THE IMPORTANT ROLE OF AMINOETHOXYVINYLGLYCINE (AVG) PRE-HARVEST APPLICATION IN FRUIT HARVEST TIME, FRUIT QUALITY AND MINERAL ELEMENT CONTENTS OF 'AKÇA' (*PYRUS COMMUNIS* L.)

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Abstract. 'Akça' pear is one of the most grown early varieties in Turkey. Although it is of high quality, it forms smaller fruits than other early varieties. In order to investigate the role of aminoethoxyvinylglycine (AVG) application in the harvest time, fruit yield and quality of 'Akça' pears, this study was carried out for 2 years in 2012 and 2013 in an orchard located in Isparta-Egirdir (Turkey) Fruit Research Institute. ReTain plant growth regulator was used for AVG. ReTain containing 15% AVG was applied to the 'Akça' pear fruits and leaves. Four concentrations of AVG (0, 100, 125, 150 ppm) and three application times [30, 21, 7 days before commercial harvest (DBH)] were evaluated using the field system. Harvest time, fruit yield, fruit size, fruit weight, fruit flesh firmness, titratable acidity (TA), soluble solid contents (SSC), fruit color, ethylene production and respiration rate, and nutritional status of fruits were determined at the harvest time. In addition, the effect of AVG applications on some leaf properties (macro-micro element content, leaf area and chlorophyll) was determined. As a result, 30 and 21 DBH AVG applications delayed the harvest time for 3 days. AVG applications reduced both ethylene production and respiration rate. All AVG applications dramatically increased fruit size (2-16%) and fruit weight (7-57%) as well as fruit flesh firmness (1-55%) of the 'Akça' pear. Given all these results, it is considered that 21 DBH AVG applications at 100 ppm will be suitable for the 'Akça' pear in terms of harvest time and fruit and leaf quality parameters.
Keywords: *ethylene inhibitor, pear, leave properties, plant growth regulator, nutritional status*

Introduction

The amount of pears produced in the world is 25.798.644 tons and, with a production amount of 462.336 tons, pear takes the 5th place in Turkey (FAOSTAT, 2018). However, it falls behind other European countries in terms of both yield per decare and exportation. One of the biggest reasons for this is that products with sufficient quality cannot be obtained due to problems related to cultivation techniques. There are many studies conducted in the world for the purpose of increasing fruit quality, and most of them are on plant growth regulators. The most frequently used natural plant growth regulator in the world is the ethylene group (23%), followed by the auxin group and gibberellins (17%), respectively. Cytokinin and Dormin are not yet widely used in the world (Barut, 1995). In recent years, AVG (aminoethoxyvinylglycine), an ethylene blocker, has been used to increase pre-harvest fruit fall and fruit quality. AVG is commercially sold worldwide as ReTain® plant growth regulator. ReTain contains 15% AVG and is a human and environmentally friendly, organic commercial product (Rath and Prentice, 2004) registered in 2001 for use in apples, peaches and nectarine fruits in Australia. Preharvest application of AVG 1–4 weeks prior to harvest inhibits biosynthesis of ethylene and influences abscission, ripening and senescence and reduces quality loss after harvest in many crops (Martinez-Romero et al., 2007; Lurie, 2008; Pech et al., 2012; Kuçuker et al., 2015b; Pasa, et al., 2017). Jobling et al. (2003) found

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that AVG treated plums allowed a delay in harvested timing, and resulted in retaining higher firmness and SSC in comparison with untreated fruit, suggesting that accumulation of soluble solids can take place when fruits are on trees for longer. Dussi et al. (2002) applied 14 DBH 125 and 180 ppm AVG to 'Williams' pears. In this study, AVG had no effect on pre-harvest fall, but both fruit size and fruit hardness increased. It was reported that 21, 14 and 7 DBH 125 ppm AVG applied to 'Abbe Fetel' pear delayed the harvest for 5 to 15 days (Andreotti et al., 2004). The pear variety 'Akça' is desired by producers and consumers for being an early comer and its quality characteristics. The fruit size of this variety is slightly smaller than other early comers, meaning a decrease in its market price and a disadvantage for producers. The purpose of this study is to determine the appropriate dose and application time of AVG as well as the effectiveness of AVG applications to improve the fruit quality of the 'Akça' pear.

Material and methods

Plant-chemical materials and experiment design

The plant material of the study was the 12-year-old Akça/Quince A trees in the pear orchard of Egirdir Fruit Research Institute Directorate Isparta, Turkey) Cultural practices such as irrigation, fertilization, plant protection and pruning were carried out regularly during the trial. Thinning was not performed for the fruits. In our study, ReTain (15% AVG) plant growth regulator (Valent BioScience Corporation) was used as the chemical material, and AVG doses were calculated based on the active substance. Four doses of AVG – namely, 0 (control), 100, 125 and 150 ppm – were used. These doses were applied to all fruits and leaves of the 'Akça' pear 30, 21, 7 days before harvest (DHB) for two years. All spray solutions contained 0.2% 'Tween 20' as surfactant. Control trees were sprayed with water + surfactant. A knapsack sprayer was used to apply AVG onto fruits and leaves at the rate of 8 L per tree (*Fig. 1*). The experiment was set up according to the design pattern of 4 repetitive random blocks, and each repetition consisted of 1 tree.

Figure 1. *'Akça' pear and application*

Determination of the effect of applications on harvest time

Determination of harvest time; observation of the fruit size, greenish-yellow coloration of the fruit ground color, hardness of the fruit flesh, and formation of the fruit top color. Harvest was carried out according to these harvest criteria and harvest time

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scales (Ozelkok and Kaynaş, 1995), and the effect of AVG applications on harvest time was determined.

