Int. J. Biosci. 2018

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 12, No. 1, p. 374-384, 2018

INNSPUB

REVIEW PAPER

OPEN ACCESS

Exogenous applications of plant hormones make wheat (*Triticum aestivum*) withstand the attack of salinity stress

Muzafar Iqbal*, Muhammad Nadeem, Saima Jamil, Maqbool Ahmed, Tahira Altaf

Department of Life Sciences, The Islamia University of Bahawalpur, Pakistan

Key words: Keywords. Wheat, Auxins, Gibberellic acid, Salicylic acid, Cytokinins, Ethylene, Abscisic acid, Brassinosteroids, Methyl-jasmonate, Strigolactones.

http://dx.doi.org/10.12692/ijb/12.1.374-384

Abstract

Plant hormones are fundamental chemical messengers synthesized within the plants which mediate their growth and development, and also response to environmental factors. Salinity is an adverse abiotic stress that distresses the hormonal balance of plant. Consequently, these hormonal vacillations in plants adjust the cellular metabolic processes and therefore, plant hormones play a critical role in mitigating salinity-induced detrimental effects. We give an update about the role of multiple plant hormones (auxins, gibberellic acid, salicylic acid, cytokinins, ethylene, abscisic acid, brassinosteroids, methyl-jasmonate and strigolactones) to ameliorate salinity stress in wheat reap. To the best of authors' awareness, this is first, merged, constructive review available about plant hormones role on wheat's characteristics under salinity stress.

* **Corresponding Author:** Muzafar Iqbal ✉ botany618@gmail.com

Introduction

Soil salinity or salinization is generally referred as the addition of soluble salts into soils (Bockheim and Gennadiyev, 2000). The most broadly conventional explanation of soil salinization is from FAO (1996) as soil which has an ECc of 4 dS m-1 or greater and soil with ECc's beyond 15 dS m-1 are measured as strongly saline. It is mainly privileged in arid as well as semi-arid environments with evapo-transpiration degrees being higher compared with precipitations volume through the year. Salts in soils may increase naturally in the subsoil (primary soil salinity) or perhaps it be introduced due to anthropogenic (secondary soil salinity) (Carillo *et al.*, 2011). Naturally, greater parts of the soils salinity are developed by geological, pedological and hydrological processes (Wanjogu *et al.*, 2001). Some of the parent materials of such soils comprise intermediary igneous rocks (Phenolytes, basalt, sandstones, lagoonal and alluvium) deposits. Another sort of salinity happens in coastal areas exposured to tides (Cyrus *et al.*, 1997). Anthropogenically, it could be arise by soil modifications, fertilizers and irrigation by means of saline water (Yadav *et al.*, 2011). Salinity is one among the most common abiotic stresses which tremendously decrease the productivity of agricultural crops in arid and semi-arid regions of the world (Hussain *et al.*, 2010). It occupies a prominent place among the soil problems throughout the world that threatens the sustainability of agricultural crops over a vast area (Flowers, 2004). According to report of FAO Land and plant nutrition service (2008), total cultivated area of world contaminated with salts is 12781 million hectares (Table 1).

Table 1. Variation in soil salinization levels in the world.

Regions	Total area	Saline soils	Percent	Sodic soils	Percent
Africa	1899.1	38.7	2.0	33.5	1.8
Asia and the pacific and Australia	3107.2	195.1	6.3	248.6	8.0
Europe	2010.8	6.7	0.3	72.7	3.6
Latin America	2038.6	60.5	3.0	50.9	2.5
Near East	1801.9	91.5	5.1	14.1	0.8
North America	1923.7	4.6	0.2	14.5	0.8
Total	12781.3	397.1	3.1%	434.3	3.4%

Note: Area reported is in million hectares (Mha).

Source: FAO Land and Plant Nutrition Service, 2008.

Triticum aestivum (wheat) is the most important cereal reap of world and is cultivated all-over the world. Wheat is cultivated to rally the demands of food for population consumptions in USA, Pakistan, china and others countries of world. However, per hectare productivity of wheat is so far lower as its production potential that is due to different factors and soil salinity is the most important one (Khan *et al.*, 2006). Salinity stress detrimentally influences the various characteristics (Germination, morphological, physiological and biochemical) of wheat (Fig. 1). It is one of the major problem affecting plant's seedlings growth and development and finally their productivity. Saline conditions increase the time (Days) for seed germination, progressively increase the time to sprouting and decline the sprouting percentage in difference wheat cultivars (Begum *et al.*, 1992; Sairam *et al.*, 2002; Akbari *et al.,* 2007).

