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ORIGINAL ARTICLE / ORIGINALBEITRAG

Effect of Aminoethoxyvinylglycine (AVG) Applications on Pre-Harvest Drop and Fruit Quality of 'Red Delicious, Red Chief' Apple Cultivar

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Abstract
The study was carried out to determine the effect of different aminoethoxyvinylglycine (AVG) application doses on pre-harvest fruit drop in semi-dwarf rootstock grafted to 'Red Delicious, Red Chief' apple in Central Anatolia Region, Turkey. Different concentrations of AVG (0, 250, 500, 750 mg/l) were applied to apple trees 4 weeks before the anticipated harvest to assess the effects of AVG on fruit drop and fruit quality. Cumulative drop percentage (%), fruit removal force (N), fruit weight (g), flesh firmness (N), soluble solids concentration (SSC, %), pH, titratable acidity (TA, g malic acid 100 g^{-1}) and fruit color (L*, C*, h°) were determined. All AVG doses significantly reduced the cumulative drop percentage compared to the control treatment. The fruit removal force and fruit flesh firmness increased, and SSC decreased compared to control with the increasing AVG doses. The amount of TA increased with the increasing AVG doses while pH decreased. The fruit weight did not change, and the red color formation was delayed by the increasing of AVG doses.

Keywords Apple · Red Delicious · Red Chief · Fruit drop · Growth regulator · Ethylene inhibitor · Aminoethoxyvinylglycin · AVG

Wirkung von Aminoethoxyvinylglycin (AVG)-Applikationen auf den Vorerntefruchtfall und die Fruchtqualität der Apfelsorte 'Red Delicious, Red Chief'

Schlüsselwörter Apfel · Red Delicious · Red Chief · Fruchtfall · Vorerntefruchtfall · Wachstumsregulator · Ethylenhemmer · Aminoethoxyvinylglycin · AVG

Introduction

The apple is among the widely cultured fruit species in the world. Turkey is on 4th place with 3,625,960 tons of apples, after Poland (Anonymous 2018). However, Turkey's apple export is much lower than the apple production of the country due to low yield per unit area and fruit quality reasons (Oğuz and Karaçayır 2009; Bashimov 2016).

One of the main reasons directly affecting the low yield and quality is the pre-harvest fruit drops prior the fruit reaching the ideal size and maximum quality (Wargo et al. 2004; Greene 2006).

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In some years, pre-harvest drops of commercial apple cultivars cause serious economic loses (Ward 2004; Yuan and Carbaugh 2007; Yuan and Li 2008). Since the ethylene increase in the trees is the main triggering factor for drops, the substances inhibiting ehtylene biosynthesis can be used for alleviating pre-harvest fruit drops in apple (Rath et al. 2006). Many researches tried several subtances, mainly AVG and NAA as well as SADH daminozide (Alar), 2,4 DP (dicloropen) 2,4,5-trikoropenoksipropionik asit (2,4,5-TP) in order to alleviate pre-harvest fruit drops in apple (Byers 1997a; Singh and Khan 2010).

Although NAA is used for fruit thinning and preventing fruit drop (Greene and Schupp 2004) many studies have shown its low effectivess in controlling the drops, and also hastens the maturation with fruit meat softening (Greene 2002, 2003; Yuan and Carbaugh 2007).

AVG is a commercial product used in many orchards of apple producing countries for delaying fruit ripening and

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improving quality of apple both at harvest and in storage (Phan-Thien and Mitchell 2004). Its effectiveness for retardation of pre-harvest drop and delaying ripening is well documented (Greene and Schupp 2004; Schupp and Greene 2004).

In studies on preharvest drop and fruit quality in apple growing, the effects of low doses of AVG were investigated. However, studies on the effects of high AVG doses have remained limited. The objective of this study was to determine the effect of several concentrations of AVG (0, 250, 500, 750 mg/l) on alleviating the pre-harvest fruit drop and improving fruit quality of 'Red Delicious, Red Chief' apple cultivar.