The effect of applications on yield and some fruit quality properties

Of the trees from each application, yield (kg tree^{-1}) per tree and yield (kg cm^{-2}) per trunk section area were determined. Average values were calculated by measuring the width (mm) and length (mm) of the fruit with the help of a calliper. The average fruit weight (g) of the fruit was calculated by weighing. Flesh firmness measurements were determined as Newton (N) with Lloyd Instruments LF Plus (Ametek, U.K.) texturing equipment. Using a CR-300 Minolta (Japan) color meter and taking measurements from both cheek areas of the fruits, fruit color was determined by CIE L*, a*, b*, C* and Hu°. SSC (with digital refractometer, %) and TA (titration method, %) were determined.

The effect of applications on ethylene production and respiratory rate in fruits

As reported by Dilmaçunal (2009), pears weighing approximately 1 kg were put into jars and kept at 20 ± 1 °C for 24 h to determine ethylene production (μL kg^{-1} h) and respiratory rate (μL kg^{-1} h). Ethylene production and respiratory rate were determined by using gas chromatography.

The effect of applications on fruit and leaf mineral element contents

N (nitrogen) analysis in fruit and leaf

In the plant sample burned with a salicylic-sulfuric acid mixture of 2.5%, ammonia formation was obtained in the base environment of the kjeldahl distillation unit. The ammonia formed was then kept in boric acid and titrated with 0.1 N sulfuric acid. It was calculated as shown in the formula below (Ryan et al., 2001) (*Eq. 1*).

$$N\% = \frac{(T-B) \times N \times 1.4}{S} \qquad \text{(Eq.1)}$$

T: Amount of sulfuric acid consumed for plant sample titration
B: Amount of sulfuric acid consumed for stratum corneum (witness) titration
N: Normality of sulfuric acid
S: Amount of plant sample used in the analysis
1.4: Coefficient

P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium), Cu (copper), Fe (iron), Mn (manganese), Zn (zinc), B (boron) analysis in fruit and leaf

Since a considerable amount of boron is lost during wet combustion, dry combustion was performed. Reading was made by ICP (Inductively Coupled Plasma Atomic Emission Spectophometer) (Ryan et al., 2001). The following steps were taken as part of dry combustion: 0.5 g ground plant material was put into porcelain crucibles, which were then placed into the muffle furnace. Furnace temperature was gradually increased to 550 °C. After reaching 550 °C, combustion continued for 6 h. Following combustion, 5 ml 2 N HCl was added into the cooled porcelain crucibles and the samples were dissolved and stirred with a plastic stick. After 15-20 min, pure water was added until

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reaching 50 ml and thoroughly stirred. 30 min later, it was filtered using a filter paper, and the extract obtained was read by ICP.

The effect of application on leaf area (LA) and total chlorophyll (spad value)

Total chlorophyll was measured using a portable chlorophyll meter on July 15 (first year) – July 10 (second year) (Minolta SPAD-502, Osaka, Japan). Designed and manufactured based on the principles of Inada (1963), this chlorophyll meter measures the amount of chlorophyll in leaves indirectly. It measures the red and infrared regions in the leaf structure (at 659 nm and 940 nm wavelengths, respectively) to determine the relative chlorophyll density. 15 leaf samples were taken in total from four sides of the trees in all applications, and the surface area of one side of each leaf was calculated as a cm^2 by a digital planimeter (Koizumi KP-90 N) (Kucukyumuk et al., 2015).

Statistical analysis of results

Variance analysis was performed with the obtained data, and differences between the treatments were tested by Duncan’s multiple range test at $P < 0.05$ using SSPS (V. 18; Statiscal software, SPSS. Inc., USA) software program. The experiment was based as a completely randomized blocking pattern as four replications and was assigned as one tree for each replication, and was assigned to one tree at each replication with each plot having 20 pear fruits.

Results

Fruit harvest time and yield

The harvest was made 2 times a year for both years, and it was seen that the applications affected harvest dates. In the 1st and 2nd years, the control group and the fruits with 7 DBH AVG ripened at the same time, while the fruits with 30 and 21 DBH AVG ripened later. After reaching maturity for the first harvest, the control and the fruits with 7 DBH AVG were harvested on July 14 in the first year and on July 6 in the second year. On the other hand, other fruits with 30 and 21 DBH AVG were harvested on July 18 in the first year and on July 9 in the second year. It was determined that AVG applications (except for 7 DBH) delayed the harvest maturity of Akça pear for up to 3-4 days. AVG applications did not have any statistically significant effect on yield per tree or yield per trunk section in both years (*Table 1*).

Table 1. *The effect of AVG treatments on yield in the ‘Akça’ pear, 2012 and 2013*

Application time[1]	AVG doses (ppm)	Yield (kg tree^{-1})		Yield (kg cm^{-2})	
		I. Year	II. Year	I. Year	II. Year
30 d	0	8.52	12.78	0.02	0.29
	100	8.93	13.40	0.02	0.28
	125	9.27	13.90	0.02	0.28
	150	9.60	14.40	0.03	0.32
21 d	0	8.68	12.78	0.03	0.29
	100	10.33	15.50	0.03	0.33
	125	10.73	16.10	0.03	0.36
	150	10.33	15.50	0.03	0.40

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7 d	0	8.22	12.78	0.02	0.29
	100	13.20	19.80	0.04	0.48
	125	10.70	16.05	0.03	0.37
	150	9.80	14.70	0.03	0.36
Time means					
30		9.08	13.62	0.02	0.29
21		10.02	14.97	0.03	0.34
7		10.48	15.83	0.03	0.37
	Dose means				
	0	8.47	12.78	0.02	0.29
	100	10.82	16.23	0.03	0.36
	125	10.23	15.35	0.03	0.34
	150	9.91	14.87	0.03	0.36
P values					
Time (T)		0.275	0.251	0.267	0.096
AVG dose (D)		0.702	0.748	0.956	0.864
T x D		0.283	0.326	0.730	0.231

[1]Days before harvest (DBH)

Fruit quality

As a result of the variance analysis performed in both application years, the time x dose interactions were found statistically significant ($p < 0.05$) in terms of fruit width (*Table 2*). In both years, the AVG applications increased fruit width. The applications with the highest fruit width in the first and second years were 21 DBH 100 ppm AVG (48.32 mm) and 30 DBH 100 ppm AVG (49.54 mm), respectively (*Table* 2). The effect of AVG applications on fruit length was statistically significant ($p < 0.05$) only in the first year as time x dose interaction (*Table* 2). Just like in fruit width, the applications with the highest fruit length were 21 DBH 100 ppm AVG (1st year). On the other hand, the lowest fruit length was observed in the control fruits with 7 DBH AVG application (1st year) (*Table 2*). Fruit weight increased with the applications in both years, and the time x dose interaction was found to be statistically significant in the analysis of variance ($p < 0.05$). The heaviest fruits were obtained from 30 and 21 DBH 100 ppm AVG applications. The least heavy fruits were again obtained from the controls (*Table 2*).

