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Foliar Applied Salicylic Acid Improves Water Deficit-Tolerance in Egyptian Cotton

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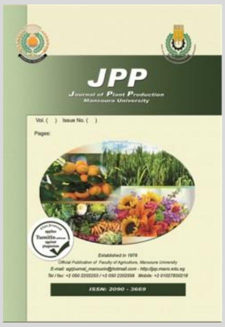

ABSTRACT

Water deficit (WD) is the major abiotic factor negatively impacts crop productivity around the world. Since, salicylic acid (SA) is one of antioxidant that plays vital role in stimulating plants to drought-tolerance. A field experiment in 2018 and 2019 seasons was conducted to test the impact of foliar applied SA at various concentrations (without spray as control, 1.0 mM and 1.5 mM) on growth, yield, fiber properties, physiological attributes, plant water relations, nutrients, and water use efficiency (WUE) in cotton plants grown under two regimes of irrigation (irrigated every 14 days as normal irrigation and irrigated every 21 days as water stress). Results revealed that foliar spraying with SA enhances WD tolerance in cotton plants by improving physiological attributes, nutrients and tissue water status by increase membrane stability index (MSI) and relative water content (RWC), and decrease electrolyte leakage (EL). These results were positively reflected in enhancing plant growth, yield, fiber properties and WUE under water stress conditions. Therefore, SA could be a hopeful material to mitigate the harmful effects of WD and reduce the number of irrigations in Egyptian cotton.

Keywords: Cotton growth, Fiber quality, WD, SA, WUE, Yield.

INTRODUCTION

Egyptian cotton (*Gossypium barbadense* L.) is renowned as an extra-long staple and is premium in the world for its elevating fiber quality. It plays a notable role in supporting the economy of country (Mahdi *et al.*, 2019). Cotton is the main raw material used in textile industry. The cotton is an important crop and grown in various parts of the world, also, it is highly sensitive to environmental stresses (Galani *et al.*, 2016 and Iqbal *et al.*, 2013).

Water deficit (WD) is one environmental factor limiting the production of the arable land around the world, where it is decreasing plant growth and yield. These decrease might be due to the increase in temperature and a reduced in water availability (Ahmed *et al.*, 2017). Improved irrigation use and appropriate planning is a possible selection norm for increasing yield under drought stress and it assesses the method and depth of water applied, whether it was used at optimum level by a plant (Sahito *et al.*, 2015). The major objective of applying the WD is to raise water use efficiency (WUE) by decrease the amount of water applied or by increase irrigation intervals (Semida *et al.*, 2017). The combined practice of WD and the antioxidant foliar applications seems to be very encouraging to realize this goal.

Continuously, plants are exhibited to an assortment of abiotic stresses (i.e., drought, salinity, heat stress, etc.). These stresses, particularly drought increases the accumulation of reactive oxygen species (ROS; superoxide, H2O2, singlet oxygen and hydroxyl radical) in cellular organelles like chloroplasts, peroxisomes, and mitochondria, harmfully impact different processes like transpiration, photosynthesis, stomatal conductance and growth (Abd El-Mageed *et al.*, 2016). However, it is necessary to increase the water stress tolerance of field crops in order to improve their productivity with finite water supply. More attention has recently been paid to safe and natural antioxidants such as proline, salicylic acid and α-tocopherol (Rady *et al.*, 2016 a, Semida *et al.*, 2017 and Mahdi *et al.*, 2017) which have the ability to inhibit the free radicals and therefore raise plant resistance to an abiotic stresses.

Salicylic acid (SA) is an antioxidant and is considered a hormone-like substance can regulate plant growth (Rady *et al.*, 2017). When providing plants with SA induces plant tolerance versus several biotic and abiotic stresses by mutating the enzymatic antioxidant activities and reducing the ROS generation. (Rady *et al.*, 2015). SA controls numerous of physiological internal processes in a plant by activating of naturally present signaling molecules (Galani *et al.*, 2016). SA plays a critical role in photosynthesis, stomatal conductance, and transpiration. It has been established that growth and development, ion uptake and transport, and permeability of membrane were positively affected by SA (Rady *et al.*, 2015). Defensive impacts of SA include up-regulation of anti-stress processes and the recovery of growth processes after the stress is over (Rady *et al.*, 2017).

