THE EFFECTS OF SUPER ABSORBENT POLYMER APPLICATION ON THE PHYSIOLOGICAL AND BIOCHEMICAL PROPERTIES OF TOMATO (*Solanum lycopersicum* L.) PLANTS GROWN BY SOILLESS AGRICULTURE TECHNIQUE

BAŞAK, H.

Department of Horticulture, Faculty of Agriculture, Kırşehir Ahi Evran University, Turkey
e-mail: hbasak@ahievran.edu.tr; phone: +90-386-280-4839; fax: +90-386-280-4832

(Received 17th Mar 2020; accepted 7th Jul 2020)

Abstract. This study, it was aimed to determine the effects of super absorbent polymers (SAP) on plant growth, yield, hormone level, leaf pigment and nutrient contents, enzyme activities, organic acid and amino acid composition, lipid peroxidation level in tomato and the amount of drained water in soilless culture. For this aim, three levels of SAPs (0, 5 and 10 g slab^{-1}) were applied into cocopeat slabs before planting seedlings in randomized plots. The results showed that the SAPs added to cocopeat substrate increased plant growth and yield by increasing leaf nutrient, pigment and hormone contents in tomato plants. However, SAP applications reduced lipid peroxidation, H_2O_2 content, antioxidant enzym activities and abscisic acid level. SAP treatment increased organic acid contents about 9.5-24.7%, except for butyric and maleic acid. In general, SAP treatment increased the amino acid contents in leaves, but decreased mainly proline, aspartate and hydroxyproline contents. The presence of sufficient water and nutrients in plants' root zones with low force allowed them to grow without stress. A 10 g polymer application gave better results than other doses on investigated parameters. In conclusion, SAPs can be used in soilless tomato farming, due to its beneficial effects on plant growth, yield and water saving.

Keywords: *polymers, hydroponic, leaf nutrients, fruit yield, water saving*

Introduction

Soilless culture provides significant savings in water and fertilizer use compared to conventional agriculture (Putra and Yuliando, 2015). This would provide significant benefits and protection of environment and natural resources. SAPs are hygroscopic materials consisting of acrylamide monomers (acrylic acid and sodium or potassium acrylate). The carboxyl group along the polymer chain has a high water absorption capacity, the crosslinks present in the chain prevent its complete dissolution (Bortolin et al., 2013). SAPs have hydrophilic groups with enormous capability of absorbing and retaining water or aqueous solutions of up to hundreds of times their weights (Sojka and Entry, 2000). Water and nutrients stored in SAPs are slowly released to the plant to improve growth under limited water supply (Islam et al., 2011). The application of SAPs also increases growth by increasing the soil's capacity to store water and nutrients (Tohidi-Moghadam et al., 2009). SAPs do not have any direct impact on human health and environment, therefore, the consumption of vegetable products grown with polymer application does not pose a toxicological risk (Sojka et al., 2007). SAPs increase in water retention capacity of soils, enabling to release of applied pesticides and chemical fertilizers in control (Wu et al., 2008). Nimah et al. (1983) reported that SAPs increased water retention in sandy and clay soils about 25% and 25-30%, respectively. Similarly, Başak et al. (2016) report that 25% water and nutrient savings were obtained by SAPs addition to cocopeat environment. SAPs relieve oxidative stress (Moghadam, 2017) and increasing cation exchange capacity of soils (Habibi et al., 2010). Hydrogel application to soil increases the amount of available water in the plant root zone, prolongs the time

DOI: http://dx.doi.org/10.15666/aeer/1804_59075921

between irrigations and prevents plants from water stress (Yazdani et al., 2007). Consequently, the significant saving can be achieved for water usage, labor and energy in irrigation and fertilization.

In the previous studies, the effect of SAPs application on plants was predominantly studied under salt and drought stress conditions in conventional farming (Habibi et al., 2010; Su et al., 2017; Li et al., 2019). Investigating the effects of water-retaining polymers on promoting plant growth under abiotic stress conditions will, also, increase their usage areas in non-stressed plants in soilless agriculture.

On the literature, there have not been any studies on the effect of SAPs applications on organic acid and amino acid contents of plants, except proline content. With the study, to determine the effects of SAPs aplication on organic acid and amino acid contents that play important roles on plant growth and tolerance to possible stress conditions will contribute in filling the gap on the literature on this regard. Therefore, the current study was planned to determine the effects of SAPs application on physiological and biochemical responses of tomato plants grown by soilless agriculture technique.

Material and Methods

Experimental conditions and SAPs applications

This study was conducted in the Horticulture Research Unit of Agricultural Faculty of Kırşehir Ahi Evran University (in Turkey) from May to September, in 2018. Experiments were conducted in a greenhouse with controlled climatic conditions. Since tomato is the most cultivated plant in soilless culture, hybrid cluster tomato variety (Kahraman F_1) was used as a plant material. The growing medium was cocopeat in form of slabs (100x20x16 cm). A synthetic polyacrylamide (SAP, Stockosorb 400K) with potassium salt base manufactured which is a crosslinked polymer developed to retain water in the agricultural and horticultural sector, was used in experiment. SAP was applied to the slabs before planting. Polymers weighted 5 and 10 g for each cocopeat slab were placed into 500 ml beakers and gelled by adding adequate water for two hours. The swollen polymers were, then, mixed homogeneously for each slab. Tomato seedlings were planted in cocopeat slabs as 3 plants per slab. The experiment was designed according to randomized plots with 4 replicates each including 3 plants. Before the study, Power and Sample Size analysis (PASS 15) was applied to determine the required sample size (NCSS, 2017). This sample size was sufficient for this study since the data were obtained from individual plants in controlled environment, soilless culture. Modified Hoagland nutrient solution was applied to cover the water and nutrient requirements of the plants according to their vegetative and generative stages (Hoagland and Arnon, 1950) (*Table 1*).