Table 2. *The effect of AVG treatments on fruit width, length and weight in the ‘Akça’ pear, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Fruit width (mm)**		**Fruit length (mm)**		**Fruit weight (g)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	45.02c-e*	42.53b*	56.79e-g*	79.55	53.17de*	47.86c*
	100	47.81ab	49.54a	63.32bc	69.64	68.07a	71.28a
	125	47.54ab	48.75a	64.72b	68.89	64.39ab	70.42a
	150	47.07a-d	48.01a	62.81b-d	68.08	60.27bc	67.00a

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21 d	0	45.74b-e	42.30b	55.97fg	60.81	53.71c-e	46.50c
	100	48.32a	49.23a	68.61a	70.64	67.10a	73.26a
	125	47.62ab	48.44a	65.68ab	66.09	64.06ab	67.41a
	150	46.31a-d	48.76a	62.16b-d	69.99	57.17cd	71.77a
7 d	0	44.05e	42.79b	53.78g	63.30	49.01e	49.17c
	100	45.89b-e	48.38a	60.09c-e	65.58	55.84cd	67.43a
	125	44.97de	48.99a	59.50d-f	65.14	52.62de	68.20a
	150	47.12a-c	44.10b	60.97cd	56.09	60.14bc	61.12b
Time means							
30		46.86	47.21	61.91	71.54	61.48	64.14
21		47.00	47.18	63.11	66.88	60.51	64.74
7		45.51	46.07	58.59	62.53	54.40	61.48
	Doses means						
	0	44.94	42.54	55.52	67.89	51.97	47.84
	100	47.34	49.05	64.01	68.62	63.67	70.66
	125	46.71	48.73	63.30	66.71	60.36	68.68
	150	46.83	46.96	61.98	64.72	59.19	66.63
P values							
Time (T)		0.037	0.629	0.032	0.083	0.015	0.710
AVG Doses (D)		0.649	0.499	0.459	0.177	0.283	0.807
T x D		0.002	0.000	0.000	0.465	0.000	0.000

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan's multiple range test

The time x dose interaction of AVG applications was statistically significant ($p < 0.05$) in terms of fruit flesh firmness in both years. In both years, fruit flesh firmness increased with the applications, and the fruit flesh firmness of the applications of 21 DBH was higher than others. 21 DBH 100 ppm AVG in the first year and 30 DBH 150 ppm AVG in the second year gave the hardest fruits (*Table 3*).

Table 3. *The effect of AVG treatments on fruit flesh firmness, SSC and TA in the 'Akça' pear, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Firmness (N)**		**SSC (%)**		**TA (%)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	88.99c*	82.22b*	12.73b*	12.13	0.17a-d*	0.17b-d*
	100	89.77bc	94.14ab	11.23d	12.83	0.17a-d	0.17b-d
	125	92.33b	97.00ab	11.33d	12.27	0.15d	0.16d
	150	90.93b	104.13a	11.87cd	12.33	0.17a-d	0.17b-d
21 d	0	86.30c	83.33b	12.80ab	12.27	0.17a-d	0.16d
	100	95.15a	93.83ab	11.90cd	12.00	0.19a	0.19a
	125	93.00a	96.95ab	12.53bc	12.07	0.17a-d	0.16d
	150	95.02a	100.08ab	12.60b	12.23	0.16b-d	0.17b-d

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7 d	0	89.83bc	63.97c	12.90ab	12.33	0.17a-d	0.18ab
	100	91.35b	89.60ab	12.83ab	12.37	0.16cd	0.17b-d
	125	91.98b	87.21ab	13.47a	11.80	0.17a-c	0.18ab
	150	87.39c	99.37ab	12.87ab	12.67	0.18ab	0.18ab
Time means							
30		90.51	94.37	11.79	12.39	0.17	0.01
21		92.37	93.55	12.46	12.14	0.17	0.01
7		90.14	85.04	13.02	12.29	0.18	0.02
	Dose means						
	0	88.37	76.51	12.81	12.24	0.17	0.01
	100	92.09	92.52	11.99	12.40	0.17	0.01
	125	92.44	93.72	12.44	12.04	0.17	0.01
	150	91.11	101.19	12.44	12.41	0.17	0.01
P values							
Time (T)		0.406	0.176	0.000	0.371	0.375	0.001
AVG Dose (D)		0.954	0.943	0.370	0.219	0.375	0.896
T x D		0.044	0.006	0.000	0.237	0.051	0.004

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan's multiple range test

In the first year, the applications increased the amount of SSC, and the time x dose interaction was found to be significant ($p < 0.05$) as a result of the variance analysis. In the second year, however, the applications were statistically insignificant. In the first year, the highest SSC (13.47%) was found in 7 DBH 125 ppm AVG *(Table 3)*. The time x dose interaction was statistically significant ($p < 0.05$) in terms of TA in both years, and the highest TA was obtained from 21 DBH 100 ppm AVG (*Table 3*).

In the first year, the effect of AVG applications on fruit color values (L*, a*, b*, C*, h°) was statistically significant ($p < 0.05$) in time x dose interactions (*Table 4*).