Moreover, it badly distresses morphological characteristics at all stages of growth under saline conditions which include leaf (shape, size, area, expansion, senescence, pubescence, cuticle tolerance and waxiness), root (length, root hairs, root area, fresh and dry weight, density) and vegetative (Plant height, diameter and fresh and dry biomass) of wheat (Kingsbury *et al.*, 1984; Rawson *et al.*, 1988; Munns *et al.*, 1995; Ahmad *et al.*, 2013). Salinity stress also interrupts wheat's physiology at both cellular and whole plant levels by developing osmotic and ionic stress. Physiological processes which are harshly affected by salt stress comprise of alteration in plant development, mineral distribution, and membrane variability resulting from calcium dislocation by sodium and membrane permeability (Moud *et al.*, 2008; Mehta *et al.*, 2010).

Wheat plants exposure to salinity increases the formation of reactive oxygen species (ROS) (Sairam *et al.*, 2002; Wimmer *et al.*, 2003; Wahid *et al.*, 2007). It reduces the biological activity of antioxidant enzymes (superoxide dismutase (SOD), glutathione reductase (GR), glutathione synthetase and ascorbate peroxidase (APX), total soluble sugars and total proteins (Sairam *et al.*, 2002; Temel *et al.*, 2015).

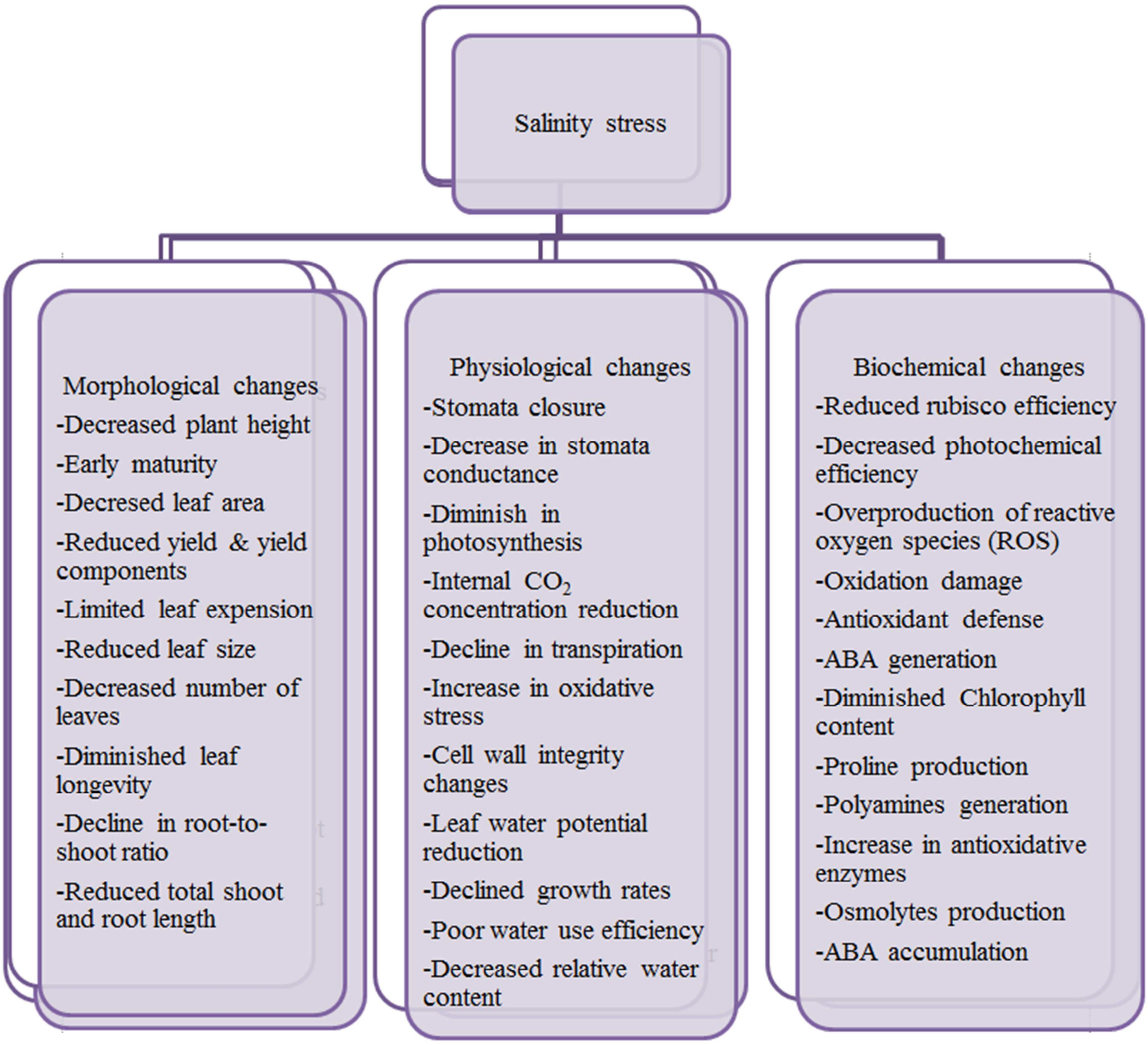

Fig. 1. Research scenario of wheat characteristics under salinity stress. (Source . Begum *et al.*, 1992; Sairam *et al.*, 2002; Akbari *et al.,* 2007; Moud *et al.*, 2008; Mehta *et al.*, 2010; Ahmad *et al.*, 2013; Temel *et al.,* 2015).

Role of plant hormones in salinity tolerance

Plant hormones like auxins, gibberellic acid, salicylic acid, cytokinins, ethylene, abscisic acid, brassinosteroids, methyl-jasmonate and strigolactones have been revealed not only to regulate wheat growth and development, but also to save from damages of salinity stress.

Auxins

Auxins play a significant role and facilitate wheat plants to grow promoting the apical meristems formation and root differentiation (Iqbal *et al.,* 2006; Egamberdieva, 2009). Several studies reported the overcoming role of auxin against salinity stress (Irfan *et al.,* 2005; Iqbal *et al.,* 2007). Salinity stress influences indole-3-acetic acid (3-IAA) homeostasis in wheat plants due to the shifts in 3-IAA distribution and metabolism (Qiao *et al.,* 2015).