Table 1. *Chemical contents of nutrient solution (mg L^{-1})*

Elements	N	P	K	Mg	Ca	S	Fe	Mn	B	Cu	Zn	Mo
Concentration	210	31	234	48	200	64	2.5	0.5	0.5	0.02	0.05	0.01

The nutrient solution was placed in a root dripper of each plant and applied equally for all treatments using a timed automation system. The automation system was programmed to start the first irrigation at 8:00 am in the morning and the last irrigation at 8:00 pm in the evening with an interval of 90 minutes. The first and last 2 of the total 9 irrigations were applied for 60 seconds while the other irrigations were applied for 90 seconds when the temperature was higher due to plants' higher water during these intervals. Since each dripper flows 200 ml of solution per minute, a total of 27.6 L of solution was applied daily to each application row occupied 12 plants.

Growth parameters and yield

The effects of SAP application on fruit yield per plant (g plant^{-1}) and morphological parameters such as plant height (cm), stem fresh weight (g) and stem diameter (mm) were determined at the end of the experiment.

Plant nutrient element analysis

Leaf macro and micro nutrients were determined on dry matter basis. Nitrogen content was determined by Kjeldahl method (Bremner, 1996). The P, K, Ca, Mg, Na, Fe and Zn contents were determined using an ICP (Inductively Coupled Plasma) spectrometer (Optima 2100 DV, ICP/OES; Perkine-Elmer, USA) (Mertens, 2005).

Leaf pigment analysis

The effect of the treatments on the leaf pigment content was determined according to the method of Arnon (1949). Fresh leaf tissues (200 mg) were homogenized in acetone (8 ml 80%). Homogenates were centrifuged at 3000 rpm and absorbances of supernatants were determined at 645, 652, 663 and 470 nm. The amounts of pigments were calculated according to the formula of Lichtenthaler and Wellburn (1983).

Antioxidant enzymes analysis

The superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) enzyme activities in the apoplastic fractions were measured by using a spectrophotometer (Sairam and Srivastava, 2002). SOD activity was determined by recording the decrease in absorbance of nitroblue tetrazolium (NBT) by the enzyme. CAT activity was measured by monitoring the decrease in absorbance at 240 nm in 50 mM phosphate buffer (pH 7.5) containing 20 mM H_2O_2. POD activity was determined (at 470 nm in 50 mM phosphate buffer (pH 5.5)) by recording the oxidation of guaiacol in the presence of H_2O_2.

Hormone analysis

Extraction and purification processes of leaf samples were executed as described by Kuraishi et al. (1991) and Battal and Tileklioğlu (2001). Gibberellic acid, salicylic acid, indole acetic acid and abscisic acid were analyzed by HPLC using a Zorbax Eclipse-AAA C-18 column (Agilent 1200 HPLC). The hormone levels were determined by using 13% acetonitrile (pH 4.98) as the mobile phase.

Amino acid analysis

Amino acid contents were analyzed by HPLC as described by Aristoy and Toldra (1991), Antoine et al. (1999) and Henderson et al. (1999). Agilent 1200 model with single detector (UV) and Zorbax Eclipse-AAA 4.6 x 150 mm, 3.5 µm column (Agilent 1200 HPLC) was used to determine the amino acid composition of the samples.

Organic acid analysis

The organic acids were determined by HPLC using Zorbax Eclipse-AAA 4.6×250 mm, 5 µm columns (Agilent 1200 HPLC) and absorbance of 220 nm in UV detector. Organic acids were analyzed by using 25 mM KH_2PO_4 (pH 2.5) as the mobile phase (Siddiqui et al., 2015).

Lipid peroxidation (Malondialdehyde-MDA) and hydrogen peroxide (H_2O_2) content analysis

The level of lipid peroxidation was measured as the amount of malondialdehyde (MDA) determination by the thiobarbituric acid (TBA) reaction (Heath and Packer, 1968). The content of H_2O_2 was determined spectrophotometrically (Velikova et al., 2000). H_2O_2 content was calculated by using samples' absorbance values from the standard curve.

Determination of water drainage

The drained solution from each slab was accumulated in buckets placed at the end of the gutter to record its volume daily during the study from 24th April 2018 to 29th September 2018.

Statistical analysis

The data were analysed by GLM procedure of SPSS (Windows Version SPSS, release 20.00). Means were compared by Duncan Multiple Range Test in the same software.

Results

Growth parameters and yield

The 10 g SAP treatment increased significantly plant height and stem fresh weight compared to the control ($P \leq 0.05$). The highest plant height (387.9 cm) and stem fresh weight (3493 g) were obtained in 10 g SAP treated slabs. Without statistical significance, stem diameter decreased with increased polymer dose, and the lowest stem diameter (20.89 mm) was obtained by 10 g polymer treatment. The 10 g polymer treatment tended to increase yield compared to other treatments (*Table 2*). This difference was not statistically significant but economically valuable.

Table 2. *Effects of SAP treatments on agronomic properties of tomato plants*

Applications		**Plant height** (cm)	**Stem fresh weights** (g)	**Stem diameter** (mm)	**Yield** (g plant^{-1})
Control		337.3b*	2728b	22.35	9003.6
SAP	**5 g**	378.5ab	2893ab	21.37	9306.4
	10 g	387.9a	3493a	20.89	9679.2
SEM		0.09	136.3	0.272	352.5
P		0.047	0.050	0.080	0.747

*Means in each column with the same letters are not significantly different ($P<0.05$)

The nutrient contents

All determined nutrients (N, P, K, Ca, Mg, Fe and Zn), except Na and B contents were increased significantly by SAP treatments compared to the control ($P<0.05$) (*Table 3*). In particular, leaf K content of 10 g SAP treated plants was significantly higher than those of 5 g SAP treated plants. Without statistical significance, leaf P, Mg and Zn contents of 10 g SAP treated plants were slightly higher than those of 5 g SAP treated plants. With the effect of SAP application, the highest increase in leaf nutrient content was determined at K concentration with 21.3%, followed by P, Zn, Ca, Mg, Fe, N concentrations with the increases of 16.2%, 15.6%, 15.4%, 14.7%, 12.6% and 11.1%, respectively. Although the SAP applications tended to reduce leaf Na and B contents without any statistical significance ($P>0.05$).

