit softening and abscission (Bonghi *et al.,* 2000). It was well documented that AVG inhibited ethylene biosynthesis, thus retarded fruit ripening (Greene and Schupp, 2004; Kang *et al.,* 2007). Flesh firmness is an important indicator of ripening in apples and decrease with progression of ripening. Several researchers indicated that pre-harvest AVG treatments delayed flesh softening of apples and reported such effect as an indicator of retarding impact of AVG on fruit ripening (Amarante *et al.,* 2002; Greene, 2005; Argenta *et al.,* 2006). Current findings corroborate those results. In this study, flesh firmness of Red Chief apple increased by AVG treatments.

Improvements in fruit colours increase the market value of the fruit. Anthocyanins were primarily responsible for the red skin colour development in apples (Lancaster, 1992). It has been notified that endogenous ethylene was one of the important factors regulating the development of red colour and accumulation of anthocyanin in apples (Blankenship and Unrath, 1988; Whale and Singh, 2007). A disadvantage of inhibiting ethylene synthesis by AVG was reported as a delay in red colour development of apples (Greene, 2005; Argenta *et al.,* 2006; Fallahi, 2007; Whale *et al.,* 2008). The retarding impacts of AVG treatments on colour development values were also observed in the present study. Red or green skin colour in fruit is one of the main factors in colour change. L* and hue angle values approaching 0 (zero) indicate an increase in red colouration (Diaz-Mula *et al.,* 2009). L and hue values of AVG-treated fruits were higher than those of control and NAA treated fruits. Wargo *et al.* (2004) reported decreasing red colour intensities (higher hue angle) with AVG treatments compared to the control treatment.

Depending on cultivars and concentrations used, different results were reported about the effects of AVG on fruit mass. Greene and Schupp (2004) showed that fruit diameter and weight in McIntosh apple significantly and linearly increased with increasing AVG concentrations. It was reported that AVG concentrations ranging from 75 to 300 mg L^{-1} did not affect fruit weight in McIntosh (Schupp and Greene, 2004) and Delicious apple (Greene, 2002). On the other hand, Amarante *et al.* (2002) stated that AVG at 250 mgL^{-1} inhibited fruit growth in Gala. Similarly, Williams (1980) reported that high doses of AVG reduced fruit size at harvest of apples. In this study, while low dose of AVG (150 mgL^{-1}) did not affect fruit weight, high doses (300 and 600 mg L^{-1}) reduced fruit weight. These results might indicate different responses of apple cultivars to AVG treatments.

Starch index values were lower in AVG treated fruits compared to control and NAA treated fruits, which indicated the conversion ratio of starch into sugar was delayed by AVG. This has been attributed to the action of AVG in inhibiting ethylene production (Yuan and Carbaugh, 2007). Similarly, Greene (2006) indicated that AVG affected ripening process of apples by inhibiting ethylene synthesis. SSC contents of AVG treated fruits were lower than that of control and NAA treated fruit likely due to delaying the conversion of starch into sugar by AVG treatments (Greene, 2002; Greene and Schupp, 2004; Wargo *et al.,* 2004). TA, other ripening criteria, was higher in AVG treatments than control and NAA treatment. Similar results were also observed by WookJae *et al.* (2006) in 'Tsugaru' apples and by Amarante *et al.* (2005) in 'Rubiduox' peaches.

Besides the research findings indicating accelerated ripening in apples through stimulation of ethylene synthesis by NAA (Marini *et al.,* 1993; Greene and Schupp, 2004), there some other research findings indicated insignificant effects of NAA on ripening parameters (Dal Cin *et al.,* 2008; Li and Yuan, 2008). In present study, NAA did not have any significant effects both on ethylene synthesis and ripening parameters such as flesh firmness, starch index and SSC. Such a case indicated that the response to NAA treatments might vary based on cultivars.