Table 4. *The effect of AVG treatments on fruit color (L*, a*, b*, C*, h°) in the 'Akça' pear, 2012*

Application time[1]	AVG doses (ppm)	L*	a*	b*	C*	h°
30 d	0	72.79a*	-19.11a*	48.47ab*	52.16bc*	111.54f*
	100	70.43de	-21.19cd	48.01bc	52.52bc	113.82b-d
	125	69.19f	-21.84de	47.32d	52.13bc	114.79ab
	150	69.92d-f	-21.59c-e	47.37d	52.07c	114.51a-c
21 d	0	72.53ab	-19.18a	48.60ab	52.32bc	111.55f
	100	67.96g	-22.21e	47.16d	52.14bc	115.23a
	125	69.54ef	-21.82de	47.58cd	52.35bc	114.64a-c
	150	70.48de	-21.30c-e	48.23a-c	52.74ab	113.84b-d
7 d	0	71.62bc	-20.15b	48.18bc	52.26bc	112.72e
	100	70.65c-e	-21.07b-d	48.85a	53.24a	113.35de
	125	70.52de	-20.82bc	48.43ab	52.76ab	113.27de
	150	70.71cd	-20.98b-d	48.00bc	52.41bc	113.63c-e

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Time means						
30		70.58	-20.93	47.79	52.22	113.66
21		70.13	-21.13	47.89	52.39	113.82
7		70.87	-20.75	48.37	52.67	113.24
	Dose means					
	0	72.31	-19.48	48.42	52.24	111.94
	100	69.68	-21.49	48.01	52.63	114.13
	125	69.75	-21.49	47.78	52.41	114.23
	150	70.37	-21.29	47.87	52.41	113.99
P values						
Time (T)		0.431	0.706	0.041	0.032	0.517
AVG Dose (D)		0.902	0.965	0.758	0.670	0.218
T x D		0.000	0.000	0.000	0.006	0.000

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan's multiple range test

The values of L*, which indicates brightness, decreased with the AVG applications. The lowest L* was obtained from 21 DBH 100 ppm AVG (67.96). The values of a*, which indicates redness, also decreased with the applications, and the lowest value was obtained from 21 DBH 100 ppm AVG, which also gave the value of b* indicating yellowness. On the other hand, the highest value of b* was obtained from 7 DBH 100 ppm AVG. As in b* values, the highest C* value was produced by 7 DBH 100 ppm AVG. The hue values of AVG-applied fruits were higher than those of the control fruits, and the highest h° value was produced by 21 DBH 100 ppm AVG (*Table 4*). In the second year of the project, the time x dose interactions of L*, a*, h° values were found to be statistically significant ($p < 0.05$). L* and a* values decreased with the AVG applications, and the lowest L* (67.78) and a* (22.58) values were observed in 21 DBH 150 ppm AVG. It was found that the h° values of the AVG applications were higher than the control fruits, and the highest h° value was obtained from 21 DBH 125 ppm AVG (*Table 5*).

Table 5. *The effect of AVG treatments on fruit color (L*, a*, b*, C*, h°) in the 'Akça' pear, 2013*

Application time[1]	AVG doses (ppm)	L*	a*	b*	C*	h°
30 d	0	73.90a*	-19.66ab*	48.36	52.32	112.12b-d*
	100	69.17b	-22.32c	47.46	52.46	115.19a
	125	70.08b	-22.00c	47.53	52.38	114.85a
	150	69.96b	-22.49c	47.19	52.28	115.49a
21 d	0	73.46a	-19.35ab	48.60	52.48	111.69cd
	100	68.95b	-22.21c	47.93	52.83	114.87a
	125	69.96b	-22.01c	47.69	52.54	114.78a
	150	67.78b	-22.58c	47.10	52.24	115.62a

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7 d	0	74.50a	-18.68a	48.74	52.30	110.94d
	100	69.68b	-21.82c	48.42	53.13	114.29ab
	125	70.73b	-21.07bc	48.19	52.66	113.63a-c
	150	69.93b	-21.30bc	47.72	52.29	114.07a-c
Time means						
30		70.78	-21.62	47.63	52.36	114.41
21		70.04	-21.54	47.83	52.52	114.24
7		71.21	-20.72	48.27	52.60	113.23
	Dose means					
	0	73.95	-19.23	48.56	52.37	111.58
	100	69.27	-22.12	47.93	52.81	114.78
	125	70.25	-21.69	47.80	52.53	114.42
	150	69.22	-22.12	47.34	52.27	115.06
P values						
Time (T)		0.499	0.328	0.115	0.505	0.266
AVG Dose (D)		0.804	0.843	0.471	0.122	0.883
T x D		0.000	0.003	0.066	0.601	0.003

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan’s multiple range test

Ethylene production and respiration rate

In the first year, ethylene production could not be determined. In terms of respiration rate, the time x dose interaction was found statistically significant ($p < 0.05$). In the second year, however, the effect of the applications on both ethylene production and respiration rate was found to be statistically significant ($p < 0.05$) in terms of time x dose interaction (*Table 6*). All AVG applications slowed both ethylene production (µL kg^{-1} h) and respiratory rate (µL kg^{-1} h) in the fruit. The lowest ethylene production was 0.15 µL kg^{-1} h and the lowest respiration rate was 12.32 µL kg^{-1} h obtained from 21 DBH 150 ppm AVG (*Table 6*).