Various studies demonstrated that plant growth, productivity and biochemical attributes in different crops have been improved by SA application under water stress (Abd El-Mageed *et al.*, 2016, Semida *et al.*, 2017 and Hafez and Seleiman, 2017). Hence, the integration of SA and WD may largely save irrigation water and improve water

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efficiency compared to their separate applied. Following the previous literature, there is very little information available about the influence of SA at wide-ranging field studies integrated with water deficit and its possible role in lessening water stress in plants, because the SA enhances preventive impacts on plants under drought thus, its application has obtained particular attention.

The current work aims to evaluate the efficiency of salicylic acid (SA) to lessening the negative influences of water deficit (WD) on cotton plants, clarifying the role of SA in increasing the growth, fiber quality and yield of water-stressed cotton plants and raise water use efficiency.

MATERIALS AND METHODS

Experimental design, treatments and plant material:

In summer 2018 and 2019 were conducted two field experiments at the farm of Faculty of Agriculture, Fayoum University. The experiment was arranged in a split-plot design in randomized complete blocks (RCBD) with three replicates, where the two irrigation regimes distributed in the main plots while, three levels of salicylic acid designed in sub-plots.

Irrigation was applied in two regimes (i.e., first regime was applied every 14 days as normal irrigation and second regime was applied every 21 days as water stress). Each main plot was surrounded with a wide alley (3 m width) to avoid interference among two irrigation regimes. The salicylic acid (SA) applied at three levels (i.e., without SA as control, 1.0 mM SA and 1.5 mM SA), and were added as foliar spray on two equal doses at 30 and 40 days after sowing. Soil of the experimental site was analyzed in both 2018 and 2019 seasons according to (Dahnke and Whitney, 1988), and results are shown in (Table 1).

Table 1. Physical and chemical properties of the experimental soil in two seasons*.

Properties	2018	2019
Physical analysis:		
Clay (%)	30.2	31.2
Sand (%)	51.3	49.5
Silt (%)	18.5	19.3
Texture class	Loamy sand	Loamy sand
Field capacity (%)	25.35	23.17
Wilting point (%)	10.57	11.34
Available water (%)	13.27	11.15
Chemical analysis:		
Organic matter (%)	0.95	0.97
$CaCO_3$ (%)	6.79	6.79
PH	7.45	7.31
ECe (dS m^{-1})	6.73	6.25
Total N (%)	0.075	0.071
P (mg kg^{-1} soil)	8.93	8.55
K (mg kg^{-1} soil)	189	183

***All analyses were done in Central Laboratory of Soil, Water and Plant Analysis (Iso17025), Faculty of Agriculture, Fayoum University, Egypt.**

Healthy seeds of Giza 95 variety of Egyptian cotton (Gossypium barbadense, L.) were sown on 21st and 25th of March 2018 and 2019, respectively. The seeds were got from Cotton Research Institute, Agricultural Research Centre, Giza, Egypt. Seeds were sown in hills spaced 25 cm apart, in ridges spaced 60 cm apart in 3.0 m × 3.5 m plots (resulting experimental plot area of 10.5 m^2), using an equivalent of 75 kg seed ha^{-1}. The planting was done one side of the ridge then thinning was done before the first irrigation to remain two plants per hill to generate the recommended planting density. All other cultural practices were done as recommended for cotton yield trial packages.

Determination of growth characteristics:

To estimation growth attributes, the plants at 70 days-old were removed from each experimental plot. All adhering soil particles were removed by shaking gently plants and then were measured shoots length by a meter scale. A number of fruiting branches $plant^{-1}$ was counted. Before drying the plants were weighed to record fresh weight (FW) and after drying in an oven the dry weight (DW) was recorded. The leaf area was measured by a graph sheet, where the squares covered by the leaf were counted.

