sciendo

Hellenic Plant Protection Journal **16:** 40-49, 2023
DOI 10.2478/hppj-2023-0006

Effects of exogenous abscisic acid on antioxidant system of salt tolerant and salt sensitive cotton cultivars

K.M. Kuldoshova*, A.A. Akhunov, N.R. Khashimova and J.F. Ziyavitdinov

Summary Salinity is one of the most imperative global problems that affect crop productivity on a large scale. Salinity impairs plant growth and development by imposing various stresses. Therefore it is vital to decode those stress factors and identify possible solutions to improve agriculture productivity. However, the adaptive mechanisms under saline conditions of glycophytes have not been studied. The present study was undertaken to determine the effects of exogenous abscisic acid (ABA) on salinity tolerance in cotton plants. Some patterns of resistance development were revealed on the seedlings of two cotton cultivars, a salt-tolerant (Gulistan) and a salt-sensitive one (C-4727). Moreover, the antioxidant potentials of these cultivars were compared. The activities of ascorbate peroxidase (APX), superoxide dismutase (SOD), as well as the quantity of endogenous ABA, malondialdehyde (MDA), and free proline (Pro) were determined in control and post treatment. Our results demonstrate significant differences between the salt- tolerant and sensitive cotton seedlings in response to saline stress, i.e., high levels of Pro and endogenous ABA, but lower MDA concentrations, and higher activity of APX and SOD for the salt-tolerant cultivar, Gulistan, as compared to the salt stress-sensitive cultivar C-4727.

Additional keywords: ascorbate peroxidase, free proline, *Gossypium hirsutum* L., lipid peroxidation, salinity, superoxide dismutase

Introduction

Soil salinity is a major environmental limitation to world agriculture affecting 800 million hectares of land throughout the world. This is over 6 % of the world's total land area, affected either by salinity (397 million hectares) or associated condition of sodicity (434 million hectares) (Munns, 2005). Salt stress alters various biochemical and physiological responses in plants and thus affects almost all plant processes including photosynthesis, growth, and development (Iqbal *et al*., 2006). In several crops negative effects of soil salinity have been well described. In tomato, salinity was determined to affect the crop yield, i.e., salt stress reduced dry and fresh weight of tomatoes and the biomass of tomato plants (Ghorbani *et al*., 2018, 2019). Studies on salinity stress will be a stride towards the urgent need of developing crop varieties possessing a higher growth rate and yield in salt-affected environments.

Phytohormones, as the main components of the plant regulatory system, play a key role not only in plant growth and morphogenetic processes but also in adaptive reactions associated with exposure to unfavorable factors (Hojin and Yong, 2015). To improve the adverse outcome of salinity stress on plant growth, diverse phytohormones are extensively used (Hojin and Yong, 2015). In this context, the plant hormone abscisic acid (ABA) is considered an important agent in the mechanisms of resistance and adaptation in plants against salt stress conditions (Bakhsh *et al*., 2011). Thus, ABA acts as a mediator in controlling adaptive plant responses to environmental stresses. It has been well documented that endogenous ABA accumulates in plants under abiotic stresses (Xiong *et al*., 2002). Nevertheless, ABA is involved in several other physiological processes, such as stomatal closure, embryo morphogenesis, development of seeds, synthesis of storage proteins and lipids (Rock and Quatrano, 1995), as well as germination, leaf senescence and defense against pathogens (Richardson *et al*., 1987). Additional-

Institute of Bioorganic Chemistry, Academy of Sciences of Uzbekistan, M. Ulughbek St. 83, Tashkent, Uzbekistan.
* Corresponding author: zarabarlos90@bk.ru

© Benaki Phytopathological Institute

ly, exogenous application of ABA enhances the tolerance of plants to various stresses including cold, heat, drought, heavy metals, anoxia, and other environmental factors (Ahmad *et al*., 2010). These and other findings suggest that ABA has a great agronomic potential for improving the stress tolerance of important crops.

Enzymes of the antioxidative system play a considerable role in the resistance of the cotton plant to stress factors (Meloni *et al*., 2002). The antioxidant state of the plant is identified by the balance between prooxidant and antioxidant reactions occurring in cells (Mandhania *et al*., 2006). Characterization of antioxidant system functions is important to evaluate how the plant adapts to environmental changes (Mittal *et al*., 2012).

The present work examines the effect of exogenous ABA on enhancing salt resistance of a salt-tolerant (Gulistan) and a salt-sensitive (C-4727) cotton cultivar. The enzymic activities of superoxide dismutase **(**SOD) and ascorbate peroxidase (APX), and quantity changes of malondialdehyde (MDA), free proline and endogenous ABA in these cultivars were also studied to establish the differences in antioxidative potential.

Materials and methods

Plant materials and stress treatment

Seven-day-old seedlings of two cotton (*Gossypium hirsutum* L.) cultivars with varying degrees of salt tolerance, i.e., a salt-tolerant (Gulistan) (Akhmedov *et al*., 2022) and a salt-sensitive one (C-4727) (Babaeva *et al*., 2020), were used in this study. The cotton seeds were treated with concentrated sulfuric acid and washed under tap water for 10-15 minutes. The seeds were further soaked in distilled water for 12 hours. The swollen seeds were wrapped in paper rolls and incubated for germination for 7 days in the moist chamber at 27°C. After the 7th day of germination, half of seedlings remained in the distilled water as control. The second half of the seedlings were divided into 4 parts and kept in saline solutions: 1% NaCl; 1% NaCl + 10^{-7} M ABA; 4% NaCl; 4% NaCl + 10^{-7} M ABA. The cotton seedlings were homogenized in liquid nitrogen and used for biochemical analysis.