Table 6. *The effect of AVG treatments on ethylene production and respiration rate in the ‘Akça’ pear, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Ethylene production (µL kg^{-1} h)**		**Respiration rate (µL kg^{-1} h)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**
30 d	0	-	3.54a*	15.41a-c*	28.16a*
	100	-	0.86d-f	15.13bc	18.22b-d
	125	-	1.12c-f	15.87a-c	15.06cd
	150	-	0.28ef	15.96a-c	13.80cd
21 d	0	-	2.98ab	16.72ab	27.38a
	100	-	0.56d-f	16.06a-c	16.55b-d
	125	-	0.82d-f	14.61c	19.08b-d
	150	-	0.15f	15.66a-c	12.32d

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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7 d	0	-	2.09bc	17.07a	23.51ab
	100	-	2.02bc	15.06bc	21.41a-c
	125	-	1.56cd	16.54ab	18.14b-d
	150	-	1.23c-e	15.96a-c	17.17b-d
Time means		-			
30		-	1.45	15.59	18.81
21		-	1.13	15.76	18.84
7		-	1.72	16.16	20.06
	Dose means	-			
	0	-	2.87	16.40	26.35
	100	-	1.15	15.41	18.73
	125	-	1.17	15.68	17.43
	150	-	0.55	15.86	14.43
P values		-			
Time (T)		-	0.441	0.427	0.851
AVG Dose (D)		-	0.166	0.218	0.181
T x D		-	0.000	0.049	0.001

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan’s multiple range test

Fruit and leave mineral element contents determination

The effect of AVG applications on the nitrogen contents of fruits was found to be statistically significant ($p < 0.05$) in both years as time x dose interaction. In both years, nitrogen contents increased with 30 and 21 DBH AVG applications but decreased with 7 DBH AVG applications. The highest and lowest nitrogen contents were obtained from 30 DBH 150 ppm AVG and from 7 DBH 125 ppm AVG, respectively (*Table 7*).

Table 7. *The effect of AVG treatments on nitrogen, calcium, magnesium in the ‘Akça’ pear fruit, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Nitrogen (%)**		**Calcium (ppm)**		**Magnesium (ppm)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	0.50bc*	0.52a*	0.08	0.07a-c*	0.06	0.06
	100	0.56b	0.57ab	0.09	0.09ab	0.07	0.07
	125	0.54bc	0.55ab	0.08	0.07a-c	0.06	0.06
	150	0.72a	0.72a	0.09	0.09a	0.07	0.07
21 d	0	0.39c	0.50b	0.07	0.06c	0.06	0.06
	100	0.55b	0.56ab	0.10	0.09a	0.06	0.06
	125	0.51bc	0.50b	0.05	0.07bc	0.05	0.05
	150	0.55bc	0.55ab	0.09	0.09a	0.07	0.07
7 d	0	0.50bc	0.48b	0.07	0.06c	0.05	0.07
	100	0.42bc	0.42b	0.08	0.08abc	0.05	0.05
	125	0.41bc	0.41b	0.08	0.08abc	0.06	0.06
	150	0.46bc	0.46b	0.08	0.08abc	0.06	0.06

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Time means							
30		0.58	0.59	0.08	0.08	0.06	0.07
21		0.50	0.53	0.08	0.08	0.06	0.06
7		0.45	0.44	0.08	0.08	0.06	0.06
	Dose means						
	0	0.46	0.50	0.07bc	0.07	0.06	0.06
	100	0.51	0.52	0.09ab	0.09	0.06	0.06
	125	0.49	0.49	0.07c	0.07	0.06	0.06
	150	0.57	0.58	0.09a	0.09	0.07	0.07
P values							
Time (T)		0.008	0.002	0.732	0.683	0.155	0.237
AVG Dose (D)		0.154	0.347	0.025	0.000	0.175	0.144
T x D		0.004	0.041	0.195	0.030	0.239	0.187

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan's multiple range test

In the variance analysis made for calcium content, only the time x dose interaction of the applications in the second year was found statistically significant ($p < 0.05$). In general, calcium content increased with the applications. In terms of magnesium content, however, no statistically significant difference was observed in both years (*Table 7*). In terms of phosphorus and potassium, there was no statistically significant difference in phosphorus content in both years, while the difference between dose averages was statistically significant ($p < 0.05$) in potassium content and the dose of 150 ppm had the highest amount of potassium (*Table 8*).

Table 8. *The effect of AVG treatments on phosphorus, potassium, copper, zinc in the 'Akça' pear fruit, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Phosphorus (ppm)**		**Potassium (ppm)**		**Copper (ppm)**		**Zinc (ppm)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	0.12	0.12	1.18	1.18	1.82	1.83	9.17b*	9.41
	100	0.13	0.14	1.21	1.22	3.65	3.76	12.64a	12.80
	125	0.11	0.11	1.04	1.04	2.28	2.15	11.28ab	12.29
	150	0.14	0.14	1.28	1.29	2.68	3.10	13.92a	14.08
21 d	0	0.12	0.12	1.16	1.12	1.74	2.44	9.09b	9.42
	100	0.12	0.12	1.14	1.14	2.30	2.30	11.25ab	11.81
	125	0.08	0.08	0.79	0.79	3.08	2.98	10.90ab	11.20
	150	0.13	0.13	1.21	1.22	3.31	3.21	10.95ab	10.97
7 d	0	0.12	0.12	1.16	1.12	1.67	2.63	9.14b	9.21
	100	0.11	0.11	1.01	1.01	2.44	2.61	8.25b	8.17
	125	0.11	0.12	1.03	1.04	2.56	2.66	8.85b	9.26
	150	0.12	0.12	1.07	1.12	2.93	3.10	10.85ab	10.98

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Time means									
30		0.13	0.13	1.18	1.18	2.61	2.71	11.75	12.15a*
21		0.11	0.11	1.08	1.07	2.61	2.73	10.55	10.85ab
7		0.11	0.12	1.07	1.07	2.40	2.75	9.27	9.40b
	Dose means								
	0	0.12	0.12	1.17a*	1.14a*	1.74	2.30	9.13	9.34
	100	0.12	0.12	1.12a	1.12a	2.79	2.89	10.72	10.93
	125	0.10	0.10	0.95b	0.96b	2.64	2.60	10.34	10.92
	150	0.13	0.13	1.18a	1.21a	2.97	3.14	11.91	12.01
P values									
Time (T)		0.331	0.335	0.260	0.219	0.882	0.995	0.016	0.016
AVG Dose (D)		0.107	0.110	0.017	0.019	0.101	0.300	0.051	0.130
T x D		0.272	0.276	0.059	0.078	0.596	0.608	0.015	0.055

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at $p < 0.05$ level according to Duncan's multiple range test

In both years, the effect of AVG applications on iron content was statistically significant ($p < 0.05$) as time x dose interaction. However, manganese and boron contents were not found to be statistically significant (*Table 9*). The effect of AVG applications on copper and zinc contents is given in *Table 8*. In zinc content, the time x dose interaction was statistically significant ($p < 0.05$) only in the first year of AVG applications. The application with the highest iron content was 30 DBH 150 ppm AVG in both years. On the other hand, the lowest iron content was observed in the control fruits with 7 DBH AVG (*Table 9*).

