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Enhancing cotton's resilience to waterlogging and salinity stress with exogenous antioxidants

Alisha Goyal and Anita Kumari
CCS Haryana Agricultural University, Hisar

Abstract: Cotton is classified as moderately salt tolerant crop with salinity threshold level of 7.7 dS m^{-1}. Salinity is a serious threat for cotton growth, yield and fiber quality. The sensitivity to salt and WL stress depends upon growth stage and type of salt. Understanding of cotton response to salinity and WL stress, its resistance mechanism and looking into management techniques may assist in formulating strategies to improve cotton performance under stress condition. The studies have showed that germination, emergence and seedling stages are more sensitive to salinity stress as compared to later stages. Salt & WL stress results in delayed flowering, less fruiting positions, fruit shedding and reduced boll weight which ultimately affect seed cotton yield. It is suggested that future research may be carried out with the combination of conventional and advance molecular technology to develop salt tolerant cultivars.

Introduction:

Cotton is one of the most important fiber and cash crop of India and plays a dominant role in the industrial and agricultural economy of the country. It is the most important fiber crop and is the basic input for textile industry. Its cultivation in our country provides direct livelihood to 6 million farmers and about 40 -50 million people are employed in cotton trade and its processing. In India, cotton is grown in about 9 million ha. Haryana is one among ten major cotton growing states of India. The growth period of cotton generally lasts from May to October/November, which coincides with the monsoon season. During this period rainfall is concentrated, abundant and long-lasting that results in waterlogged conditions leading to yield losses and even total crop failure of the cotton. This causes a substantial loss to local agricultural development and farmer's incomes.

The major abiotic stress factors affecting cotton production are drought, low light, high temperature, waterlogging (WL) and salinity. Waterlogging and salinity are the major stresses which affect the crop productivity. Saline soil is defined in term of electrical conductance of saturated paste extract with soils having electrical conductivity of its saturation extract (ECe) higher than 4 dS m-1. Cotton is moderately salt tolerant crop with salinity threshold level of 7.7 dS m-1 (Zhang et al. 2013). Many other crops vary in their ability to tolerate salinity levels (Table 1). Salt stress disturbs the osmotic and ionic homeostasis at cellular level, inhibits photosynthesis, and reduces the cellular energy and results in redox imbalance. Consequently, inhibited photosynthesis damage the cellular metabolism which leads to abnormal plant growth (Zhang et al. 2016). Abiotic stresses affect the different growth stages of cotton such as germination, emergence, seedling stage, root growth, flowering and ball (Table 2). Flowering and bud formation are the most sensitive growth stages for waterlogging stress and have significant impact on morphological parameters, quality parameters and yield components (Guang *et al.,* 2012, Wang *et al.,* 2017). WL reduces the chlorophyll content as well as the leaf photosynthetic rate of cotton, and biomass accumulation in the cotton bolls (Milroy and Bange, 2013, Kuai et al., 2014; Zhang et al., 2015). WL stress resulted in reduced cotton yield due to lower number of total fruit nodes, decreased boll number and weight, and increased boll abscission and rot rates but the extent of reduction is duration dependent (Bange *et al.*, 2004; Jiang *et al.*, 2013, Wu *et al.*, 2014). WL also reduced quality of cotton fiber by affecting fiber length, specific strength, and uniformity as well as the lint percentage, seed index, and lint index (Bange *et al.*, 2004). For post-disaster recovery, the roots of the cotton recover

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faster than the crown after WL, and the reduction of oxidized roots is faster at the squaring stage compared with the flowering stage (Liu *et al.*, 2015).

Table 1: An overview of important crops regarding their salt and waterlogging tolerance ability

S. No.	Crop	Threshold level of EC (ds m^{-1})	Status	Yield loss (%)	Reference
1	Cotton	7.7	Tolerant	50-90	Khorsandi and Anagholi (2009)
2	Wheat	6	Moderately tolerant	13.4	Mojid et al. (2013)
3	Sorghum	2.8	Moderately sensitive	50	Kafi et al. (2018)
4	rice	2	Moderately sensitive	30-35	Joseph and Mohanan (2013)
5	Maize	1.3	Moderately sensitive	16-22	Katerji et al. (2000. And Sharif et al. (2007)
6	Onion	1.2	Sensitive	50	Sta – Baba et al. (2010)

In Haryana most of soils are saline and there is problem of combined salinity and waterlogging (WL) reported in nine districts of Rohtak, Jhajjar, Bhiwani, Hisar, Sonepat, and some parts of Jind, fatehabad, sirsa and Palwal (CSSRI, 2016 report). Agricultural lands subjected to both stresses are present in many parts of the world such as Australia, USA, Pakistan, India, Iran, Thailand, and Egypt. Combined WL and salinity cause even greater damage to plants, thus having a major negative impact on agricultural production (Barrett-Lennard, 2003; Zheng et al., 2009). The combined effects of salinity and WL are common in saline areas, particularly where shallow saline-water tables exist or where soils are also sodic, reducing water infiltration and causing water to pond on the soil surface (Barrett-Lennard, 2003). Globally, 60-80 million ha of the lands are affected moderately by both WL and salinity (WBCSD, 2014). This may be because of intensive irrigation practices in agriculture (Smedema and Shiati, 2002), rise of saline water tables (Hatton et al., 2003), and seawater invasion in coastal environments (Carter et al., 2006). Agricultural production losses due to water-logging and salinity in India are estimated to be around U$D 28.5 million (ICRISAT Report, 2011).