Extraction of enzyme extract

About 200 mg of seedlings of both varieties were homogenized in 5 ml of 50 mM phosphate buffer (pH 7.8) containing 1% polyvinylpyrrolidone (PVP), 1 mM ascorbic acid and 1 mM phenylmethylsulphonyl fluoride (PMSF) as described by Moran *et al.* (1994). After centrifugation at 7, 000 x g for 15 min at 4-8°C the supernatant was dialyzed against the same extraction buffer to be used as an enzyme extract.

Ascorbate peroxidase

The APX was assayed according to Nakano and Asada (1981). To a reaction mixture containing 1 ml 50 mM phosphate buffer (pH 7.0), 0.2 mM ascorbic acid, 0.2 mM ethylenediaminetetraacetic acid (EDTA) and the enzyme, 20 mM H_2O_2 was added. The absorbance was recorded at 290 nm on the UV-Vis spectrophotometer (ELICO, India) (extinction coefficient of 2.8 mM^{-1} $1cm^{-1}$ at 30s intervals up to 7 min). A correction was made for the low, non-enzymatic oxidation of ascorbic acid by H_2O_2. The specific activity of the enzyme was expressed as units/mg protein.

Superoxide dismutase

The SOD activity was determined as described by Giannopolitis and Ries (1977). Assays were carried out on a rotating plate under illumination. One unit of SOD activity was defined as the amount of enzyme required to cause 50% inhibition of the rate of p-nitro blue tetrazolium chloride reduction at 560 nm.

Total protein determination

To measure the activity of antioxidative enzymes, such as APX and SOD, to make a standard curve and to read the absorbance, quantitation of total protein content of samples was performed according to the Lowry method (1951) using bovine serum albumin

© Benaki Phytopathological Institute

(BSA; Sigma-Aldrich, USA).

Lipid peroxidation

The Rogozhin *et al.* (1998) methodology of thiobarbituric acid (TBA) reaction was followed to determine the level of lipid peroxidation in terms of MDA concentration in the samples. For these analyses, about 500 mg of seedlings were homogenized with 5 ml of 0.1 % trichloroacetic acid (TCA) and then centrifuged at 7, 000 x g for 15 min. For every 1 ml of aliquot, 4 ml of 20% TCA containing 0.5% TBA was added. The mixture was heated at 95°C for 30 min and then cooled immediately on an ice bath. The resultant mixture was centrifuged at 7, 000 x g for 15 min, and the absorbance of the supernatant was recorded at 532 nm. The concentration of MDA was calculated by using an extinction coefficient of 156 $mM^{-1}cm^{-1}$.

Determination of proline

The method of Bates *et al.* (1973) was used for the determination of proline. About 500 mg of leaf tissue was homogenized in 5 ml of 3% aqueous sulphosalicylic acid. The homogenate was centrifuged at 7, 000 x g for 15 min. In a test tube, 1 ml of the extract was mixed with 2 ml of acid-ninhydrin containing 1.25 g of ninhydrin in 30 ml of glacial acetic acid and 20 ml of 6 M phosphoric acid. Subsequently, 2 ml of glacial acetic acid was added and the mixture was heated for an hour at 100°C. Later, 4 ml of toluene was used to extract the reaction mixture. Further, the reaction mixture was vortexed for 20-25 sec. The chromophore containing toluene was aspirated from the aqueous phase, and the absorbance of the toluene layer was measured at 520 nm with toluene as blank. Values were expressed as millimole per gram of fresh weight.

Abscisic acid quantitation by HPLC

The quantitation of ABA was performed using Agilent Technologies 1200 series for HPLC (USA). The column 250 x 4.6-mm of strong anion exchanger (5- µm spherical particles of Adsorbosphere SAX, Alltech Associates, USA) was used for the next step of purification. The samples were dissolved in the mixture of acetonitrile (30%) and 0.1% phosphoric acid (70%). Acetonitrile was a mobile phase solvent A; trifluoroacetic acid was used as a solvent B at 1 ml min-1. The solvent B concentration gradient was 30–50% at 10 min, 50–50% at 5 min, and 50–30% at 2 min. A Waters model 440 fixed-wavelength UV absorbance detector (Waters Corporation, USA) (254 nm) was used to detect ABA.

Statistical analyses

The results were statistically analyzed using Graph Pad Prism 8. Values are expressed as mean ± SD for three biological replicates per treatment. The analysis was conducted using T-test at P= 0.05.

Results and discussion

To assess the activity of antioxidant systems of a salt-tolerant (Gulistan) and a salt-sensitive (C-4727) cotton cultivar, we determined the effects of the main enzymes of their antioxidant protective system, i.e., the APX and SOD. The response of this system to salinization is known to depend on the variety and type of plant, its physiological state, as well as on the level and duration of stress (Miguel *et al*., 2006). In our study, we managed to identify the direct correlation between the levels of antioxidant system induction and the degree of plant resistance to salinization.