Determination of physiological attributes:

Leaf total soluble sugars concentrations (mg g^{-1} DW) were estimated as stated by Irigoyen *et al.* (1992). Leaf free proline contents (mg g^{-1} DW) were assessed using the rapid colourimetric method, as described by Bates *et al.* (1973). Leaf anthocyanin concentration (mg g^{-1} DW) was analyzed using the method described by Mancinelli (1990). The method of Rady (2011) was used to assess the membrane stability index (MSI) and the following formula was applied: MSI (%) = $[1 - (C1 \div C2)] \times 100$. The method of Hayat *et al.* (2007) was used to estimate the relative water content (RWC) to calculated using the following formula: RWC (%) = $[(FM - DM) \div (TM - DM)] \times 100$. To measure the total leakage of inorganic ions from leaves were used method of Sullivan and Ross (1979) and Electrolyte leakage (EL) was calculated through following formula: EL (%) = $[(EC2 - EC1)/EC3] \times 100$.

Determination of nutrient status:

Method of Hafez and Mikkelsen (1981) was used to determine the leaf nitrogen (N) concentration (mg g^{-1} DW). Using a Perkin-Elmer Atomic Absorption and Flame Photometer were estimated concentrations of leaf phosphorus (P), potassium (K), calcium (Ca), and sodium ions (Na) concentrations (mg g^{-1} DW) (Paeg *et al.*, 1982).

Determination of yield components and water use efficiency:

At the end of each experiment (19th and 23rd of October 2018 and 2019, respectively), yield components were recorded e.g., number of open bolls $plant^{-1}$, 100-seed weight (g), seed cotton yield $plant^{-1}$ (g) and seed cotton yield $hectare^{-1}$ (ton). Water use efficiency (WUE) values, as kg of seed cotton yield m^{-3} of applied water, were estimated according to Jensen (1983).

Determination of fiber properties:

A sample of 50 g of lint yield was taken to measure fiber length (mm) micronaire reading, fiber strength (gram/tex) and fiber elongation (%).These measurements were carried out in the Technology Research Division, Cotton Research Institute, Giza, Egypt, according to ASTM (2005).

Statistical analysis:

All data of the present study were subjected to analysis of variance (ANOVA) that arranged in a split-plot in randomized complete blocks design; according to Gomez and Gomez (1984) homogeneity of error variances were tested. Combined analysis of data for the two seasons was performed and significant differences between each two treatments were compared at $P \leq 0.05$ by the Duncan's multiple range test.

RESULTS AND DISCUSSION

Results

Growth characteristics:

Cotton plants grown under water stress conditions exhibited significant decreases in all tested growth characteristics (i.e., shoot length, number of fruiting branches plant^{-1}, leaf area plant^{-1}, shoot fresh weight and shoot dry weight) by 16.31%, 18.09%, 15.33%, 16.36% and 20.12%, respectively compared to plants grown under normal conditions (Table 2). On the other hand, foliar applied 1.0 mM SA was more effective, at alleviate the detrimental effects of water stress and increasing the above growth characteristics compared to control (have no SA application). These increases were 20.48%, 48.53%, 57.39%, 45.79% and 42.80%, respectively compared to their control.

Table 2. Effect of foliar applied salicylic acid (SA; mM) on growth characteristics of cotton plants grown under normal and water stress condition.

Treatments		Shoot length (cm)	Number of fruiting branches plant^{-1}	Leaf area plant^{-1} (dm^2)	Shoot fresh weight (g)	Shoot Dry weight (g)
Irrigation regimes	**SA**					
Normal	Control	83.15 c	13.74 c	27.55 c	91.63 c	12.23 c
	1.0	99.72 a	19.83 a	41.37 a	125.54 a	17.42 a
	1.5	90.53 b	16.17 b	33.82 b	99.91 b	14.74 b
	Mean	91.13 A	16.58 A	34.25 A	105.69 A	13.80 A
Water stress	Control	67.54 c	11.19 c	22.53 c	73.90 c	9.93 c
	1.0	81.37 a	16.62 a	35.46 a	107.74 a	14.18 a
	1.5	79.91 b	12.93 b	28.72 b	83.56 b	11.35 b
	Mean	76.27 B	13.58 B	29.00 B	88.40 B	11.82 B

Mean values in the same column for each trait with the same lower small or upper bold-case letters are not significantly different by Duncan's Multiple Range Test at P ≤ 0.05; Normal = irrigated every 14 days; Water stress = irrigated every 21 days; Control = without SA.