Table 3. *Effects of SAP applications on leaf nutrient contents*

Applications		**N** (%)	**P** (mg kg^{-1})	**K** (mg kg^{-1})	**Ca** (mg kg^{-1})	**Mg** (mg kg^{-1})	**Na** (mg kg^{-1})	**Fe** (mg kg^{-1})	**Zn** (mg kg^{-1})	**B** (mgkg^{-1})
Control		2.17b*	1871b	4678b	4431b	355.3b	185.8	31.03b	12.34b	19.25
SAP	**5 g**	2.33a	2077ab	5002b	4895a	377.5ab	184.3	35.82a	13.69ab	18.47
	10 g	2.41a	2174a	5674a	5115a	407.5a	177.5	34.93a	14.27a	17.44
SEM		0.037	54.9	139.4	96.8	10.1	3.658	0.819	0.322	0.391
P		0.007	0.053	0.001	0.001	0.042	0.662	0.019	0.021	0.169

*Means in each column with the same letters are not significantly different ($P<0.05$)

Leaf pigment contents

The effect of SAP application on leaf carotenoid content was not found statistically significant ($P>0.05$). However, its chlorophyll a content was decreased by SAP treatments, while chlorophyll b and total chlorophyll contents were increased significantly ($P<0.01$). The highest chlorophyll b (1.379 mg g^{-1} FW) and total chlorophyll (5.817 mg g^{-1} FW) contents were obtained in plants treated with 10 g polymer (*Table 4*).

Table 4. *Effects of SAP treatment on leaf pigment contents (mg g^{-1} FW)*

Applications		**Chlorophyll a**	**Chlorophyll b**	**T. Chlorophyll**	**Carotenoid**
Control		2.905a*	1.043c	5.583b	1.189
SAP	**5 g**	2.871a	1.215b	5.669b	1.180
	10 g	2.828b	1.379a	5.817a	1.179
SEM		0.0098	0.0029	0.0306	0.0023
P		0.002	0.001	0.002	0.169

*Means in each column with the same letters are not significantly different ($P<0.05$)

Antioxidant enzymes, Lipid peroxidation (Malondialdehyde-MDA) and hydrogen peroxide (H_2O_2) content

MDA and H_2O_2 levels, which are considered as stress indicators in plants, were decreased by SAP doses. The lowest MDA (6.59 µmol g^{-1}) and H_2O_2 (17.94 mmol kg^{-1}) levels were observed in 10 g SAP treated plants. SOD, CAT and POD enzyme activities were decreased significantly by SAP treatment compared to control. The lowest SOD (692 EU g leaf^{-1}), CAT (203.5 EU g leaf^{-1}) and POD (13434 EU g leaf^{-1}) enzyme activities were observed in 10 g SAP treated plants (*Table 5*).

Table 5. *Effects of SAP treatment on antioxidant enzyme activities, H_2O_2 and MDA levels*

Applications		**H_2O_2** (mmol kg^{-1})	**MDA** (µmol g^{-1})	**SOD** (EU g leaf^{--1})	**CAT** (EU g leaf^{--1})	**POD** (EU g leaf^{--1})
Control		27.01a*	9.38a	1009a	233.3a	15580a
SAP	**5 g**	21.46b	8.27a	834b	215.3b	14451b
	10 g	17.94b	6.59b	692c	203.5b	13434c
SEM		1.33	0.41	845	4.51	298.9
P		0.003	0.004	0.001	0.007	0.001

*Means in each column with the same letters are not significantly different ($P<0.05$)

Hormone contents

Compared to control plants, SAP treatments significantly increased gibberellic acid level, while the salicylic acid and IAA contents were increased by only 5 g SAP dose. The level of ABA, which is considered as a stress hormone, was significantly decreased with SAP application (*Table 6*). The highest ABA concentration was determined in control plants as 0.18 ng µl^{-1}.

Table 6. *Effects of SAP treatment on hormone and salicylic acid contents (ng µl^{-1})*

Applications		**Gibberellic acid**	**Salicylic acid**	**IAA**	**ABA**
Control		67.77b*	17.98a	1.16b	0.18a
SAP	**5 g**	78.78a	18.48a	1.29a	0.15b
	10 g	78.08a	15.74b	1.18b	0.16b
SEM		1.972	0.436	0.038	0.007
P		0.018	0.006	0.007	0.006

*Means in each column with the same letters are not significantly different ($P<0.05$)

Organic acid compositions

The impacts of SAP treatments on plant organic acid concentrations were given in *Table 7*. SAP treatments increased organic acids concentrations significantly compared to control, except butyric acid and maleic acid. 10 g SAP treatment increased oxalic acid (0.778 ng µL^{-1}), propionic acid (1.768 ng µL^{-1}), malonic acid (9.935 ng µL^{-1}), citric acid (11.908 ng µL^{-1}) and succinic acid (21.258 ng µL^{-1}) concentrations when compared to other treatments. In 10 g SAP treated plants' leaves, oxalic, propionic, tartaric, malonic, malic, lactic, citric, fumaric and succinic acid contents (respectively 12.3%, 9.5%, 16.4%, 27.7%, 13.5%, 12.2%, 17.8%, 14.8% and 17.1%) were higher than those of control.

Amino acid compositions

The impacts of SAP treatments on plant amino acid compositions were given in *Table 8*. SAP treatments significantly increased asparagine, serine, arginine, cysteine, valine, methionine, tryptophan, phenylalanine, isoleucine and lysine concentrations in the leaves. On the other hand, aspartate, hydroxyproline and proline contents significantly reduced by SAP applications compared to those of control plants. With the effect of SAP application, the highest increase was determined in the content of arginine with a rate of 15%, while the highest decrease was determined in the content of proline with a rate of 14.2%.