APX is a key enzyme in the ascorbate-glutathione cycle playing a critical role in H_2O_2 scavenging (Chawla *et al.,* 2013). APX uses ascorbate as an electron donor to reduce H_2O_2 to water. Our findings showed that the resistant cultivar had a much higher APX level in 1 hour (32.23 units) as compared to the sensitive cultivar C-4727 (20.6 units) (Table 1). There was no appreciable change in APX activity in the tolerant variety, but the sensitive one demonstrated APX increase at both levels of salinity stress. The 4% NaCl solution enhanced APX activity in C-4727, but it was much lower than in the tolerant cultivar. These results are supported by Benavides *et*

© Benaki Phytopathological Institute

Table 1. The exogenous effect of ABA on the activities of APX and SOD in seedlings of two cotton varieties**,** Gulistan (salt-tolerant) and C-4727 (salt-sensitive), under conditions of NaCl salinity for 1 h and 24h.

Samples	Gulistan (salt-tolerant)		C-4727 (salt-sensitive)	
	1 Hour	24 Hours	1 Hour	24 Hours
APX, units/mg protein				
Control	27.6 ± 1.2c	25.4 ± 1.2c	22.7 ± 1.0d	21.0 ± 0.5d
1% NaCl	32.2 ± 1.4b	34.0 ± 1.5b	20.6 ± 0.9d	16.0 ± 0.7d
1% NaCl + ABA	39.4 ± 1.5a	30.7 ± 1.1c	24.6 ± 1.2d	20.5 ± 0.9d
4% NaCl	32.3 ± 1.0b	28.8 ± 1.2c	21.0 ± 1.0d	26.1 ± 1.2c
4% NaCl + ABA	38.7 ± 1.3a	33.3 ± 1.5b	22.1 ± 1.0d	23.0 ± 1.1d
SOD, units/mg protein				
Control	4.0 ± 0.1c	3.9 ± 0.1c	2.7 ± 0.1d	2.7 ± 0.1d
1% NaCl	5.5 ± 0.2b	5.1 ± 0.2b	3.0 ± 0.1d	3.5 ± 0.1d
1% NaCl + ABA	6.3 ± 0.2b	6.0 ± 0.3b	3.4 ± 0.1d	3.2 ± 0.1d
4% NaCl	3.9 ± 0.1d	6.2 ± 0.2b	4.6 ± 0.2c	2.6 ± 0.1d
4% NaCl + ABA	4.4 ± 0.2c	9.1 ± 0.4a	5.1 ± 0.2b	4.1 ± 0.2c

Means in each column followed by the same letter(s) do not differ significantly at $P \leq 0.05$.

al. (2000) who reported a more significant elevation of the APX levels in salt-tolerant potato clones than the one in a salt-sensitive clone. Similarly, Meneguzzo *et al.* (1999) observed a greater increase in APX activity in a salt-sensitive cultivar than in a salt-tolerant one of wheat when exposed to NaCl stress. With the increase in salt stress, APX activity also increased in wheat (Heidari and Mesri 2008), cotton (Desingh and Kanagaraj 2007), stevia (Omran *et al*., 2021) and sea rocket (Amor *et al*., 2007) suggesting that high level of APX and salt-induced increase in APX activity could impart tolerance by detoxifying H_2O_2 generated upon exposure of plants to saline conditions.

Regarding the effect of exogenous ABA, the activity of APX in the seedlings of the salt-tolerant cotton cultivar was significantly higher in samples treated with 1% NaCl + ABA, as compared with the ones treated with NaCl (39.43 units versus 32.23 units) while the control sample exhibited a significantly lower APX activity (27.6 units) (Table 1). Our results suggest that oxidative stress can play a key role in the salt tolerance of the seedlings of a cotton cultivar under the salt stress; our salt-tolerant cultivar, Gulistan, turned out to have more efficient antioxidant protection promoting resistance to the oxidative stress.

The SOD activity increased progressively with the increase of salinity in the salt-resistant cultivar but receded in the sensitive one (Table 1). After 1 and 24 hours in 1% NaCl solution, the level of SOD activity was significantly higher in the salt-tolerant cultivar than the one in the salt-sensitive cultivar (5.53, and 5.1 units in Gulistan and 3.0 and 3.55 units in C-4727, respectively). After 24 hours in 4% NaCl + ABA solution, the increase of the enzyme activity was observed in both cultivars. Possibly, the SOD activity increase allows reducing lipid peroxidation under higher salt stress. These observations are in agreement with those reported earlier in *Solanum tuberosum* (Benavides *et al*., 2000), *Brassica juncea* (Chawla *et al.,* 2012) and *Najas graminia* (Rout and Shaw, 2001) where the salt-tolerant cultivars had a higher level of the enzyme activity compared to that in the salt-sensitive ones. Similar to the present findings, the SOD activity increased in the salt-tolerant cultivars but reduced in the salt-sensitive cultivar of wheat (Mandhania *et al*., 2006), cotton (Meloni *et al*., 2002)

© Benaki Phytopathological Institute

and *Catharanthus roseus* (Jaleel, 2009). Contrarily, salinity has been reported to stimulate the SOD activity in both salt-tolerant and salt-sensitive cultivars of *Brassica juncea* with a higher level in the salt-tolerant ones (Chawla *et al*., 2012). An increase in the SOD activity upon salinization in leaves of all the salt-tolerant cotton cultivars could accelerate the dismutation of superoxide ions generated upon salt-treatment, which may allow these varieties to survive under oxidative stress (Desingh and Kanagaraj, 2007). In the salt-sensitive cultivar, reduction in the SOD activity would limit its metabolic capacity to withstand oxidative stress.