Material and Methods

The study area was located in Kırşehir province of Central Anatolia, Turkey, situated in 39° 11′ 45″ N latitude and 34° 09′ 01″ E longitude, and the altitude was 1036 m. The experiment was carried out in 2019, in a commercial orchard containing 12-year-old 'Red Delicious, Red Chief' apple cultivar grafted to the MM 106 rootstock. Three different concentrations of aminoethoxyvinylglycine (AVG) (0, 250, 500, 750 mg/l) were prepared using ReTain (Valent-BioScience Corp. Libertyville, III) containing 15% AVG used in the experiment. The AVG doses were applied on trees 4 weeks before the anticipated harvest time (September 4, 2019) (Greene 2003; Rath et al. 2006). The spray solutions contained a surfactant to ensure homogeneous dispersion of the AVG solutions which were applied in the early morning of a windless weather using a back sprayer. Only water + surfactant was applied to the trees determined as the control treatment. The doses of AVG applied were determined using the information on literature (Schupp and Greene 2004; Yildiz et al. 2012).

The study was carried out with 3 replicates on total of 60 trees, 5 trees in each treatment, including the control treatment. Two of the 5 trees used in each replicate were used to determine the fruit characteristics and the other 3 were used to follow the progression of fruit drop.

Cumulative Drop Percentage

The fruits on the trees were counted and recorded along with the experiment started. The counting of fruits dropped to the ground were started 2 days after the AVG spraying date and continued to count at 2 days intervals. The number of dropped fruits was divided to the number of fruits at the beginning, and the percentage of weekly drop was determined.

Fruit Removal Force

The fruit removal force of 10 fruits in each replicate was determined weekly from the AVG application date to the anticipated harvest time. The removal force of fruits was determined using a digital force gauge (Force Gauge brand, model PCE-PTR 200) in the direction of fruit stem axis with the help of a hanger prepared according to the dimensional properties of the fruits.

Quality Analysis of Fruits at Harvest

The weights of fruits picked up randomly from each replicate at the anticipated harvest date was determined using a precision scale sensitivity with 0.01 g sensitivity; the firmness of fruits was measured with the 11.1 mm tip of the penetrometer (Force Gauge brand, model PCE-PTR 200). Soluble solids concentration of fruits was analyzed using a digital refractometer (Hanna HI 96801), and pH was measured with a digital pH meter (Hanna, model HI9321). For titratable acidity (TA), 10 ml of deionized water was added on 10 ml of fruit juice. The aliquots were titrated to pH 8.2 using 0.1 N sodium hydroxide (NaOH), and the malic acid concentration (g Malic acid/100 g) was calculated using the amount of NaOH spent in the titration.

Color Characteristics

Color measurement of fruits picked up randomly from each replicate at harvest date was carried out using a colorimeter (Konica-Minolta CR-410). The CIE L*, a*, b* values for color measurement were determined by after the calibration process based on a white plate. After the calibration, the chroma (opacity, brightness, liveliness) value was calculated using a* and b* values with the following equation:

$$C^* = [(a^2 + b^2)]^{1/2}$$

The hue angle (0°: red pink, 90°: yellow, 180°: green and 270°: blue), which determines the main components of the color, was calculated with the following equation (McGuire 1992):

$$Hue°h = \tan^{-1}(b/a).$$

Results

Cumulative Drop Percentage

The effect of different AVG doses on cumulative drop percentage is given in Table 1.