Table 7. *Effects of SAP treatment on the organic acid content (ng μl^{-1})*

Applications		**Oxalic**	**Propionic**	**Tartaric**	**Butyric**	**Malonic**	**Malic**
Control		0.693b[*]	1.615b	4.223b	11.520	7.970b	2.948b
SAP	**5 g**	0.668b	1.650ab	4.835a	12.582	8.843ab	3.332a
	10 g	0.778a	1.768a	4.915a	11.495	9.935a	3.345a
SEM		0.018	0.029	0.109	0.253	0.312	0.068
P		0.022	0.044	0.002	0.167	0.015	0.008

Applications		**Lactic Laktic**	**Citric**	**Maleic**	**Fumaric**	**Succinic**
Control		16.070b	10.105b	3.658	4.373b	18.163b
SAP	**5 g**	17.225a	11.305ab	3.693	4.873a	18.013b
	10 g	18.023a	11.908a	3.673	5.018a	21.258a
SEM		0.294	0.317	0.038	0.092	0.524
P		0.006	0.042	0.944	0.000	0.002

[*] Means within column not followed by the same letter differ significantly

Table 8. *Effects of SAP treatment on the amino acid content (pmol μL^{-1})*

Applications		**Aspartate**	**Glutamate**	**Asparagine**	**Serine**	**Glutamine**	**Histidine**	**Glycine**
Control		3657a[*]	2358	6127b	6904b	4599	2265	2052
SAP	**5 g**	3588b	2401	6158b	7276ab	4582	2326	1999
	10 g	3561b	2415	6266a	7701a	4722	2380	1961
SEM		15.192	15.23	21.89	124.08	38.39	23.38	21.72
P		0.011	0.319	0.006	0.012	0.288	0.124	0.243

Applications		**Threonine**	**Arginine**	**Alanine**	**Tyrosine**	**Cysteine**	**Valine**	**Methionine**
Control		4250	6168c	5605	954	579b	324b	1108b
SAP	**5 g**	4375	6668b	5623	976	628a	326b	1174ab
	10 g	4249	7093a	5449	969	651a	362a	1247a
SEM		41.08	127.29	37.93	7.79	11.36	6.44	22.99
P		0.386	0.001	0.112	0.545	0.012	0.007	0.027

Applications		**Tryptophan**	**Phenylalanine**	**Isoleucine**	**Leucine**	**Lysine**	**Hyd.pro.**	**Proline**
Control		753ab	1739b	856b	1982	1442b	2049a	254a
SAP	**5 g**	695b	1818ab	887b	1951	1473b	2027a	243a
	10 g	796a	1862a	939a	1873	1568a	1826b	218b
SEM		15.90	20.26	12.84	21.29	22.16	43.44	5.58
P		0.014	0.022	0.009	0.085	0.033	0.050	0.001

[*] Means within column not followed by the same letter differ significantly

The amount of water drainage

The effect of SAP application on monthly drained water are given in *Table 9*, monthly differences in drained water between SAP applications and control are presented in *Figure 1*. *Table 9* shows that there was a significant interaction between month and SAP treatment (P<0.01) according to univariate analysis. In June and July, the amount of drained water from plants in cocopeat slabs with 5 and 10 g of polymer added was higher than those of the control without polymer application. The drained water showed a linear increase during May, June and July (*Figure 1*). In addition, the amount of drained water measured in plants treated with 10 g polymer was significantly higher in June and July compared to 5 g SAP treatment (P<0.05). However, the differences in the amount of drained water between polymer-treated plants and control were not significant, especially in mid-August (*Figure 1*).

Table 9. *Effect of SAP application on drained water (ml)*

Months	**Experimental groups**				
	Control	**5 g SAP**	**10 g SAP**	**SEM**	**P**
May	5637.3c	6104.1abc	6947.7ab	334.8	0.273
June	3685.5dB	4878.2cB	7146.4abA	411.4	0.001
July	3929.8dC	5511.1bcB	8217.3aA	331.7	0.000
August	7123.6b	7127.7ab	6929.1ab	371.9	0.970
September	9339.1aA	7465.9aA	5359.1bB	447.9	0.001
SEM	305.9	290.4	309.1		
P	0.000	0.022	0.065		

Different letters in the same row (A,B,C) and same column (a,b,c) are statistically different (P<0.05)

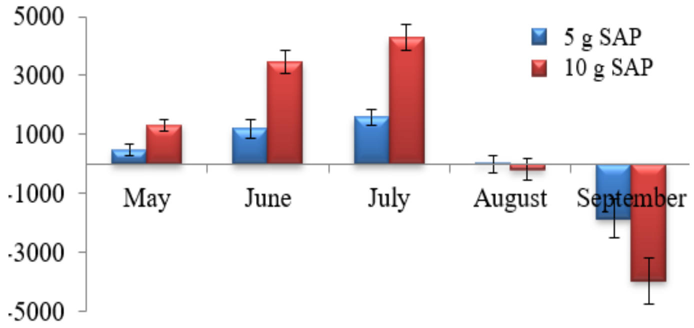

Figure 1. *Differences in drained water in SAP applications compared to that of control (ml)*

In the drainage amounts in September, the drainage amounts determined in 5 and 10 g polymer applications were determined to be 1873.2 ml and 3980 ml lower than the control application, respectively.

Discussion

Hydrophilic polymers increase water holding capacity and water usage efficiency (Dorraji et al., 2010). Furthermore, polymers stimulate the formation of new roots, providing higher water and nutrient uptake. As a result, SAP treatments increase fruit yield as well as growth and development in plants. In this study, 5 and 10 g SAP applications increased stem fresh weight by 6.4% and 28%, as respective increases in yield about 3.4% and 7.5%. Consistent with our findings, the positive effects of SAPs applications on plant weight, height and yield in cucumber, pepper, and tomato and soya bean (Maboko, 2006; Yazdani et al., 2007; Sayyari and Ghanbari, 2012; Başak et al., 2016; Li et al., 2019). The increases in plant growth and yield by SAP treatment can be attributed to the presence of sufficient amount of water and nutrients which can be easily taken with low pressure in the root area.

It was determined that SAP added to the cocopite slabs increased the leaf nutrient contents about 11.1-21.3%. Similarly, Mikiciuk et al. (2015) reported that polymer application increased nitrogen and potassium contents in strawberry leaves but did not affect phosphorus, sulphur and sodium contents. Sita et al. (2005), also, indicated that the increasing doses of hydrogel treatment in chrysanthemum (*Dendrathema grandiflorum*) plant positively affected plant growth and Ca and Mg uptakes. Soilless agriculture has salinity risk in root zone, since plants are irrigated with solutions containing nutrients in every drop. The excess of Na creates problem, thus its accumulation in the root zone is not desired. Fortunately, in the present study, SAP application did not allow Na accumulation in root zone. SAPs absorb nutrients with water and, consequently, slowly release them back to plants. Thus, plants can absorb water and nutrients in the root area with less energy. The present results showed that SAP treatment had allowed plants to take the nutrients in stable and sufficient level.