Under high salinity stress, the increase of reactive oxygen in plant species leads to lipid peroxidation (LPO) in the cell membrane. MDA is the main product of membrane lipid peroxidation when plants are under salt stress, and its levels reflect the degree of cell membrane damage (Mittal *et al*., 2012). Therefore, MDA concentrations can be a marker of a plant salt tolerance. In our study, MDA concentrations were found to lower by 8% at salinization after 1 hour in a 1% NaCl solution in Gulistan variety (Fig. 1). After 24-hour exposure to 1% NaCl, we observed a more significant decrease of MDA in Gulistan cultivar (52%). When ABA was added, a considerable reduction in MDA concentrations occurred (16.7%). After 1-hour and 24-hour exposures to 1% and 4% NaCl, MDA concentrations in Gulistan cultivar declined by 16% and 9.2%, respectively. ABA declined the MDA concentrations by 30.5% and 21%, respectively. Hence, salt resistance seems to stimulate the capability of protection from oxidative damage by both exposures. In contrast, in the salt-sensitive C-4727 cultivar, MDA concentrations increased considerably at any degree of salinization (Fig. 3). When ABA was added, further reduction in MDA was observed which was more significant than the one observed in the salt-tolerant cultivar. Increased MDA levels in tomato leaves under different salinity stress (Ghorbani *et al*., 2018) support our results. Our findings demonstrate that Gulistan variety is more resistant to salt stress than C-4727. The accumulation of lipid peroxidation products may not occur in the seedlings of Gulistan due to higher activity of antioxidant enzymes.

A considerable increase in the concentrations of proline took place under the effect of 1% NaCl within 1 hour in the salt-resistant Gulistan cultivar (Fig. 2). The accumulation

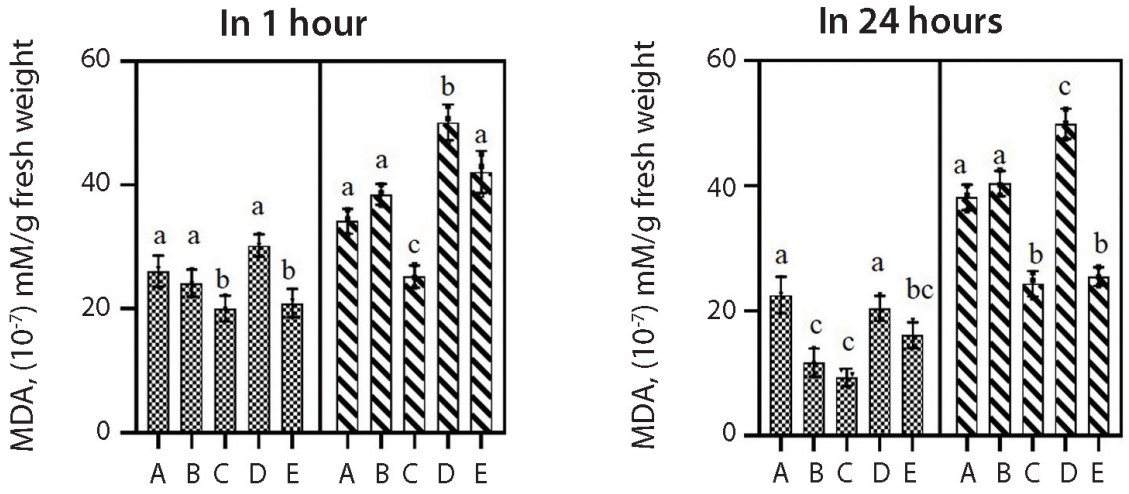


Figure 1. Effect of exogenous ABA on MDA concentrations in cotton seedlings under conditions of NaCl salinity for 1h and 24h.

Note: ▩ - salt-tolerant Gulistan cotton cultivar; ◪ - salt- sensitive C-4727 cotton cultivar; A: Control; B: 1% NaCl; C: 1% NaCl + ABA; D: 4% NaCl; E: 4% NaCl + ABA. Means with the same letter(s) on top of the columns do not differ significantly.