Physiological attributes:

The Cotton plants irrigated every 21 days had significantly increased of total soluble sugars, free proline and electrolyte leakage (EL%) by 30.21%, 39.26% and 9.47%, respectively, while anthocyanin, membrane stability index (MSI%) and relative water content (RWC%) significantly decreased by 9.09%, 7.83% and 6.40%, respectively compared to those in cotton plants irrigated every 14 days (Tables 3&4). However, foliar applied SA was observed to overcome these adverse effects of water deficit and significantly increased total soluble sugars, free proline, anthocyanin, RWC% and MSI% and significantly decreased EL% compared to control (without SA application). The best SA concentration was 1.0 mM that increased total soluble sugars, free proline, anthocyanin, MSI% and RWC% by 34.78%, 88.96%, 42.86%, 24.74% and 19.07% and decreased EL% by 18.08%, respectively compared to control.

Table 3. Effect of foliar applied salicylic acid (SA; mM) on total soluble sugars, free proline and anthocyanin of cotton plants grown under normal and water stress condition.

Treatments		Total soluble sugars (mg g^{-1} DW)	Free proline (mg g^{-1} DW)	Anthocyanin (mg g^{-1} DW)
Irrigation regimes	**SA**			
Normal	Control	3.55 c	1.18 c	0.51 c
	1.0	5.17 a	2.15 a	0,71 a
	1.5	4.39 b	1.57 b	0.59 b
	Mean	4.37 B	1.63 B	0.55 A
Water stress	Control	4.83 c	1.54 c	0.42 c
	1.0	6.51 a	2.91 a	0.60 a
	1.5	5.72 b	2.37 b	0.49 b
	Mean	5.69 A	2.27 A	0.50 B

Mean values in the same column for each trait with the same lower small or upper bold-case letters are not significantly different by Duncan's Multiple Range Test at P ≤ 0.05; Normal = irrigated every 14 days; Water stress = irrigated every 21 days; Control = without SA.

Table 4. Effect of foliar applied salicylic acid (SA; mM) on membrane stability index (MSI %), relative water content (RWC %) and electrolyte leakage (EL %) of cotton plants grown under normal and water stress condition.

Treatments		MSI %	RWC %	EL %
Irrigation regimes	**SA**			
Normal	Control	54.31 c	62.29 c	13.55 a
	1.0	67.29 a	73.49 a	11.18 c
	1.5	61,33 b	67.55 b	12.24 b
	Mean	60.80 A	67.78 A	12.32 B
Water stress	Control	50.01 c	57.99 c	14.93 a
	1.0	62.38 a	69.05 a	12.23 c
	1.5	55.73 b	63.28 b	13.31 b
	Mean	56.04 B	63.44 B	13.49 A

Mean values in the same column for each trait with the same lower small or upper bold-case letters are not significantly different by Duncan's Multiple Range Test at P ≤ 0.05; Normal = irrigated every 14 days; Water stress = irrigated every 21 days; Control = without SA.

Nutrient status:

Cotton plants grown under water deficit conditions had significantly decreased concentrations of N, P, K and Ca by 24.11%, 28.62%, 30.66% and 26.11%, while showed declined concentration of Na by 29.92%, respectively compared to those cotton plants grown under normal conditions (Table 5). On the other side, foliar applied 1.0 mM SA was more effective, at alleviating the harmful effects of drought stress and significantly increased concentrations of N, P, K and Ca, while decreased concentration of Na compared to control (SA-free plants). These increases in concentrations of N, P, K and Ca were 62.95%, 74.51%, 76.75% and 81.93%, while decrease in concentration of Na was 33.72%., respectively compared to control.

Table 5. Effect of foliar applied salicylic acid (SA; mM) on nutrient status of cotton plants grown under normal and water stress condition.