***Conclusion*:** Current findings revealed that fruit ripening of Red Chief apples might be retarded and pre-harvest fruit drops might be efficiently controlled with AVG treatments. High AVG doses did not yielded any further positive outcomes, contrarily reduced fruit sizes. It was also concluded that NAA was not as effective as AVG in preventing pre-harvest drops.

***Acknowledgment*:** The ReTain® used in this study was supplied by Valent Bio Science Company and Regulaid surfactant was supplied by Kalo Company. Authors appreciate the supports of these companies. Acknowledgements are extended to Associate Professor Dr. Zeki GÖKALP (an expert scientist in agriculture and a certified English translator) for his technical supports for the presentation of this paper.

REFERENCES

Amarante, C.V.T., A. Simioni, C.A. Megguer and L.B.E. Blum. 2002. Effect of aminoethoxyvinilglycine (AVG) on preharvest fruit drop and maturity of apples. ***Rev. Bras.*** Frutic. 24:661-664.

Amarante, C.V.T., A.M.F. Drehmer, F. Souza and P. Francescatto. 2005. Preharvest spraying with gibberellic acid (GA_3) and aminoethoxyvinylglycine (AVG) delays fruit maturity and reduces fruit losses on peaches. Rev. Bras. Frutic. 27:1-5.

Anonymous. 2012. Annual weather forecasts. Turkish state meteorological service, Tokat, Turkey.

Argenta, L.C., M.J. Vieira, J.G. Krammes, J.L. Petri and C. Basso. 2006. AVG and 1-MCP effects on maturity and quality of apple fruit at harvest and after storage. Acta Hort. 727:495-503.

Autio, W.R. and W. Bramlage. 1982. Effect of AVG on maturation, ripening and storage of apples. J. Amer. Soc. Hort. Sci. 107:974-1077.

Blankenship, S.M. and C.R. Unrath. 1988. PAL and ethylene content during maturation of 'Red' and 'Golden Delicious' apples. Phytochemistry 27:1001-1003.

Blanpied, G.D. and K.J. Silsby. 1992. Prediction of harvest date windows for apples. Cornell Cooperative Extension Bull. 2212:1-12.

Bonghi, C., P. Tonutti and A. Ramina. 2000. Biochemical and molecular aspect of fruitlet abscission. Plant Growth Regul. 31:35-42.

Bramlage, W.J., D.W. Greene, W.R. Autio and J.M. Mclaughlin. 1980. Effect of aminoethoxyvinylglycine on internal ethylene concentration and storage of apples. J. Amer. Soc. Hort. Sci. 105:847-851.

Brown, KM. 1997. Ethylene and abscission. Physiol. Plant. 100:567-576.

Byers, R.E. 1998. Effects of aminoethoxyvinylglycine (AVG) on preharvest fruit drop and maturity of 'Delicious' apples. J. Tree Fruit Prod. 2:53-75.

Dal Cin, V., M. Danesin, A. Botton, A. Boschetti, A. Dorigoni and A. Ramina. 2008. Ethylene and preharvest drop: The effect of AVG and NAA on fruit abscission in apple (*Malus domestica* Borkh.). Plant Growth Regul. 56:317-325.

Diaz-Mula, H.M., P.J. Zapata, F. Guillen, D. Martínez-Romero, S. Castillo, M. Serrano and D. Valero. 2009. Changes in hydrophilic and lipophilic antioxidant activity and related bioactive compounds during postharvest storage of yellow and purple plum cultivars. Postharvest Biol. Technol. 51: 54-363.

Fallahi, E. 2007. Influence of 1-aminoethoxyvinylglycine hydrochloride and α-naphthalene acetic acid on fruit retention, quality, evolved ethylene, and respiration in apples. Int. J. Plant Prod. 1:53-61.

Greene, D.W., K. Kaminsky and J. Sincuk. 1987. An evaluation of stop drop materials in 1986. Proc. New England Fruit Meeting 93:74-78.