Chlorophyll content is an important biochemical indicator of stress tolerance in plants (Percival et al., 2003). Therefore, the increase in chlorophyll levels of SAP treated plants can considered as an indication that plants are not experienced water and nutrient stress. In other words, these plants take water and nutrients sufficiently. SAP treatment increased, especially, N and Mg uptakes (*Table 3*), allowing to form the central ion of chlorophyll and, consequently, building a darker green leaf color (Buehner, 1956). Similar to our findings, SAP addition significantly increased the amounts of chlorophyll in cucumber (Li et al., 2019) and pepper (Sayyari and Ghanbari, 2012) plants.

The present results show that SAP application does not cause any oxidative stress in plants. On the contrary, it reduces the formation of free oxygen radicals causing cellular damage. In our findings, the decrease in free oxygen radicals was happened by decreased MDA content and SOD enzyme activity with SAP application. Also, the decreases in CAT and POD enzyme activities might be due to the decrease in H_2O_2 level. CAT and peroxidases (POD and APX) are involved in detoxification of H_2O_2 (Mittler, 2002). Similar to our findings, Habibi et al. (2010) reported that the application of SAP in corn plants reduced the level of MDA, an important indicator of oxidative damage. Su et al. (2017) found significant negative relationships between SAP water absorption capacity and proline content, peroxidase activity, H_2O_2 and MDA levels. Moghadam (2017) reported that total chlorophyll content in wheat plant were increased by SAP application doses (5 and 10 g per kg soil), while these doses decreased SOD, CAT enzyme activities and MDA content significantly. Pouresmaeil et al. (2013) determined positive and significant correlations between SOD, CAT, GPX enzyme activities with MDA content in SAP applied red bean plants.

The increase in N content of plants may increase the synthesis of hormones due to its stuructural role in protein synthesis. In this study, N content increased significantly by SAP treatment compared to control. Calcium increases IAA level while Zn and B increase the auxin activity (Öktüren and Sönmez, 2005). The current results revealed that SAP treatment induced Ca and Zn uptake and, consequently, IAA content. Marulanda et al. (2009) reported linear relationships between IAA level and nutrient intake (P, Ca, Fe, Mn, Zn, B and Cu). The activity of growth regulating hormones such as indole acetic acid, cytokinin and gibberellic acid were increased by the presence of K (Marschner, 1986). The results showed that the increase in K intake with the effect of SAP treatment may be related to the increase in gibberellic acid and IAA contents (*Table 6*). Similar to our result, Özen and Onay (1999) reported that SAP treatments increased GA level but decreased ABA level. Salicylic acid, a plant growth regulator, is a signal molecule that has a regulatory role in the activation of biochemical pathways associated with stress tolerance (Sticher et al., 1997). It can be postulated that the decreases in ABA and salicylic acid levels by SAP application might be attributed to the presence of ideal moisture level in root region.

SAP treatment increased organic acid contents from 9.5 to 24.7%, except butyric and maleic acid. Although the plants were not in any stress condition in the current experiment, the increases in organic acid compositions that increase the plant tolerance against abiotic and biotic stress conditions were determined as the positive effects of SAP application.

Organic acids (oxalic, malonic, acetic, glycolic and formic acids) increase P, Ca, Fe, Zn and Mn ions uptakes in plants (Ohwaki and Hirata, 1992; Marschner, 2011). Arıkan et al. (2018) reported that the increased in organic acid content resulted in increases in plant nutrient elements, especially Fe content in peach leaves. İpek (2019) reported that the applications of rhizobacteria in raspberry plants increase the nutritional content, as well as increase the organic acid composition by 1 to 21%, excluding oxalic acid and succinic acid. This shows that SAP application may have allowed plants uptake more nutrients. In our findings, a strong linear relationship was determined between the organic acid compositions and nutrient uptake, similar to previous studies.

Amino acids, which play important roles in physiological and metabolic events of plants, have different functions. Some amino acids play significant roles in growth and development which are decreased by stress; some other are defense amino acids that increased by stress. Amino acids such as aspartate, hydroxyproline, alanine, glycine and proline accumulate in plants when exposed to stress conditions (Sanchez et al., 1998; Mansour, 2000; Maclean et al., 2009). In our findings, aspartate, hydroxyproline and proline contents were decreased by SAP application. This decrease can be explained by preventing humidity fluctuations in the root area of SAP treated plants. This might have kept plants away from stress by providing the ideal moisture level. Increasing amino acid levels that prevent cell damage and accumulation of reactive oxygen derivatives was reported important in protecting the plant under abiotic stress conditions (Keller and Torres-Martinez, 2004; Gregan et al., 2012).

Beside the direct effect of SAP application on plant growth and development, the increases in amino acid contents of plants make more tolerant to the stress conditions during vegetation period, as indirect positive effect of SAP. Amino acids and organic acids ensure osmotic balance, stabilize cellular macromolecules and neutralize free radicals produced under stress conditions (Sneha et al., 2013). In our findings, it was determined that the increases in amino acid and organic acid contents prevented the accumulation of free oxygen radicals and, consequently, significantly reduced SOD, CAT and POD enzyme activities.

Acting as osmoregulator, proline increases in salinity and drought stress conditions to help plants to tolerate stress conditions (Shannon, 1997; Ashraf and Foolad, 2007). The accumulation of proline in plants is also a sign that plants are under stress conditions. In our findings, it can be said that beside the effect of SAP application on reducing the proline content, the polymer provides stable moisture level in the root region, as well as increasing the uptake of nutrients effective in maintaining osmotic balance such as K, Ca, Mg. Similar studies showed that SAP application reduced the proline content in other plant species such as cucumber, *Caragana korshinskii*, sorghum, wheat, pepper and lettuce (Sayyari and Ghanbari, 2012; Being et al., 2014; Tahmasebi et al., 2015; Su et al., 2017; Rostampour, 2017; Li et al., 2019).