Treatments		N	P	K	Ca	Na
Irrigation regimes	**SA**	**(mg g^{-1}DW)**	**(mg g^{-1} DW)**	**(mg g^{-1} DW)**	**(mg g^{-1} DW)**	**(mg g^{-1} DW)**
Normal	Control	27.19 c	0.77 c	15.71 c	5.95 c	16.95 a
	1.0	39.22 a	1.19 a	29.91 a	9.87 a	11.03 c
	1.5	33.71 b	1.01 b	22.35 b	7.73 b	13.26 b
	Mean	33.37 A	0.99 A	22.66 A	7.85 A	13.75 B
Water stress	Control	19.03 c	0.51 c	10.85 c	4.04 c	21.53 a
	1.0	31.01 a	0.89 a	21.44 a	7.35 a	14.27 c
	1.5	25.93 b	0.72 b	16.03 b	6.01 b	17.78 b
	Mean	25.32 B	0.71 B	16.11 B	5.80 B	17.86 A

Mean values in the same column for each trait with the same lower small or upper bold-case letters are not significantly different by Duncan's Multiple Range Test at P ≤ 0.05; Normal = irrigated every 14 days; Water stress = irrigated every 21 days; Control = without SA.

Yield components and water use efficiency (WUE):

The cotton plants watered every 21 days exhibited significant reduction in yield components (i.e., number of open bolls $plant^{-1}$, 100-seed weight, seed cotton yield $plant^{-1}$ and seed cotton yield $hectare^{-1}$) by 16.75%, 15.50%, 24.63% and 13.15%, while WUE significantly increased by 24.27%, respectively compared to cotton plants watered every 14 days (Table 6). In contrast, foliar applied SA was observed to mitigate these adverse effects of water stress and significantly increased the yield and compoents and further WUE. The best SA concentration was 1.0 mM that increased the aforementioned yield characteristics and WUE compared to control (no SA spraying). These increases in number of open bolls $plant^{-1}$, 100-seed weight, seed cotton yield $plant^{-1}$, seed cotton yield $hectare^{-1}$ and WUE were 44.58%, 32.34%, 72.95%, 51.75% and 32.43%, respectively compared to their control.

Table 6. Effect of foliar applied salicylic acid (SA; mM) on yield components and water use efficiency (WUE%) of cotton plants under normal and water stress condition.

Treatments		Number of open bolls	100-Seed weight	Seed cotton yield	Seed cotton yield	WUE
Irrigation regimes	**SA**	**$plant^{-1}$**	**(g)**	**$plant^{-1}$ (g)**	**$hectare^{-1}$ (ton)**	**(%)**
Normal	Control	14.15 c	2.45 c	29.73 c	1.93 c	0.29 c
	1.0	18.65 a	3.07 a	45.27 a	2.35 a	0.41 a
	1.5	16.45 b	2.74 b	37.88 b	2.11 b	0.33 b
	Mean	16.42 A	2.75 A	37.63 A	2.13 A	0.34 B
Water stress	Control	11.17 c	2.01 c	20.89 c	1.43 c	0.37 c
	1.0	16.15 a	2.66 a	36.13 a	2.17 a	0.49 a
	1.5	13.68 b	2.31 b	28.06 b	1.95 b	0.42 b
	Mean	13.67 B	2.33 B	28.36 B	1.85 B	0.43 A

Mean values in the same column for each trait with the same lower small or upper bold-case letters are not significantly different by Duncan's Multiple Range Test at P ≤ 0.05; Normal = irrigated every 14 days; Water stress = irrigated every 21 days; Control = without SA.

Fiber properties:

Data of fiber properties in terms fiber length, fiber strength and fiber elongation of cotton plants water-stressed significantly decreased by 16.24%, 15.55% and 14.81%, while micronaire reading significantly increased by 20.30%, respectively compared to unstressed cotton plants (Table 7). On the contrary, foliar applied 1.0 mM SA was more effective, at overcome these adverse effects of water deficit and significantly increased fiber length, fiber strength and fiber elongation, and significantly decreased micronaire reading compared to control (without any SA). The increases in fiber length, fiber strength and fiber elongation were 31.80%, 36.95% and 39.17%, while decrease in micronaire reading was 8.55%, respectively compared to control.

Table 7. Effect of foliar applied salicylic acid (SA; mM) on fiber properties of cotton plants grown under normal and water stress condition.