© Benaki Phytopathological Institute

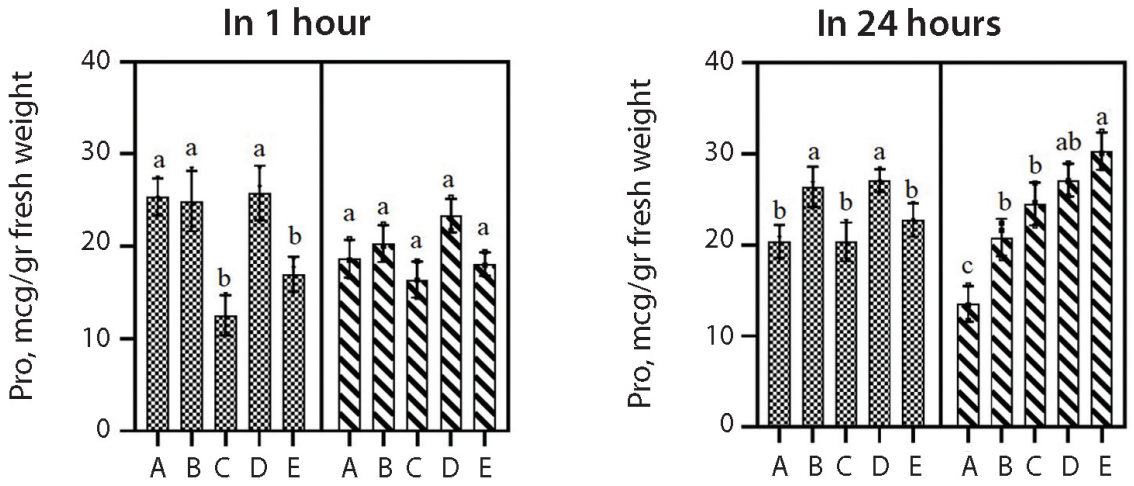


Figure 2. Effect of exogenous ABA on concentration of free proline in cotton seedlings under conditions of NaCl salinity for 1h and 24h.

Note: ▩ - salt-tolerant Gulistan cotton cultivar; ◪ - salt- sensitive C-4727 cotton cultivar; A: Control; B: 1% NaCl; C: 1% NaCl + ABA; D: 4% NaCl; E: 4% NaCl + ABA. Means with the same letter(s) on top of the columns do not differ significantly.

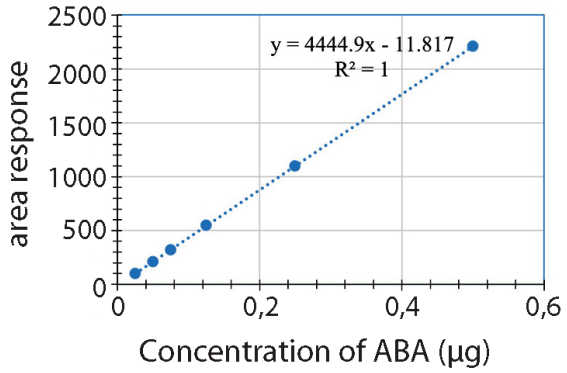


Figure 3. Calibration curve for determination of endogenous ABA concentration.

of proline under salinity stress has been reported in *Pisum sativum* (Najafi *et al*., 2006), *Brassica juncea* (Rais *et al*., 2013) and *Triticum aestivum* (Ashfaque *et al*., 2014). Proline performs a protective function against salinity stress in plants (Kishor *et al*., 2005; Verbruggen and Hermans, 2008). It acts as a compatible osmolyte, enzyme protectant, free radical scavenger, cell redox balancer, cytosolic pH buffer and stabilizer for subcellular structures (Kishor *et al*., 2005; Verbruggen and Hermans, 2008) to bring about salinity tolerance. Proline could also act as a major source of energy and nitrogen during immediate post-stress metabolism. Accumulating in plants, proline supplies energy for their growth and survival, thereby inducing salt tolerance (Silveira *et al*., 2003). Similar findings were reported by Hassine and Lutts (2010). The exogenous ABA was found to decrease the amount of proline after 1-hour exposure in 1% and 4% NaCl solutions, in both cultivars. After 24 hours, 1 and 4% salinization caused a rapid increase in proline levels (Fig. 2). According to Nikolaeva *et al*. (2015), exogenous ABA inhibits the rate of synthesis of proline or stimulates its degradation intensity in saline conditions.

In our study, a calibration curve was used to determine the concentration of endogenous ABA (Fig. 3). The treatment with 1% and 4% NaCl solutions led to a significantly higher accumulation of endogenous ABA in cotton seedlings in 1-hour and 24-hour exposures (Fig. 4). Upon addition of exogenous ABA, the concentration of endogenous ABA increased in the seedlings of Gulistan in 1 hour by 15% (1% NaCl+ABA) and by 20% (4% NaCl+ABA). After 24 hours, endogenous ABA concentration doubled in the seedlings exposed to 1% NaCl, while no significant changes were observed in the seedlings treated with 4%NaCl. In the control seedlings of Gulistan cultivar, high concentrations of endogenous ABA were observed, i.e., after 1-hour