Table 9. *The effect of AVG treatments on iron, manganese, boron in the 'Akça' pear fruit, 2012 and 2013*

Application time[1]	AVG doses (ppm)	Iron (ppm)		Manganese (ppm)		Boron (ppm)	
		I. Year	II. Year	I. Year	II. Year	I. Year	II. Year
30 d	0	13.90e*	14.45cd*	5.27	5.61	12.00	11.48
	100	19.27ab	18.91ab	7.23	7.73	17.73	17.99
	125	17.33b-d	17.37b-d	6.14	6.41	11.97	12.03
	150	21.21a	21.22a	7.07	7.20	14.71	15.36
21 d	0	13.87e	13.82d	4.84	5.32	12.14	12.71
	100	17.04b-e	17.09b-d	6.60	6.78	12.41	12.28
	125	17.78bc	17.75bc	6.24	6.57	13.02	12.60
	150	17.01b-e	16.86b-d	6.11	6.55	13.39	13.46
7 d	0	14.03e	14.09cd	4.75	5.26	12.60	11.19
	100	14.45de	14.91cd	5.40	5.74	15.21	15.51
	125	14.98c-e	14.96cd	5.87	6.09	14.90	15.18
	150	16.37b-e	16.21b-d	5.67	6.00	11.82	13.40
Time means							
30		17.93	17.99	6.43	6.74	14.10	14.21
21		16.43	16.38	5.95	6.30	12.74	12.76
7		14.96	15.04	5.42	5.77	13.63	13.82

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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	Dose means						
	0	13.93	14.12	4.95	5.40	12.25	11.79
	100	16.92	16.97	6.41	6.75	15.12	15.26
	125	16.70	16.69	6.08	6.36	13.30	13.27
	150	18.20	18.10	6.28	6.58	13.31	14.07
P values							
Time (T)		0.019	0.019	0.159	0.107	0.625	0.582
AVG Dose (D)		0.003	0.007	0.055	0.042	0.361	0.191
T x D		0.000	0.002	0.310	0.171	0.659	0.453

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan’s multiple range test

The effect of AVG applications was found to be statistically insignificant on the nitrogen content of leaves but statistically significant ($p < 0.05$) on the magnesium content as time x dose interaction only in the second year and again statistically significant ($p < 0.05$) on the calcium content as time x dose interaction in both years of the project (*Table 10*).

Table 10. *The effect of AVG treatments on nitrogen, calcium, magnesium in the ‘Akça’ pear leave, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Nitrogen (%)**		**Calcium (ppm)**		**Magnesium (ppm)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	1.98	1.92	1.98b*	1.80b*	0.43	0.47ab*
	100	1.95	1.82	1.78bc	1.55cd	0.40	0.39c
	125	2.07	1.99	2.03ab	2.06a	0.44	0.48a
	150	2.05	1.85	1.95bc	1.64b-d	0.40	0.39c
21 d	0	1.93	1.79	1.79bc	1.82b	0.42	0.48a
	100	1.97	1.89	2.42a	1.76bc	0.42	0.43a-c
	125	1.95	1.91	2.03ab	1.81b	0.43	0.46ab
	150	2.02	1.89	1.76bc	1.72b-d	0.41	0.45ab
7 d	0	2.00	1.76	1.50c	1.78bc	0.25	0.45ab
	100	2.03	1.95	1.89bc	1.51d	0.42	0.43a-c
	125	2.04	1.83	1.97bc	1.60b-d	0.40	0.42bc
	150	1.96	1.90	1.92bc	1.83b	0.43	0.46ab
Time means							
30		2.01	1.89	1.94	1.76	0.42	0.43
21		1.97	1.87	2.00	1.78	0.42	0.46
7		2.01	1.86	1.82	1.68	0.38	0.44
	Dose means						
	0	1.97	1.83	1.75	1.80	0.37	0.47
	100	1.98	1.89	2.03	1.61	0.41	0.42
	125	2.02	1.91	2.01	1.82	0.43	0.45
	150	2.01	1.88	1.88	1.73	0.41	0.44
P values							
Time (T)		0.262	0.818	0.322	0.352	0.296	0.299
AVG Dose (D)		0.498	0.549	0.152	0.037	0.404	0.033
T x D		0.349	0.609	0.034	0.001	0.161	0.009

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan’s multiple range test

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The leaves with the highest calcium content (2.42 ppm) were obtained from 21 DBH 100 ppm AVG in the first year and from 30 DBH 125 ppm AVG in the second year (*Table 10*). In terms of magnesium contents, the amount of magnesium decreased with the applications in the second year in general; it increased only in 30 DBH 125 ppm AVG (*Table 10*). With respect to the effect of AVG applications on phosphorus and potassium contents, the time x dose interaction for phosphorus and the difference between doses for potassium were found statistically significant ($p < 0.05$) (*Table 11*). *Table 11* shows the effect of AVG applications on the copper and zinc contents of the Akça leaves. It was seen that the applications increased the copper content. The effect of AVG applications was statistically significant on the iron and boron contents of leaves as well. As time x dose interaction, iron content in both years and boron content only in the second year were found statistically significant ($p < 0.05$) (*Table 12*). Iron content had the highest value in 30 DBH 125 ppm AVG in the first year and in 7 DBH 100 ppm AVG in the second year. For boron, however, it was 7 DBH 100 ppm AVG with a value of 36.72 ppm (*Table 12*).