Treatments		Fiber length (mm)	Micronaire reading	Fiber strength (g/tex)	Fiber elongation (%)
Irrigation regimes	**SA**				
Normal	Control	28.73 c	3.51 a	34.97 c	5.97 c
	1.0	35.94 a	3.15 c	51.29 a	8.21 a
	1.5	32.05 b	3.39 b	43.19 b	7.02 b
	Mean	32.24 A	3.35 B	43.15 A	7.07 A
Water stress	Control	23.65 c	4.21a	30.91 c	5.03 c
	1.0	31.17 a	3.85 c	42.33 a	7.00 a
	1.5	26.19 b	4.02 b	36.08 b	6.03 b
	Mean	27.00 B	4.03 A	36.44 B	6.02 B

Mean values in the same column for each trait with the same lower small or upper bold-case letters are not significantly different by Duncan's Multiple Range Test at P ≤ 0.05; Normal = irrigated every 14 days; Water stress = irrigated every 21 days; Control = without SA.

Discussion

Increasing lack of irrigation water is a major threat to sustainable cotton production (Ahmed *et al.,* 2017). Water shortage has put a large stress on scientists to insert drought-tolerant cotton varieties (Sahito *et al.,* 2015). Water stress is a critical environmental abiotic stress impacting growth and internal physiological processes in plant (Semida *et al.* 2017). This study attempts to follow a water deficit (WD) strategy to qualify cotton plants to tolerate drought with supporting plants by antioxidants applications such as salicylic acid (SA). Foliar application with SA could be a very promising approach to alleviate the harmful effects of WD by prompting a broad range of drought stress-tolerance techniques in cotton plants.

In the current study, the growth characteristics of cotton plants grown under drought conditions decreased compared to those of plants grown under normal conditions (Table 2). This reduction in the growth might be due to a decrease in cell elongation caused by the inhibiting impact of WD on growth-stimulating hormones which, in turn, lead to reduce in cell turgor, volume, and eventually growth (Mahdi *et al.,* 2017). However, foliar-applied SA may help reduce the injurious effects of WD and increased the growth traits of water-stressed cotton plants. The increase in dry material of drought-stressed plants in response to treatment with SA might be due to inducing of an antioxidant system to protect the plant from damage (Semida *et al.,* 2017). The action of SA to increase plant dry matter, eliminating the negative influences of WD stress, maybe due to SA contributes in promoting plant growth under limited water availability condition. (Abd El-Mageed *et al.,* 2016).

Total soluble sugars and free proline are main components of osmoregulation in the wide leaves of many plant species (Semida *et al.,* 2017). Additionally, anthocyanins are used as an indication of the cellular protective function in the secondary metabolism process (Rady *et al.,* 2016 b). Therefore, increasing the level of anthocyanins in water-stressed cotton plants with the application of SA indicates an index of a good mechanism for plant tolerance to changes in environmental conditions. Our results show that the SA applied is beneficial for improving the ability of cotton plants to the water stress-tolerance as a result of increasing drought tolerance through the increase in total soluble sugars, free proline and anthocyanin concentrations (Table 3). Our results are in accord with as stated by Loutfy *et al.* (2012) they stated that SA application increased TSS accumulation and this might be contributing as a solute for the osmotic regulation and/or a substrate for the protein and polysaccharide syntheses and thereby for the growth of whole plants.

In this manner, preserving cellular membranes integrity under stress conditions is an essential part of drought-tolerance mechanisms (Khoshbakht and Asgharei, 2015). SA is well-known to produce a wide range of metabolic responses in plants and impacts a range of plant functions, including plant water relations (Hayat *et al.,* 2010). In this study, cotton plants sprayed with 1.0 mM SA showed ameliorative effect of water deficit-tolerance by increasing membrane stability index (MSI%) and relative water content (RWC%), which was connected with decreased electrolyte leakage (EL%) compared with those plants that had not been treated with SA (Table 4). likewise, the same trend were obtained for squash plants (Abd El-Mageed *et al.,* 2016), onion plants (Semida *et al.,* 2017) and basil plants (Taha *et al.,* 2020) grown under water deficit conditions.

Our results show that cotton plants grown under WD conditions exhibited decreases in the concentrations of N, P, K and Ca, while increased the concentration of Na compared with non-stressed plants (Table 5). These results are in agreement with those of (Ahmed *et al.,* 2017) they demonstrated that drought lessens nutrient uptake N, P and K by roots and their transport inside in plant because of limited transpiration rates, impaired active transport, and membrane permeability. The beneficial effects of SA appeared as mitigated the negative effects of WD and positive changes occur in mineral nutrients by increasing in concentrations of N, P, K and Ca in cotton plants and decreasing in concentration of N. Thus, SA protects plants against harmful effects of water stress through its roles in maintaining the structural integrity of the plasma membrane and increasing the uptake of mineral nutrients. Similar results have been reported. (Abd El-Mageed *et al.,* 2016).