Table 2: Effects of abiotic stresses during different growth stages of cotton

Growth stage	Reasons	Effect on growth	References
Germination	Less and delayed germination because of reduced vigor index and germination potential	Negative	Guo- Wei et al. (2011)
Emergence	Delayed emergence leads to non-availability of nutrients. Less plant vigor	Negative	Ahmad et al. (2002)

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Seedling stage	Reduction in plant height, leaf expansion, shoot dry weight and net photosynthetic rate	Negative	Ahmad et al. (2002)
Root growth	Reduction in root length and number of secondary roots	Negative	Shaheen et al. (2012)
Flowering and Boll	Delayed onset of flowering, less fruit bearing position	Negative	Peng et al. (2016)

Salinity stress also affects cotton growth, as according to Saleh (2012) salt stress (200 mol m^{-3} NaCl) for 7 weeks resulted in reduction of seedling height, root length, leaf number, leaf area, leaf chlorophyll a and b, osmotic potential, chlorophyll content index (CCI), dry biomass and root/shoot weight ratio in four cotton (*Gossypium hirsutum L.)* varieties. High concentrations of Na^+ causes osmotic imbalance, membrane disorganization, reduction in growth, inhibition of cell division and expansion, which also leads to reduction in photosynthesis and production of reactive oxygen species (Parida and Das, 2005). Zhao *et al.,* (2007) reported that salinity reduced leaf chlorophyll in the oat plant this could be due to the inhibition of the synthesis or increased disintegration of chlorophyll in the leaf. Increased activity of antioxidative enzymes in response to WL has been observed by many researchers like Tang *et al*., (2010) in pigeonpea, under salinity stress Xiaoli *et al*., (2009) in *Hordeum vulgare*, Rios and Pinto, (2014) in *Zea mays* and Kumari *et al., (2017)* in *Cicer arietinum*.

In cotton crop the number of days, depth of WL, growth stage affects the growth and development, physiological metabolism, yield, and quality (Ashraf et al., 2011, Cao et al., 2012; Dodd et al., 2013). Excessive generation of reactive oxygen species (ROS), or oxidative stress, is an integral part of many stress situations, including hypoxia and salinity. These ROS are extremely reactive in nature and induce damage to a number of cellular molecules and metabolites such as proteins, lipids, pigments, DNA etc (Ashraf., 2012). A marked alteration in the endogenous levels of different enzymatic and non-enzymatic antioxidants has been reported under WL stress (Tang et al., 2010)

Only a very few crop species can tolerate the combination of salinity and WL (Bennett *et al*., 2009), and the physiological and molecular mechanisms conferring this tolerance remain elusive. Exogenous application of compound with antioxidant properties could alleviate the toxic effects of abiotic stresses. Exogenous protectants such as osmoprotectants, plant hormones, antioxidants and polyamines have been found effective in mitigating the salt-induced damage in plants (Yusuf *et al.,* 2012). Exogenous application of free radical scavengers by could help in detoxification of stress-induced free radical production (Zhang *et al.,* 2006). Effect of salinity was also found to be alleviated by several compound like Paclobutrozol in wheat (Hajihashemi *et al*., 2009), ascorbic acid in potato (Sajid and Aftab., 2009), mannitol and thiourea *Zea mays* (Kaya *et al*., 2013) when applied exogenously. It is well known that abscisic acid (ABA), ethylene (ET), salicylic acid (SA) and jasmonates (JA) these four kinds of phytohormones play major roles in mediating plant defense response against pathogens and abiotic stresses (Ryu and Cho 2015, Nakashima et al. 2013). Najeeb *et al.* (2016) suggested that 125 [a.i.] ha^{-1} of aminoethoxyvinylglycine (AVG) applied 24 h before WL as the best rate for mediating the negative effects of WL on cotton growth and yield. Increased growth and recovery of AVG-treated cotton plants could be a result of inhibited ACC biosynthesis in root tissues. AVG increased cotton lint yield by blocking ethylene-induced fruit abscission in the shoot.

Exogenous application free radical scavengers like antioxidants (SNP-nitric oxide donor and Ascorbic acid) could help in detoxification of stress induced oxidative stress. These antioxidants set a balance between generation and scavenging of free radicals and helps plant survival under stress

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conditions. The role of exogenous application of antioxidants in mitigation of stress will be studied. Cotton production has significant contribution towards economy and an erratic cotton output trend may offset lint-fabric continuum and may upset our exim policies. However, further studies are needed to elucidate the mechanism involved in cotton growth and yield improvement.

Conclusion:

Globally, combination of salinity and water logging are the serious problem for ensuring food security as more than half of countries are facing this problem. Salt stress imposes specific ions toxicity, somatically induced water stress and nutrients imbalance which impart adverse effects on plant growth, development and ultimately crop establishment. Salt stress affects the metabolic activities of enzymes, impairs nutrients uptake and results into nutritional disorders which leads to yield reduction and fiber quality deterioration. Waterlogging reduces nutrient availability, O_2 diffusion and cellular respiration, which influence plant water relations and impair biomass gain. Yield losses are greatly exacerbated by developmental effects of waterlogging, including ethylene-induced abscission of flowers. Development of salt and waterlogging tolerant cotton cultivars offer the cost-effective management strategy against salt and waterlogging stress in cotton.

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