Table 1 The effect of different AVG doses on cumulative drop percentage of 'Red Delicious, Red Chief' apple

Treatments mg/l	Cumulative drop (%)			
	September 11	September 18	September 25	October 4
Control	7.01 ± 1.21 a	15.96 ± 3.22 a	23.76 ± 2.83 a	34.53 ± 4.51 a
250 mg/l	6.38 ± 0.68 a	11.02 ± 1.58 a	15.03 ± 1.73 b	19.72 ± 2.47 b
500 mg/l	6.06 ± 1.26 a	11.13 ± 0.53 a	15.2 ± 1.90 b	19.72 ± 2.73 b
750 mg/l	5.05 ± 1.44 a	8.71 ± 2.38 a	11.11 ± 2.89 b	15.02 ± 4.41 b

Different letters in a column indicate significant differences ($p < 0.05$) among AVG treatments

All AVG doses significantly decreased the cumulative drop ratio compared to the control treatment (34.53%) in the anticipated harvest date. The difference in cumulative drop ratio between AVG doses and control treatment was found to be statistically significant on September 25 and October 4 ($p < 0.05$). However, the difference among the AVG doses (19.72, 19.72 and 15.02% for 250, 500 and 750 mg/l, respectively) was not statistically significant, though the drop ratio in 250 mg/l dose was slightly lower than the 500 mg/l treatment.

Fruit Removal Force

The effect of different AVG doses on fruit removal force is given in Table 2.

The difference in fruit removal force between the control and AVG treatments was statistically significant ($p < 0.05$). The removal force applied to pick up a fruit from the branch regularly decreased in all AVG applications depending on the ripening of fruits towards the harvest date. The removal force in all weeks was higher with the increased AVG doses compared to the control. The highest removal force value (17.97 N) in harvest date was recorded in 750 mg/l AVG application, while the lowest value (9.89 N) was in the control application. The fruit removal force recorded in 250 (12.13 N) and 500 mg/l (15.61 N) AVG treatments were also higher than the control.

Quality Analysis at Harvest

The effect of different AVG doses on some of fruit quality parameters such as fruit weight, flesh firmness, soluble solids concentration (SSC), pH and titratable acidity (TA) is given in Table 3.

The effect of AVG treatments on fruit weight was statistically insignificant, and the fruit weights in control and AVG treatments were similar.

The highest flesh firmness value (86.76 N) was obtained in 750 mg/l AVG application and the lowest value (73.57 N) was recorded in the control. The flesh firmness value increased with the increasing dose of AVG applications.

The highest SSC value (13.24) was recorded in the control, while the lowest value (11.50) was obtained in the 750 mg/l AVG application.

The difference in pH values between the treatments at the harvest date was statistically insignificant ($p > 0.05$). The highest pH value (3.82) was obtained in the control while the lowest value (3.61) was in the 750 mg/l AVG application.

Table 2 The effect of different AVG doses on fruit removal force of 'Red Delicious, Red Chief' apple

Treatments	Fruit removal force (N)			
	September 11	September 18	September 25	October 4
Control	17.71 ± 0.39 d	15.95 ± 1.30 c	12.48 ± 0.38 d	9.89 ± 0.24 d
250 mg/l	29.37 ± 0.71 c	24.48 ± 0.85 b	18.44 ± 0.40 c	12.13 ± 0.22 c
500 mg/l	32.12 ± 0.90 b	26.37 ± 0.43 b	20.68 ± 0.44 b	15.61 ± 0.13 b
750 mg/l	35.77 ± 0.29 a	30.28 ± 0.54 a	25.46 ± 0.90 a	17.97 ± 0.64 a

Different letters in a column indicate significant differences ($p < 0.05$) among AVG treatments

Table 3 The effect of AVG treatments on fruit weight, fruit flesh firmness and some biochemical properties of 'Red Delicious Red Chief' apple