Table 11. *The effect of AVG treatments on phosphorus, potassium, copper, zinc in the ‘Akça’ pear leave, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Phosphorus (ppm)**		**Potassium (ppm)**		**Copper (ppm)**		**Zinc (ppm)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	0.19a-d*	0.16	1.04	1.32	10.25d*	9.61	34.91	36.74
	100	0.17b-d	0.17	1.18	1.37	14.25ab	12.86	40.40	35.99
	125	0.18b-d	0.16	1.32	1.30	12.89a-d	13.55	38.71	33.40
	150	0.16c	0.16	1.34	1.28	12.83a-d	10.26	31.70	29.81
21 d	0	0.22a	0.16	1.04	1.21	10.49cd	9.37	35.80	34.58
	100	0.21a-c	0.15	1.36	1.25	14.76ab	9.76	36.06	28.35
	125	0.17b-d	0.16	1.23	1.26	13.64ab	12.13	39.73	30.51
	150	0.16c	0.15	1.09	1.33	15.33a	9.65	34.82	31.23
7 d	0	0.21ab	0.15	0.97	1.24	10.13d	9.65	36.60	35.22
	100	0.16c	0.15	1.16	1.31	13.30a-c	15.04	33.82	31.84
	125	0.16c	0.15	1.15	1.45	11.98b-d	11.34	37.22	31.19
	150	0.18b-d	0.16	1.04	1.41	12.58a-d	12.55	37.79	34.03
Time means									
30		0.17	0.16	1.22	1.32	12.56	11.57	36.43	33.99
21		0.19	0.15	1.18	1.26	13.56	10.23	36.60	31.17
7		0.18	0.16	1.08	1.35	12.00	12.15	36.36	33.07
	Dose means								
	0	0.21	0.16	1.02b*	1.26	10.29	9.54	35.77	35.52
	100	0.18	0.16	1.23a	1.31	14.11	12.55	36.76	32.06
	125	0.17	0.16	1.24a	1.34	12.84	12.34	38.56	31.70
	150	0.17	0.16	1.15ab	1.34	13.58	10.82	34.77	31.69
P values									
Time (T)		0.281	0.085	0.149	0.220	0.182	0.246	0.987	0.159
AVG Dose (D)		0.006	0.919	0.025	0.465	0.000	0.080	0.155	0.067
T x D		0.015	0.232	0.053	0.534	0.002	0.187	0.134	0.065

[1]Days before harvest (DBH)
*each column, values followed by the same letter are not significantly different at $p < 0.05$ level according to Duncan’s multiple range test

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Table 12. *The effect of AVG treatments on iron, manganese, boron in the 'Akça' pear leave, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Iron (ppm)**		**Manganese (ppm)**		**Boron (ppm)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**	**I. Year**	**II. Year**
30 d	0	62.37ab*	59.36ab*	57.25	176.43	32.03	32.84bc*
	100	67.46a	51.82c-e	69.46	147.17	34.71	33.90bc
	125	71.00a	58.83a-c	65.42	166.37	36.88	33.29bc
	150	69.33a	51.09de	53.55	144.13	33.71	32.08cd
21 d	0	54.19b	59.24a-c	56.79	158.95	31.70	32.75bc
	100	67.19a	52.48b-e	51.36	151.43	36.63	29.95de
	125	64.96a	49.36e	61.15	146.80	34.05	29.19e
	150	70.40a	56.95a-d	65.22	148.10	37.70	35.41ab
7 d	0	62.17ab	59.84ab	59.66	139.71	31.12	32.86bc
	100	69.39a	61.71a	72.77	175.83	35.55	36.72a
	125	69.07a	57.34a-d	66.52	154.23	32.12	31.66c-e
	150	64.49a	56.62a-d	60.85	158.60	31.66	32.97bc
Time means							
30		67.54	55.27	61.42	158.53	34.33	33.03
21		64.19	54.51	58.63	151.32	35.02	31.83
7		66.28	58.88	64.95	157.09	32.62	33.55
	Dose means						
	0	59.58	59.48	57.90	158.36	31.62	32.82
	100	68.01	55.33	64.53	158.14	35.63	33.52
	125	68.34	55.17	64.37	155.80	34.35	31.38
	150	68.07	54.89	59.87	150.28	34.36	33.49
P values							
Time (T)		0.406	0.074	0.414	0.736	0.199	0.186
AVG Dose (D)		0.001	0.170	0.543	0.883	0.069	0.180
T x D		0.011	0.008	0.546	0.700	0.124	0.000

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at p < 0.05 level according to Duncan's multiple range test

The effect of applications on leaf area (cm^2) and chlorophyll value (spad value) in the leaves of 'Akça' variety

The effect of AVG applications on the leaf area of 'Akça' variety was statistically significant ($p < 0.05$) as time x dose interaction only in the first year. Leaf area expanded with the applications, and the largest leaf area was observed in 21 DBH 125 ppm AVG (*Table 13*). Their effect on the chlorophyll value of the leaves of 'Akça' variety was found statistically significant ($p < 0.05$) as time x dose interaction in both years. The amount of chlorophyll increased in general with the applications. The highest spad value was obtained from 30 DBH 125 ppm AVG and 21 and 7 DBH 100 ppm AVG (*Table 13*).

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Table 13. *The effect of AVG treatments on Leaf area and total chlorophyll in the 'Akça' pear leave, 2012 and 2013*

Application time[1]	**AVG doses (ppm)**	**Leaf area (cm^2)**		**Total chlorophyll (spad value)**	
		I. Year	**II. Year**	**I. Year**	**II. Year**
30 d	0	33.01cd*	34.65	44.12b-d*	45.74cd*
	100	33.48cd	30.95	45.47a-c	46.78bc
	125	36.32b-d	36.73	46.07ab	49.86a
	150	36.04b-d	39.45	44.07b-d	47.74a-c
21 d	0	32.33d	33.62	41.74d	44.11d
	100	36.70bc	36.23	48.16a	49.60a
	125	41.01a	38.41	44.87a-d	48.78ab
	150	36.17b-d	38.27	45.14a-d	47.92a-c
7 d	0	33.11cd	32.21	42.95b-d	43.99d
	100	34.50cd	34.57	46.13ab	48.99ab
	125	38.96ab	38.35	42.24cd	48.40ab
	150	39.56ab	38.49	42.63b-d	48.30ab
Time means					
30		34.71	35.45	44.93	47.53
21		36.55	36.63	44.98	47.60
7		36.53	35.90	43.49	47.42
	Dose means				
	0	32.82	33.49	42.93	44.61
	100	34.89	33.92	46.59	48.46
	125	38.76	37.83	44.40	49.01
	150	37.26	38.74	43.95	47.99
P values					
Time (T)		0.283	0.816	0.221	0.981
AVG Dose (D)		0.106	0.201	0.022	0.598
T x D		0.000	0.322	0.000	0.000