In this respect, the flowering and boll-forming period is the key yield determinant stage of cotton plant (Ahmed *et al.,* 2017). Drought stress happening in this stage will certainly seriously influence cotton growth and eventually productivity. Our results show yield and its components for cotton plants grown under water stress decreased compared to those plants non-stressed, while increased water use efficiency (WUE) (Table 6). These results are reasoning because the lack of water available influences diverse biological processes in plants like photosynthetic efficiency, MSI and gas exchange attributes (Abd El-Mageed *et al.,* 2016). Additionally, it might be attributed to decrease uptakes of needed nutrients from soil and consequently influenced cell division and development (Hafez and Seleiman, 2017). However, yield and its components and WUE increased with treatment of SA compared to the control. The previous results are in harmony with as stated by Semida *et al.* (2017) they noted an increase in plant biomass and yield of onion treated with SA under water stress. Additionally, Abd El-Mageed *et al.* (2016) mentioned that the capability of SA to stimulate Rubisco activity under water shortage may be responsible for the improvement in yields of squash treated with SA.

In this connection, drought is a main limiting factor for fiber and lint quality after flowering and delayed maturity in cotton plants (Ahmed *et al.,* 2017). Also, delays in opening of bolls and leaf senescence have the influence of extension of the boll-filling stage, which affects fiber and seed quality positively (Mittal *et al.,* 2015). Furthermore foliar application of 1.0 mM SA improved of fiber properties in cotton plants by increase of fiber length, fiber strength and fiber elongation, also by decrease of micronaire reading under WD compared to control (Table 7). Similar results have been reported previously (El-Beltagi *et al.,* 2017).

CONCLUSION

In summary, foliar applied with 1.0 mM SA may enhance plant stress-defense responses, to alleviate the harmful impacts of WD. It directly stimulates protection from damage of cell membrane by reducing EL and Na and increasing accumulation of TSS and RWC, acting as osmotic and metabolic regulators or substrates and in a part as cell component stabilizers which together, increased WUE. Moreover, foliar-applied with SA is useful for increasing the growth, fiber quality and yield of Egyptian cotton plants under WD by reduce the number of irrigations.

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الرش الورقي بحمض السالسليك يحسن تحمل نقص المياه في القطن المصري

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يعتبر نقص المياه العامل اللاحيوي الرئيسي الذي يؤثر سلباً على إنتاجية المحاصيل حول العالم. يعد حمض السالسليك أحد مضادات الأكسدة حيث يلعب دوراً حيوياً في تحفيز النباتات لتحمل الجفاف. أجريت تجربتان حقليتان خلال موسمي 2018 و2019 لاختبار تأثير الرش الورقي بحمض السالسليك بتركيزات مختلفة (بدون رش كمعاملة كنترول و 1.0 و 1.5 ملليمول) على النمو والمحصول وخصائص الألياف والصفات الفسيولوجية والعلاقات المائية للنبات والعناصر الغذائية وكفاءة استخدام المياه في نباتات القطن النامية تحت نظامين من الري (الري كل 14 يوم كمعاملة كنترول والري كل 21 يوم كإجهاد مائي). أظهرت النتائج أن الرش الورقي بحمض السالسليك يعزز من تحمل نقص المياه عن طريق تحسين الصفات الفسيولوجية والعناصر الغذائية وحالة ماء الأنسجة من خلال زيادة دليل ثبات الغشاء ومحتوى الماء النسبي وانخفاض الاستنزاف الالكتروليتى. وانعكست هذه النتائج ايجابيا في تحسين نمو النبات والمحصول وخصائص الألياف وكفاءة استخدام المياه تحت ظروف الإجهاد المائي. ومن ثم يعتبر حمض السالسليك مادة مبشرة للتخفيف من التأثيرات الضارة لنقص المياه وتقليل عدد الريات في القطن المصري.