According to the first 3-month of the study, monthly drained water in 10 g polymer applicated cocopeat slabs were determined as 23%, 94% and 109% higher than control ones in may, july, and june, respectively (*Table 9*). In the control slabs, some amount of water in the root zone between irrigation times was consumed by the plant, some amount was both drained and evaporated. Therefore, the control plants need more water in the next irrigation. In this case, it causes the water to be absorbed more by the growing medium, causing less drainage. The amount of drainage increased by increased SAP doses supported the present hypothesis. It was determined that SAP saved the water in the environment until the next irrigation, prevented water loss especially from evaporation and drainage, and absorbed only the reduced amount of water when watering again. The excess water that cannot be absorbed, that was drained. This situation resulted in higher drainage in SAP applied slabs compared to control ones. As the amount of water supplied to all environments was equal, it can be concluded that control plants consumed more water than SAP applied plants. SAP can absorb up to 95% water and release it long time period so that potential soil moisture is available to plants (Kiatkamjornwong, 2007).

The polymers improved soil porosity, structure and water holding capacity (Karimi et al., 2009). In September, it is observed that the amount of drainage increased in control application compared to SAP applications (*Table 9*). This situation supports the current hypothesis above. In September, the decreases in water consumption of the plant and air temperatures, consequently decrease evaporation, allowing root area of the control plants remains constantly moist and a large part of the water supplied drains, causing high drainage. The maximum water holding capacity of SAPs is called as swelling equilibrium value (r), and the characteristic temperature at which the water is retained is called as phase transition temperature (LCST-Lower Critical Solution Temperature). Hydrogels absorb water when the ambient temperature is below the phase transition temperature, and release water to the environment when it is above the phase transition temperature (Altay, 2010). Lower ambient temperatures compared to phase transition temperature might have decreased the drained water in SAP treatments after mid-August. The water retention capacities of the SAPs increased as the temperatures dropped in September. The increased SAP dose caused a decrease in the amount of drainage, especially in September, confirms the present view (*Table 9*). According to this table, SAP treated slabs drained higher amount of water compared to control slab during trial. This means that the small amount of water was sufficient for plants in SAP slabs. Above all, SAP treatment affect plants growth and yield positively. This will guidance to growers when SAP contained slabs are used they can minimise water usage.

Conclusion

In this study, SAP application increased growth, yield, leaf chlorophyll, hormone and nutrient contents, organic acid, except butyric acid and maleic acid, and amino acid composition, except aspartate, hydroxyproline and proline, but reduced lipid peroxidasion, H_2O_2, ABA levels and antioxidant enzym activities. The present study showed that SAP applications generally increased organic acid and amino acid contents in leaves of tomato plants grown by soilless agriculture technique. This increase did not only have a positive effect on plant development, but also made plants more tolerant to the stress conditions they may encounter them during the vegetation period.

Our data showed that the applied SAP had marked effect on tomato growth in soilless culture. This positive effect is due to the considerable absorption of nutrient solution by SAP and giving gradual absorbed solution to plant root. It was understood that the better uptake of sufficient water and nutrients which are kept in the root zone with low force enabled the plant growth free from stress.

The high drainage amount determined in SAP applied plants indicated that the amount of water given can be reduced or the irrigation interval can be extended. This will allow less usage of water and chemical fertilizers in either soilless and conventional agriculture. To conclude, SAP application in soilless farming would be a good strategy for water and fertilizer economy in environmental friendly production. This allows the changes in irrigation and fertilization strategies in soilless culture. In future studies, it is recommended to investigate the effect of polymer applications under restricted irrigation conditions.

Acknowledgement. This study was supported by Kırşehir Ahi Evran University Scientific Research Projects Coordination Unit with ZRT.A4.19.026 project number.

REFERENCES

[1] Altay, A. (2010): Synthesis Of Hydrophobic Group Containing Poly (Nisopropylacrylamide) Hydrogels and Investigation of Theirs Phase Transition Temperatures (Lcst). – Master's Thesis Selçuk University, Konya, Turkey. (in Turkish).

[2] Antoine, F. R., Wei, C. I., Littell, R. C., Marshall, M. R. (1999): HPLC method for analysis of free amino acids in fish using o-phthaldialdehyde precolumn derivatization. – Journal of Agricultural and Food Chemistry 47: 5100-5107.

[3] Arıkan, Ş., Eşitken, A., İpek, M., Aras, S., Şahin, M., Pırlak, L., Turan, M. (2018): Effect of Plant Growth Promoting Rhizobacteria on Fe Acquisition in Peach (*Prunus Persica* L.) Under Calcareous Soil Conditions. – Journal of Plant Nutrition 41(17): 2141-2150.

[4] Aristoy, M. C., Toldra, F. (1991): Deproteinization techniques for HPLC amino acid analysis in fresh pork muscle and dry-cured ham. – Journal of Agricultural and Food Chemistry 39: 1792-1795.

[5] Arnon, D. I. (1949): Copper enzymes in isolated chloroplasts, polyphenoloxidase in Beta vulgaris. – Plant Physiology 24: 1-15.

[6] Ashraf, M., Foolad, M. R. (2007): Roles of glycine betaine and proline in improving plant abiotic stress resistance. – Environmental and Experimental Botany 59: 206-216.

[7] Başak, H., Şahin, E., Kıymaz, S. (2016): Effect of Water Holding Polymers and Water Restriction on Growth of Tomato Cultivated in Different Soilless Cultures. – VII International Scientific Agriculture Symposium “Agrosym 2016”, Jahorina, Bosnia and Herzegovina, 6-9 October, pp. 2101-2109.

[8] Battal, P., Tileklioğlu, B. (2001): The effects of different mineral nutrients on the levels of cytokinins in maize (*Zea mays* L.). – Turkish Journal of Botany 25: 123-130.

[9] Beig, A. V. G., Neamati, S. H., Tehranifar, A., Emami, H. (2014): Evaluation of chlorophyll fluorescence and biochemical traits of lettuce under drought stress and super absorbent or bentonite application. – Journal of Stress Physiology & Biochemistry 10(1): 301-315.