Measurements	Treatments			
	Control	250 mg/l	500 mg/l	750 mg/l
Fruit weight (g)	198.42 ± 16.1 a	200.05 ± 19.57 a	200.73 ± 10.97 a	200.82 ± 5.37 a
Flesh firmness (N)	73.57 ± 0.34 d	76.26 ± 0.41 c	85.04 ± 0.27 b	86.76 ± 0.40 a
Soluble solids concentration (%)	13.04 ± 0.31 a	12.40 ± 0.04 b	11.89 ± 0.13 bc	11.50 ± 0.15 c
pH	3.82 ± 0.05 a	3.70 ± 0.04 ab	3.67 ± 0.02 b	3.61 ± 0.09 b
TA (g malic acid $100\,g^{-1}$)	0.20 ± 0.00 c	0.22 ± 0.01 b	0.23 ± 0.00 b	0.25 ± 0.00 a

Different letters in a column indicate significant differences ($p < 0.05$) among AVG treatments

Table 4 Lightness (L*), chroma and hue angle values of 'Red Delicious Red Chief' apple treated with different AVG doses

Color characteristics	Treatments			
	Control	250 mg/l	500 mg/l	750 mg/l
L	33.96 ± 0.01 c	35.53 ± 0.22 b	35.67 ± 0.41 b	38.43 ± 0.26 a
Chroma	26.27 ± 0.02 b	26.43 ± 0.10 ab	26.46 ± 0.19 ab	26.67 ± 0.31 a
Hue	30.17 ± 0.13 d	33.03 ± 0.51 c	34.40 ± 0.52 b	37.20 ± 0.22 a

Different letters in a column indicate significant differences ($p < 0.05$) among AVG treatments

The effect of treatments on TA value at harvest date was statistically very significant ($p < 0.01$). The highest TA value (0.25) was obtained in 750 mg/l AVG application while the lowest value (0.20) was recorded in the control treatment.

Color Characteristics

The lightness (L), chroma and hue angle values measured to determine the fruit color formation of the Red Delicious Red Chief apple at the time of anticipated harvest are given in Table 4.

The highest L (38.43), chroma (26.67) and hue angle (37.20) values were obtained in 750 mg/l AVG application while the lowest values were measured in the control. The L* value, which indicates brightness and varies between 0 and 100, the chroma determines the saturation and vitality of the color, and the hue angle (0°: reddish pink, 90°: yellow, 180°: green and 270°: green) determines the main components of the color (McGuire 1992). The L*, chroma and hue angle values of apples increased with the increase in AVG doses.

Discussion

Higher efficiency of AVG applications in reducing the pre-harvest fruit drop compared to the other growth regulators has been reported also by several other researchers (Greene 2002; Kang et al. 2007; Yuan and Carbaugh 2007; Ozturk et al. 2012; Ünsal and Yıldırım 2017). The fruit drop ratio, which was low at the beginning of the experiment in the control treatment, increased towards the harvest date and reached the highest level (34.53%) at harvest. Byers (1997a) reported that AVG applications reduced the cumulative drop rate of different apple varieties by 3 times compared to the control. Similarly, Yildiz et al. (2012) stated that AVG applications, regardless of the concentrations, in the 'Red Chief' apple variety significantly decreased the pre-harvest drop ratio compared to the control. A linear decrease has been reported between increasing the concentration of AVG and fruit drop ratio (Byers 1997a, b; Greene and Schupp 2004; Schupp and Greene 2004; Yildiz et al. 2012). The findings on fruit drop ratio in this study are compatible with the findings of before mentioned studies. In this study, the increasing doses of AVG significantly reduced the pre-harvest ratio in 'Red Delicious Red Chief' apple.

Autio and Bramlage (1982) stated that AVG increases the fruit removal force. Similarly, the increases in removal rate compared to the other treatments have been reported also in 'Delicious' apple by Greene (2002), 'Jonagold' apple by Öztürk (2012), 'Braeburn' apple by Öztürk et al. (2015) and 'Red Chief' apple by Yildiz et al. (2012). The results obtained in this study are in accordance with the previous studies. The removal force in 'Red Delicious Red Chief' apple with the AVG treatments applied was higher than the control.