Greene, D.W. 2002. Preharvest drop control and maturity of 'Delicious' apples as affected by aminoethoxyvinylglycine (AVG). J. Tree Fruit Prod. 3:1-10.

Greene, D.W. and J.R. Schupp. 2004. Effect of aminoethoxyvinylglycine (AVG) on preharvest drop, fruit quality, and maturation of 'McIntosh' apple. II. Effect of timing and concentration relationship and spray volume. HortScience 39:1036-1041.

Greene, D.W. 2005. Time of aminoethoxyvinylglycine application influences preharvest drop and fruit quality of 'McIntosh' apples. HortScience 40:2056-2060.

Greene, D.W. 2006. An update on preharvest drop control of apples with aminoethoxyvinylglycine (ReTain). Acta Hort. 727:311-319.

Kang, I., J. Byun, H. Kweon, M. Kim, S. Kwon, M. Park, D.H. Lee, C. Choi and D.G. Choi. 2007. Effects of aminoethoxyvinylglycine on preharvest drop, fruit color, and quality of 'Tsugaru' Apples. Hort. Environ. Biotechnol. 48:159-164.

Lancester, J.E. 1992. Regulation in skin color in apples. Crit. Rev. Plant Sci. 10:487-502.

Li, J. and R. Yuan. 2008. NAA and ethylene regulate expression of genes related to ethylene biosynthesis, perception, and cell wall degradation during fruit abscission and ripening in 'Delicious' apples. J. Plant Growth Regul. 27:283-295.

Marini, R.P., R.E. Byers and D.L. Sowers. 1993. Repeated application of NAA control preharvest drop of 'Delicious' apples. J. Hort. Sci. 68:247-253.

Schupp, J.R. and D.W. Greene. 2004. Effect of aminoethoxyvinylglycine (AVG) on preharvest drop, fruit quality, and maturation of 'McIntosh' apples. I. concentration and timing of dilute application of AVG. HortScience 39:1030-1035.

Silverman, F.P., P.D. Petracek, M.R. Noll and P. Warrior. 2004. Aminoethoxyvinylglicine effects on late-season apple fruit maturation. Plant Growth Regul. 43:153-161.

Wook.J., I.K. Kang, H.J. Kweon, M.J. Kim, D.H. Kim, D.H. Lee, and J.K. Byun. 2006. Usage potentiality of starch pattern index at aminoethoxyvinylglycine treatment to prevent preharvest drop in 'Tsugaru' apple fruits. Korean J. Hort. Sci. 24:64-69.

Wargo, J.M., I.A. Merwin and C.B. Watkins. 2004. Nitrogen fertilization, midsummer trunk girdling, and AVG treatments affect maturity and quality of 'Jonagold' apples. HortScience 39:493-500.

Whale, S.K. and Z. Singh. 2007. Endogenous ethylene and color development in the skin of 'Pink Lady' Apple. J. Amer. Soc. Hort. Sci. 132:20-28.

Whale, S.K., Z. Singh, M.H. Behboudian, J. Janes and S.S. Dhaliwal. 2008. Fruit quality in 'Cripp's Pink' apple, especially color, as affected by preharvest sprays of aminoethoxyvinylglicine and ethephon. Sci. Hortic. 115:342-351.

Williams, M.W. 1980. Retention of fruit firmness and increase in vegetative growth and fruit set of apples with aminoethoxyvinylglycine. HorScience 15:76-77.

Yaun, R. and D.H. Carbaugh. 2007. Effects of NAA, AVG, and 1-MCP on ethylene biosynthesis, preharvest fruit drop, fruit maturity, and quality of 'Golden Supreme' and 'Golden Delicious' apples. HortScience 42:101-105.

Yaun, R. and J. Li. 2008. Effect of sprayable 1-MCP, AVG, and NAA on ethylene biosynthesis, preharvest fruit drop, fruit maturity, and quality of 'Delicious' apple. HortScience 43:1454-1460.