[10] Bortolin, A., Aouada, F. A., Mattoso, L. H., Ribeiro, C. (2013): Nanocomposite PAAm/methyl cellulose/montmorillonite hydrogel: evidence of synergistic effects for the slow release of fertilizers. – Journal of Agricultural and Food Chemistry 61: 7431-7439.

[11] Bremner, J. M. (1996): Nitrogen total. – In: Sparks, D. L. (ed.) Methods of Soil Analysis, Part III. Chemical Methods. 2nd ed. Madison, W.I., USA, Soil Science Society of America Journal pp. 1085-1122.

[12] Buehner, A. (1956): Grundsaetzlisches zur Düngung der Weinberg. – Weinberg und Keller 3: 453-462.

[13] Dorraji, S. S., Golchin, A., Ahmadi, S. (2010): The effects of hydrophilic polymer and soil salinity on corn growth in sandy and loamy soils. – Clean-Soil, Air, Water 38(7): 584-591.

[14] Gregan, S. M., Wargent, J. J., Liu, L., Shinkle, J., Hofmann, R. W., Winefield, C., Trought, M., Jordan, B. J. (2012): Effects of solar ultraviolet radiation and canopy manipulation on the biochemical composition of Sauvignon Blanc grapes. – Australian Journal of Grape and Wine Research 18: 227-238.

[15] Habibi, D., Moslemi, Z., Ardakani, M. R., Mohammadi, A. (2010): Effects of super absorbent polymer and plant growth promoting rhizobacteria (PGPR) on yield and oxidative damage of maize under drought stress. – International Conference on Chemistry and Chemical Engineering, Cape Town, South Africa.

[16] Heath, R. L., Packer, L. (1968): Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. – Archives of Biochemistry and Biophysics 125: 189-198.

[17] Henderson, J. W., Ricker, R. D., Bidlingmeyer, B. A., Woodward, C. (1999): Amino acid analysis using Zorbax Eclipse-AAA Columns and the Agilent 1200 HPLC. – Agilent Technologies Part No. 5980-1193E.

[18] Hoagland, D. R., Arnon, D. I. (1950): The water-culture method for growing plants without soil. – California Agricultural Experiment Station Circ. No. 347.

[19] İpek, M. (2019): Effect of rhizobacteria treatments on nutrient content and organic and amino acid composition in raspberry plants. – Turkish Journal of Agriculture and Forestry 43(1): 88-95.

[20] Islam, M. R., Xue, X., Mao, S., Zhao, X., Eneji, A. E., Hu, Y. (2011): Superabsorbent polymers (SAP) enhance efficient and eco-friendly production of corn in drought affected areas of northern China. – African Journal Biotechnology 10(24): 4887-4894.

[21] Karimi, A., Noshadi, M., Ahmadzadeh, M. (2009): Effects of super absorbent polymer (IGETA) on crop, soil water and irrigation interval. – Journal of Science and Technology of Agriculture and Natural Resources 12: 415-420.

[22] Keller, M., Torres-Martinez, N. (2004): Does UV radiation affect Winegrape composition? – Acta Horticulturae 64: 313-319.

[23] Kiatkamjornwong, S. (2007): Superabsorbent polymers and superabsorbent polymer composites. – Science Asia 33: 39-43.

[24] Kuraishi, S., Tasaki, K., Sakurai, N., Sadatoku, K. (1991): Changes in levels of cytokinins in etiolated squash seedlings after illumination. – Plant Cell Physiology 32: 585-591.

[25] Li, Y., Shi, H., Zhang, H., Chen, S. (2019): Amelioration of drought effects in wheat and cucumber by the combined application of super absorbent polymer and potential biofertilizer. – The Journal of Life and Environmental Sciences (PeerJ) 7: e6073.

[26] Lichtenthaler, H. K., Wellburn, A. R. (1983): Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. – Biochemical Society Transactions 11: 591-592.

[27] Maboko, M. M. (2006): Growth, yield and quality of tomatoes (*Lycopersicon esculentum* Mill.) and lettuce (*Lactuca sativa* L.) as affected by gel-polymer soil amendment and irrigation management. – Master's Dissertation, Natural and Agricultural Sciences University of Pretoria, South Africa.

[28] Maclean, A. M., White, C. E., Fowler, J. E., Finan, T. M. (2009): Identification of a hydroxyproline transport system in the legume endosymbiont Sinorhizobium meliloti. – Molecular Plant-Microbe Interactions Journal 22(9): 1116-1127.

[29] Mansour, M. M. F. (2000): Nitrogen containing compounds and adaptation of plants to salinity stress. – Biologia Plantarum 43(4): 491-500.

[30] Marschner, H. (1986): Mineral Nutrition of Higher Plants. – Institute of Plant Nutrition University of Hohenheim Federal Republic of Germany, Germany, p. 850.

[31] Marschner, H. (2011): Marschner’s Mineral Nutrition of Higher Plants. – 3rd ed. San Diego, C.A, Academic Press., USA.

[32] Marulanda, A., Barea, J. M., Azcón, R. (2009): Stimulation of plant growth and drought tolerance by native microor-ganisms (AM fungi and bacteria) from dry environments:mechanisms related to bacterial effectiveness. – Journal of Plant Growth Regulation 28: 115-124.

[33] Mertens, D. (2005): AOAC official method 975.03. – In: Horwitz, W., Latimer, G. W. (eds.) Metal in Plants and Pet Foods. Official Methods of Analysis, eighteenth ed. AOAC-International, Suite 500, 481, North Frederick Avenue, Gaitherburg, Maryland 20877-2417, USA, pp. 3e4 (Chapter 3).

[34] Mikiciuk, G., Mikiciuk, M., Hawrot-Paw, M. (2015): Influence of superabsorbent polymers on the chemical composition of strawberry (*Fragaria × ananassa* Duch.) and biological activity in the soil. – Folia Horticulturae 27(1): 63-69.

[35] Mittler, R. (2002): Oxidative stress, antioxidants and stress tolerance. – Trends in plant science 7(9): 405-410.