[1]Days before harvest (DBH)
*Each column, values followed by the same letter are not significantly different at $p < 0.05$ level according to Duncan's multiple range test

Discussion

It was determined that 30 DBH and 21 DBH AVG applications (all doses) delayed the harvest maturity of Akça pear for up to 3-4 days. It was well documented that AVG inhibits ethylene biosynthesis, thus retards fruit ripening (Amarante et al., 2002; Schupp and Greene, 2004; Petri et al., 2006; Kang et al., 2007). Similar results were also observed in this study. Clayton et al. (2000) reported that ReTain applied 14 and 7 days before harvest delayed the harvest for up to 4-10 days in the Bartlett pear. The increase in fruit weight with the AVG applications also led to an increase in fruit yield. As reported by Romani et al. (1983), since AVG allows for late ripening, fruit continues to grow, leading to an increase in size and yield. Delayed harvest provides flexibility in fruit processing-packing, storage and marketing planning. Pasa et al. (2017) stated that fruit set, number of fruit per tree and yield were significantly improved by AVG sprayed one week after full bloom with doses ranging from 40 to 100 mg L^{-1} for 'Santa

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Maria', while for 'Abate Fetel' the most responsive dose was 100 mg L^{-1}. Fruit quality attributes and fruit size were not affected by treatments. Dussi et al. (2002) applied 14 DBH 125 and 180 ppm AVG to Williams pears**.** In this study, AVG did not have any effect on pre-harvest fall, but an increase in size and hardness was detected. Pre-harvest AVG applications to Williams pear caused a delay in fruit ripening and increased fruit size (Romani et al., 1983). In our study, compared to the control fruits, the AVG applications increased fruit width by about 2-16% and fruit weight by 7-57%.

In the study performed by Clayton et al. (2000) on Bartlett pear, it is reported that AVG increased fruit firmness compared to the control group and maintained both their shelf life and storage as well as their firmness more than controls. The 'Akça' pear is in demand in both domestic and international markets because it is an early comer summer variety. Therefore, shelf life shortens during transport. Higher fruit firmness means a longer shelf life. For this reason, in line with the data obtained by this study, an increase in fruit firmness is considered to reduce quality losses during transport. According to our findings, L* values expressing brightness decreased with the AVG applications. a* values indicating redness were lower in the AVG applications, which is parallel with AVG's retardant effect on ripening and thus coloring.

All AVG applications slowed both ethylene production (μL kg^{-1} h) and respiratory rate (μL kg^{-1} h) in the fruit. Similar to our findings, Clayton et al. (2000) and Butar and Çetinbaş (2017) reported that AVG reduced both ethylene amount and respiration rate and that the application doses had the same effect in Williams pear. In the AVG studies conducted on other varieties, it was reported that ethylene production and respiration rate slowed down (Amarante et al., 2002; Schuup and Greene, 2004; Petri et al., 2006; Kang et al., 2007; Ozturk et al., 2012; Yıldız et al., 2012).

When applied externally, plant growth regulators, which are synthesized naturally in the plant, may have different physiological effects depending on application period and concentration (Salisbury and Ross, 1985). In our study, different application periods and doses of AVG plant growth regulator affected fruits' mineral element contents differently even in different years. Butar and Çetinbaş (2017) stated that a change in AVG application time and dose led to different mineral element contents in 'Williams' pear fruits. In a study conducted on the 'Akça' pear, the contents of N, P, K, Ca, Mg, Zn, Fe, Mn and Cu in the fruit were found to be 3.37, 0.73, 8.25, 0.65, 8.25, 6.63, 4.08, 3.01 mg kg^{-1}, respectively (Kuçuker et al., 2015a). Partly similar results were obtained in our study. AVG applications affect mineral element contents in different ways in leaves as in fruits. It is reported that pear contains 1.134-1.682% nitrogen, 0.46-1.08% potassium, 1.81-3.1% calcium, 0.28-0.55% magnesium, 0.078-0.22% phosphorus, 51.5-197.5 mg kg^{-1} iron, 4.85-8.0 mg kg^{-1} copper, 16-57.5 mg kg^{-1} zinc, and 20-99.5 mg kg^{-1} manganese (Gunen et al., 2003). In our study, these elements were found to exist in the above-given ranges. AVG plant growth regulator is thought to have both increasing and decreasing effects on the mineral element contents in the fruits and leaves of 'Akça' pear. However, decreases did not negatively affect fruit or leaf quality in our study.

Since ethylene hormone causes chlorophyll decomposition in plants (Taiz and Zieger, 2008; Karaçalı, 2009), in an environment where ethylene hormone is suppressed, chlorophyll decomposition is either delayed or slowed down. Accordingly, in our opinion, the AVG applications in our study led to an increase in both leaf area and chlorophyll amount because delayed ethylene production enabled the leaves to nourish and photosynthesize more and have a larger area, and delayed chlorophyll decomposition gave rise to a higher chlorophyll amount.

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Conclusion

Taking all results into account, it was concluded in present study that AVG was definitely effective in increasing the quality of 'Akça' pears. The treatments applied in a dose of 100 ppm 21 days before the anticipated harvest time had more effective results in 'Akça' pear in terms of harvest time and fruit quality. Furthermore, since plant nutrients (macro and micro) and plant growth regulator are in interaction with each other, more detailed studies are necessary on this subject.

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