© Benaki Phytopathological Institute

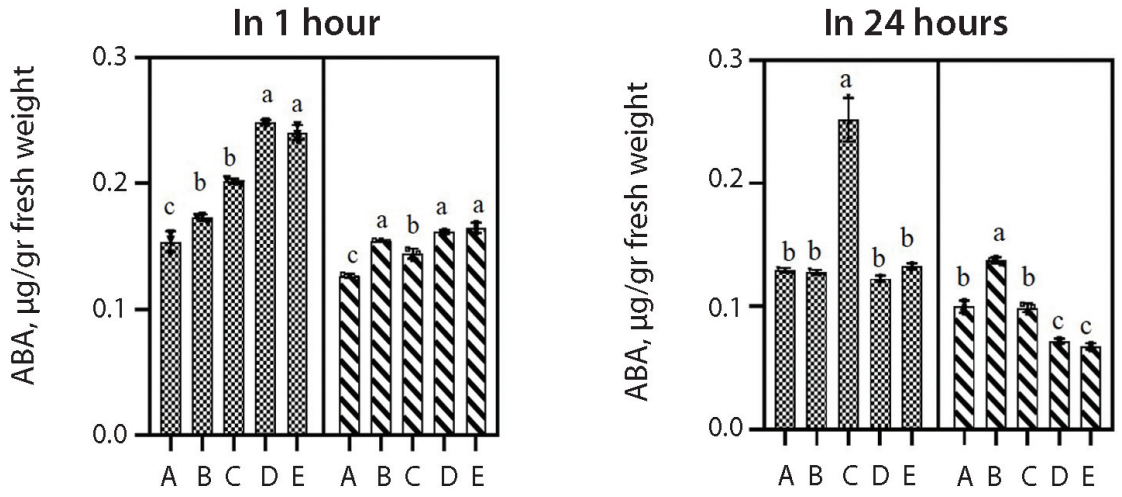


Figure 4. Effect of exogenous ABA on concentration of endogenous abscisic acid in cotton seedlings under conditions of NaCl salinity for 1h and 24 h.

Note: ▩ - salt-tolerant Gulistan cotton cultivar; ◥ - salt- sensitive C-4727 cotton cultivar; A: Control; B: 1% NaCl; C: 1% NaCl + ABA; D: 4% NaCl; E: 4% NaCl + ABA. Means with the same letter(s) on top of the columns do not differ significantly.

exposure to 4% NaCl, the ABA concentration increased by 61.7% on average. Prolonged exposure of plants to salinization reduced their survival and the level of endogenous ABA, especially at higher concentrations of salts. The resistance of cotton to the short-term effect of chloride salinization is associated with an increased level of ABA. It should be emphasized that the accumulation of endogenous ABA in cotton seedlings under salinization with low concentrations of salt was temporary, starting to decline with the increase in salt concentration. The exposure of plants to high salt stresses is known to rapidly induce a proportional increase in the endogenous level of ABA (Kang *et al*., 2005) and the expression of its biosynthetic genes in the plant. The elevated endogenous ABA helps plants to acclimate under lower water availability by closing stomata and accumulating numerous proteins and osmoprotectants for an osmotic adjustment (Hojin Ryu and Yong-Gu Cho, 2015). Talanova *et al*., 1994 demonstrated that in plants grown in saline soil endogenous ABA manifests itself either as a factor that triggers the formation of increased resistance or as one of the direct participants providing an increase in resistance in the first hours of exposure to this factor.

Conclusions

Our work demonstrated significant differences in the response of sensitive and resistant cotton cultivars to salt stress, which are closely associated with differences in the activity of antioxidant enzymes and the concentrations of MDA. The resistance of cotton cultivars to salinity is associated with the high efficiency of the enzymatic system for neutralizing the reactive oxygen intermediates, thus increasing the oxidation-reduction homeostasis and the preservation of the cell components. The introduction of exogenous ABA can change the intensity of LPO as well as the activity of antioxidant enzymes in cotton, making a possible decrease of lipid peroxidation, depending on the sensitivity of the cultivars, the salinity levels and the exposure. Overall, our results indicate an important role of ABA in tolerance to salt stresses and provide new insights into the possible biochemical mechanism of enhanced salt tolerance.

Authors express their deep gratitude to senior researchers of the Laboratory of Chemistry of Proteins and Peptides, Institute of Bioorganic Chemistry, Uzbekistan Academy of Sciences.

© Benaki Phytopathological Institute

We thank Ishimov U.J., PhD in chemistry, for his assistance in ABA measurements.

Conflict of Interest

The authors declare that they have no conflict of interest.

Literature Cited

Ahmad, P., Jaleel, C.A., Salem, M.A., Nabi, G. and Sharma, S. 2010. Roles of enzymatic and non-enzymatic antioxidants in plants during abiotic stress. *Critical Reviews in Biotechnology*, 30: 161-175.

Akhmedov, D.Kh., Jabborov, J.S. and Mannopov R.S. 2022. IOP Conf. Ser.: *Earth Environmental Science* 1068 012027.

Babaeva, D., Esanov, R., Akhunov, A., Gafurov, M., Khashimova, N. and Matchanov, A. 2020. Biological activity of the supramolecular complex of glycyrrhizic and salicylic acids. *Chemistry of Natural Compounds*, 56: 278-281.

Bakhsh, I., Awan, I., Sadiq, M., Niamatullah, M., Zaman, Ku. and Aftab, M. 2011. Effect of plant growth regulator application at different growth stages on the economical yield potential of coarse rice *Oryza Sativa* L. *Journal of Animal and Plant Science,* 21: 612-616.

Bates, L.S., Waldren, R.P. and Teare, I.D. 1973. Rapid Determination of free proline for water stress studies. *Plant and Soil*, 39: 205-207.

Benavides, M.P., Marconi, P.L., Gallego, S.M., Comba, M.E. and Tomaro, M.L. 2000. Relationship between antioxidant defence systems and salt-tolerance in *Solanum tuberosum*. *Journal Australian Journal of Plant Physiology*, 27: 273-278.

Desingh, R. and Kanagaraj, G. 2007. Influence of salinity stress on photosynthesis and antioxidative systems in two cotton varieties. Journal General and Applied Plant Physiology, 33: 221-234.