Non-significant effect of AVG treatments on fruit weight has been reported by Greene (2002), Schupp and Greene (2004), Greene (2006) and Yuan and Li (2008). Similar to the previous studies, the effect of AVG applications on fruit weight was statistically insignificant in this study and the fruit weight in control and AVG applications were similar.

The fruit flesh firmness increased with increasing AVG doses. Likewise, several other researchers; Wang and Dilley (2001) in 'Gala' and 'Jonagold' apple varieties, Greene (2005) in 'McIntosh' apple variety, Yuan and Carbaugh (2007) 'Golden Delicious' apple varieties, Brackmann et al. (2015) in 'Brookfield' apple variety and Ünsal and Yıldırım (2017) in 'Scarlet Spur' apple variety; reported that AVG applications delayed fruit ripening and maintained fruit flesh firmness compared to the control treatments. In addition, Robinson et al. (2006) reported that pre-harvest AVG application delays the climacteric rise in respiration of fruits, which delays the maturation and helps to maintain the flesh firmness of fruits.

The level of SSC varies depending on the maturity status and is considered as an indicator of sugar content of the fruits. The level of SSC increases by breaking down of the starch into sugar (Stover et al. 2003). The AVG reduces the SSC content of the fruit by delaying starch degradation (Silverman et al. 2004; Yuan and Carbaugh 2007; Brackmann et al. 2015; Öztürk et al. 2015), therefore, the lowest SSC level (11.52%) was recorded at harvest time in 750 mg/l AVG application. Lower SSC content of fruits in AVG applications compared to the control treatments has been reported by Silverman et al. (2004) in 'Red Chief' apple variety, by Wargo et al. (2004) in 'Jonagold' apple variety, and by Escalada and Archbold (2009) in 'Lodi', 'Senshu', 'Redchief' 'Delicious' and 'Red Fuji' apple va-

rieties. Consistent with the findings of previous studies, the amount of SSC in this study also decreased with the increased AVG doses.

The TA content compared to the control increased with the increasing doses of AVG. In contrast to TA, the pH level decreased with the increasing doses of AVG. The results on pH and TA indicated the maturity delaying effect of AVG applications (Greene 2006). In addition, Sır (2006) reported a decrease in TA and an increase in pH with the maturation of the fruits.

Rudell et al. (2005) reported that the Hue angle value close to zero in apples indicates increasing the formation of red color, and the L* and chroma values decrease in general with the increase of the hue angle. Wargo et al. (2004) reported that hue angle was higher in fruits treated with AVG compared to the fruits in control treatment. Consistent with our findings, the application of AVG in 'Gala' and 'Jonagold' (Wang and Dilley 2001), in 'McIntosh' (Stover et al. 2003), in 'Jonagold' (Wargo et al. 2004) and in 'Red Chief' (Yildiz et al. 2012) apples delayed the formation of red color.

In low AVG applications performed by the researchers, (Greene and Schupp 2004) 'McIntosh' apple variety, at 75, 150 and 225 mg/l AVG doses, rate of fruit drops 30%, (Yildiz et al. 2012) 'Red Chief' apple variety 150, 300, 600 mg/l AVG found that the rate of drop was 19% at doses, and they reported that as the dose of AVG increases, the rate of drop will decrease. Considering this situation, the dose value of AVG was tried to be determined by trying high doses (0, 250, 500, 750 mg/l) of AVG compared to other researchers. As a result, according to the researchers, 14 and 4% found a decrease in fruit drop. The results of this study revealed the positive effects of AVG applications at 4 weeks before the anticipated harvest date on the pre-harvest fruit drop and fruit quality characteristics of the 'Red Delicious Red Chief' apple. The application of especially 750 mg/l AVG dose significantly decreases the losses caused by the pre-harvest drop, increases the strength of attachment to the branch and improves the flesh firmness of fruits; therefore, AVG application provides a great economic benefit to the commercial apple growers.

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Conflict of interest S. Boyacı declares that she has no competing interests.

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