[36] Moghadam, H. R. T. (2017): Super absorbent polymer mitigates deleterious effects of arsenic in wheat. – Rhizosphere 3: 40-43.

[37] NCSS, L. C. (2017): Power Analysis and Sample Size. – Software (PASS 15): Kaysville, Utah, USA.

[38] Nimah, N. M., Ryan, J., Chaudhry, M. A. (1983): Effect of synthetic conditioners on soil water retention, hydraulic conductivity, porosity, and agregation. – Soil Science Society of America Journal 47: 742-745.

[39] Ohwaki, Y., Hirata, H. (1992): Differences in carboxylic acid exudation among P-starved le-guminous crops in relation to carboxylic acid contents in plant tissues and phospho-lipid level in roots. – Soil Science and Plant Nutrition 38: 235-243.

[40] Öktüren, F., Sönmez, S. (2005): The Relationship Between Plant Nutrition Elements and Some Plant Growht Regulators (Hormones). – Batı Akdeniz Agricultural Research Institute, Derim 22(2): 20-32. (in Turkish).

[41] Özen, H. Ç., Onay, A. (1999): Plant Growth and Development Physiology. – Dicle Üniversity press, Diyarbakır, p. 166. (in Turkish).

[42] Percival, G. C., Fraser, G. A., Oxenham, G. (2003): Foliar salt tolerance of Acer genotypes using chlorophyll fluorescence. – Journal of Arboriculture 29: 61-65.

[43] Pouresmaeil, P., Habibi, D., Boojar, M. M. A., Tarighaleslami, M. (2013): Effect of super absorbent polymer application on chemical and biochemical activities in red bean (*Phaseolus vulgaris* L.) cultivars under drought stress. – European Journal of Experimental Biology 3(3): 261-266.

[44] Putra, P. A., Yuliando, H. (2015): Soilless culture system to support water use efficiency and product quality: a review. – Agriculture and Agricultural Science Procedia 3: 283-288.

[45] Rostampour, M. F. (2017): Evaluation of Relative Membrane Permeability of Sorghum (*Sorghum bicolor*) Affected Super Absorbent Polymer and Water Deficit Conditions. – Journal of Crop Nutrition Science 3: 27-39.

[46] Sairam, R., Srivastava, G. (2002): Changes in antioxidant activity in sub-cellular fractions of tolerant and susceptible wheat genotypes in response to long term salt stress. – Plant Science 162: 897-904.
[47] Sanchez, F. J., Manzanares, M., Andres, E. F., Tenorio, J. L., Ayerbe, L. (1998): Turgor maintenance, osmotic adjustment and soluble sugar and proline accumulation in 49 pea cultivars in response to water stress. – Field Crops Research 59: 225-235.
[48] Sayyari, M., Ghanbari, F. (2012): Effects of super absorbent polymer a200 on the growth, yield and some physiological responses in sweet pepper (*Capsicum annuum* L.) under various ırrigation regimes. – International Journal of Agricultural and Food Research 1(1): 1-11.
[49] Shannon, M. C. (1997): Adaptation of Plants to Salinity. – Advances in Agronomy 60: 76-120.
[50] Siddiqui, S. N., Umar, S., Iqbal, M. (2015): Zinc-induced modulation of some biochemical parameters in a high-and a low-zinc-accumulating genotype of *Cicer arietinum* L. grown under Zn-deficient condition. – Protoplasma 252: 1335-1345.
[51] Sita, R. C. M., Reissmann, C. B., Marques, R., Oliveira, E., Taffarel, A. D. (2005): Effect of Polymers Associated with N and K Fertilizer Sources on Dendrathema grandiflorum Growth and K, Ca and Mg Relations. – Brazilian Archives of Biology and Technology 48: 335-342.
[52] Sneha, S., Rishi, A., Dadhich, A., Chandra, S. (2013): Effect of salinity on seed germination, accumulation of proline and free amino acid in *Pennisetum glaucum* (L.) R. Br. – Pakistan Journal of Biological Sciences 17: 877-881.
[53] Sojka, R. E., Entry, J. A. (2000): Influence of polyacrylamide application to soil on movement of microorganisms in runoff water. – Environmental Pollution 108(3): 405-412.
[54] Sojka, R. E., Bjorneberg, D. L., Entry, J. A., Lentz, R. D., Orts, W. J. (2007): Polyacrilamide in Agriculture and Environmental Land Management. – Advances in Agronomy 158: 233-234.
[55] Sticher, L., Mauch-Mani, B., Métraux, J. P. (1997): Systemic acquired resistance. – Annual Review of Phytopathology 35: 235-270.
[56] Su, L. Q., Li, J. G., Xue, H., Wang, X. F. (2017): Super absorbent polymer seed coatings promote seed germination and seedling growth of Caragana korshinskii in drought. – Journal of Zhejiang University Science B (Biomedicine and Biotechnology) 18(8): 696-706.
[57] Tahmasebi, N., Moghadam, H. R. T., Borzou, A. (2015): Effects of Super Absorbent Polymer on the Quantity, Quality, Physiological and Biochemical Wheat (*Triticum aestivum* L.) in soils infected with Lead. – Biological Forum 7(1): 192-197.
[58] Tohidi-Moghadam, H. R., Shirani-Rad, A. H., Nour-Mohammadi, G., Habibi, D., Mashhadi-Akbar-Boojar, M. (2009): Effect of super absorbent application on antioxidant enzyme activities in Canola (*Brassica napus* L.) cultivars under water stress conditions. – American Journal Agricultural and Biological Sciences 4: 215-223.
[59] Velikova, V., Yordanow, I., Edreva, A. (2000): Oxidative stress and some antioxidant systems in acid rain treated bean plants protective role of exogenous polyamines. – Plant Science 151: 59-66.
[60] Wu, L., Liu, M., Liang, R. (2008): Preparation and properties of a double-coated slow-release NPK compound with superabsorbent and water retention. – Bioresource Technology 99: 547-554.
[61] Yazdani, F., Allahdadi, I., Akbari, G. A. (2007): Impact of süper absorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition. – Pakistan Journal of Biological Sciences 10(23): 4190-4196.