Chawla, S., Jain, S. and Jain, V. 2012. Salinity induced oxidative stress and antioxidant system in salt-tolerant and salt-sensitive cultivars of rice (*Oryza sativa* L.). *Journal Plant Biochemistry and Biotechnology,* 22: 27-34.

Ghorbani, A., Razavi, S.M., Omran, V.O.G. and Pirdashti, H. 2018. *Piriformospora indica* inoculation alleviates the adverse effect of NaCl stress on growth, gas exchange and chlorophyll fluorescence in tomato (*Solanum lycopersicum* L.). *Journal of Plant Biology*, 20: 729-736.

Ghorbani, A., Razavi, S.M., Omran, V.O.G. and Pirdashti, H. 2018. *Piriformospora indica* alleviates salinity by boosting redox poise and antioxidative potential of tomato. *Russian Journal Plant Physiology,* 65: 898-907.

Ghorbani, A., Omran, V.O.G., Razavi, S.M., Pirdashti, H. and Ranjbar, M. 2019. *Piriformospora indica* confers salinity tolerance on tomato (*Lycopersicon esculentum* Mill.) through amelioration of nutrient accumulation, K^+/Na^+ homeostasis and water status. *Plant Cell Reports,* 38: 1151-1163.

Giannopolitis, N. and Ries, S.K. 1977. Superoxide dismutase. I. Occurrence in higher plants. *Plant Physiology,* 59: 309-314.

Greenway, H. and Munns, R. 1980. Mechanisms of salt tolerance in nonhalophytes. *Annual Review of Plant Physiology*, 31: 149-190.

Hassine, A.B. and Lutts, S. 2010. Differential responses of saltbush *Atriplex halimus* L. exposed to salinity and water stress in relation to senescing hormones abscisic acid and ethylene. *Journal of Plant Physiology*, 167: 1448-1456.

Heidari, M. and Mesri, F. 2008. Salinity effects on compatible solutes, antioxidants enzymes and ion content in three wheat cultivars. *Pakistan Journal of Biological Sciences,* 11: 1385-1389.

Hojin, R., and Yong, G.Ch. 2015. Plant hormones in salt stress tolerance. *Journal Plant Biology*, 58: 147-155.

Iqbal, M., Ashraf, M, Jamil, A. and Rehman, S. 2006. Does seed priming induce changes in the levels of some endogenous plant hormones in hexaploid wheat plants under salt stress. *Journal of Integrative Plant Biology,* 48: 181-189.

Jaleel, C.A. 2009. Soil salinity regimes alters antioxidant enzyme activities in two varieties of *Catharanthus roseus*. *Journal of the Botanical Research Institute of Texas*, 2: 64-68.

Kang, D., Seo, Y., Lee, J.D., Ishii, R., Kim, K.U., Shin, D.H., Park, S.K. and Lee, I. 2005. Jasmonic Acid differentially affects growth, ion uptake and abscisic acid concentration in salt-tolerant and salt-sensitive rice cultivars. *Journal of Agronomy and Crop Science*, vol. 191: 273–282.

Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. 1951. Protein measurement with folin phenol reagent. *Journal Biological Chemistry*, 193: 265-275.

Mandhania, S., Madan, S. and Sawhney, V. 2006. Antioxidant defense mechanism under salt stress in wheat seedlings. *Journal Biologia Plantarum*, 50: 227-231.

Meloni, D.A., Oliva, M.A., Martinez, C.A. and Cambraia, J. 2002. Photosynthesis and activity of superoxide dismutase and glutathione reductase in cotton under salt stress. *Journal of Environmental and Experimental Botany*, 49: 69-76.

Meneguzzo, S., Navari-Izzo, F. and Izzo, R. 1999. Antioxidative responses of shoots and roots of wheat to increasing NaCl concentration. *Journal of Plant Physiology*, 155: 274-280.

Miguel, A.T., Jonathan, D.G. and Jeffery, L. D. 2006. Reactive oxygen species signaling in response

© Benaki Phytopathological Institute

to pathogens. *Journal Plant Physiology*, 141: 373–378.

Mittal, S., Kumari, N. and Sharma, V. 2012. Differential response of salt stress on *Brassica juncea* photosynthetic performance, pigment, proline D1 and antioxidant enzymes. *Journal Plant Physiology Biochemistry*, 54: 17-26.

Mitteler, R. 2002. Oxidative stress, antioxidants and stress tolerance. *Journal Trends in Plant Science*, 7: 405-410.

Moran, J.F., Becana, M., Iturbe-Ormaetxe, I., Frechilla, S., Klucas, P. and Aparicio-Tejo, R.V. 1994. Drought induced oxidative stress in pea plants, *Journal Planta*, 194: 346-352.

Munns, R. 2005. Genes and salt tolerance: bringing them together. *Journal New Phytologist*. 167: 645-663.

Nakano, Y. and Asada, K. 1981. Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. *Plant Cell Physiology*, 22: 867-880.

Nikolaeva, M.K., Maevskaya, S.N. and Voronin, P.Y. 2015. The activity of antioxidant and osmoprotective systems and photosynthetic gas exchange of seedlings of corn under drought conditions. *Plant Physiology*, 62: 340-348.

Omran, V.O.G., Ghorbani, A. and Otaghsara, S.A. 2021. Melatonin alleviates NaCl-induced damage by regulating ionic homeostasis, antioxidant system, redox homeostasis, and expression of steviol glycosides-related biosynthetic genes in *in vitro* cultured *Stevia rebaudiana* Bertoni. *In Vitro Cellular and Developmental Biology – Plant*, 57: 319-331.

Ozgur, R., Uzilday, B., Sekmen, A.H. and Turkan, I. 2013. Reactive oxygen species regulation and antioxidant defence in halophytes. *Journal Functional Plant Biology,* 40: 832-847.

Richardson, M., Valdez-Rodriguez, S. and Blanco-Lahra, A. 1987. A possible function for thaumatin and a TMV-induced protein suggested by homology to a maize inhibitor. *Journal Nature*, 327: 432-438.

Rock, C. and Quatrano, R.S. 1995. The role of hormones during seed development. P. Davies (Ed.), plant hormones, physiology, biochemistry and molecular biology *Dordrecht: Kluwer Academic Publishers,* pp. 671-697.

Rogozhin, V.V., Kurilyuk, T.T. and Kershengolts, B.M. 1998. A method for determining the concentration of malondialdehyde using thiobarbituric acid. *Patent of the Russian Federation* No. 2112241.

Rout, M.P. and Shaw, B.P. 2001. Salt tolerance in aquatic macrophytes: Possible involvement of the antioxidative enzymes. *Journal Plant Science*, 160: 415-423.

Seo, H.S., Kim, S.K., Jang, S.W., Choo, Y.S., Sohn, E.Y. and Lee, I.J. 2005. Effect of jasmonic acid on endogenous gibberellins and abscisic acid in rice under NaCl stress. *Journal Biologia Plantarum*, 49: 447-450.

Silveira, J., Almeida, V. R., De Da Rocha, I., Moreira, A., De Azevedo, M. R. and Oliveira, J.T. 2003. Proline accumulation and glutamine synthetase activity are increased by salt-induced proteolysis in cashew leaves. *Journal Plant Physiology*, 160: 115-123.

Xiong, L., Schumaker, K. and Zhu, J.K. 2002. Cell signaling during cold, drought and salt stress. *Journal Plant Cell*, 14: 165-183.

Talanova, V.V. and Titov, A.F. 1994. Endogenous abscisic acid content in cucumber leaves under the influence of unfavourable temperatures and salinity. *Journal of Experimental Botany*, 45: 1031-1033.

Received: 9 September 2020; Accepted: 1 June 2023

Επιδράσεις του εξωγενούς αμπσισικού οξέος στο αντιοξειδωτικό σύστημα ανθεκτικών και ευαίσθητων στην αλατότητα ποικιλιών βαμβακιού

K.M. Kuldoshova, A.A. Akhunov, N.R. Khashimova και J.F. Ziyavitdinov

Περίληψη Η αλατότητα είναι ένα από τα πιο επιτακτικά προβλήματα παγκοσμίως που επηρεάζουν σε μεγάλο βαθμό την παραγωγικότητα των καλλιεργειών. Η αλατότητα μειώνει την αύξηση και ανάπτυξη των φυτών προκαλώντας ποικίλες καταπονήσεις. Επομένως είναι ζωτικής σημασίας να αποκωδικοποιηθούν αυτοί οι παράγοντες καταπόνησης και να βρεθούν πιθανές λύσεις για τη βελτίωση της γεωργι-

© Benaki Phytopathological Institute

κής παραγωγής. Εντούτοις, δεν έχουν μελετηθεί οι μηχανισμοί προσαρμογής των γλυκοφύτων σε συνθήκες αλατότητας. Η παρούσα μελέτη διενεργήθηκε με σκοπό τον προσδιορισμό των επιδράσεων του εξωγενούς αμπσισικού οξέος (ABA) στην αντοχή φυτών βαμβακιού στην αλατότητα. Διαπιστώθηκαν μερικοί μηχανισμοί ανάπτυξης αντοχής στην αλατότητα σε σπορόφυτα δύο ποικιλιών βαμβακιού, μιας ανθεκτικής (Gulistan) και μιας ευαίσθητης (C-4727) στην αλατότητα. Επιπλέον, συγκρίθηκαν οι αντιοξειδωτικές ιδιότητες αυτών των ποικιλιών. Έγινε προσδιορισμός της δράσης της ασκορβικής υπεροξειδάσης (APX), της δισμουτάσης του υεροξειδίου του υδρογόνου (SOD), καθώς και της ποσότητας του ενδογενούς ABA, της μαλονδιαλδεΰδης (MDA) και της ελεύθερης προλίνης (Pro) στο μάρτυρα και μετά την επέμβαση. Τα αποτελέσματα δείχνουν σημαντικές διαφορές μεταξύ ανθεκτικών και ευαίσθητων στην αλατότητα σποροφύτων βαμβακιού ως απόκριση των φυτών στην καταπόνηση από υψηλή συγκέντρωση αλάτων. Στην ανθεκτική ποικιλία Gulistan διαπιστώθηκαν υψηλότερα επίπεδα Pro και ενδογενούς ABA, αλλά χαμηλότερες συγκεντρώσεις MDA και μεγαλύτερη δραστηριότητα APX και SOD, σε σύγκριση με την ευαίσθητη ποικιλία C-4727.

Hellenic Plant Protection Journal **16:** 40-49, 2023

© Benaki Phytopathological Institute