TaARGOS and TaARGOS-D transcripts were notably induced through salinity stress and incorporated auxin function into salinity stress through seed germination, thus modulating germination and seedlings growth under elevated salinity (Zhao *et al.,* 2017). Foliar-spray of auxin counteracted the growth limitations induced by salinity stress in wheat and enhanced growth and yield characteristics of wheat seedlings (Agami *et al.,* 2013). The exogenous applications of auxin proficiently regulate the osmotic potential and play a vital role in sustaining wheat growth under osmotic stress (Ivanov, 2009). A considerable reduction in 3-IAA concentration in the roots of wheat plants under salinity stress and exogenous auxin applications enhanced various growth characteristics was accounted by Sakhabutdinova *et al.* (2003). Furthermore, exogenously applied auxin improves wheat's morphological (plant height, root length, number of leaves, leaf area, root hairs count) and physiological (water relations, Stomatal conductance, photosynthesis and chlorophyll content) attributes under salinity stress and thus, increases yield and yield components (Gulnaz *et al.,* 1999; Aldesuquy, 2000; Afzal *et al.*, 2005). Biochemical and molecular characteristics such as total sugars, total protein, total antioxidants, SOD, GR and APX activity and Cu/Zn-SOD and Mn-SOD genes enhanced functions to tolerate salinity are also reported by Sairam *et al.* (2002), AM (2011) and Barakat *et al.* (2013).

Gibberellic acid

Gibberellic acid (GA) is the plant hormone which plays critical roles in growth as well as metabolism of wheat plants particularly cell elongation (Sastry and Shekhawa, 2001). A fundamental function for the GA in response to salt-stress has become progressively more evident and drop in GA content and signaling mechanism has been revealed to correlate to the plant growth and development under salt stress (Ashraf *et al.,* 2002; Irfan *et al.,* 2005). Gibberellic acid abridges salinity-induced toxic and growth inhibiting effects in a wheat system by triggering ions and hormonal homeostasis (Iqbal *et al.,* 2013). GA- induced priming increased in yield and yield components of two wheat cultivars (Grieve *et al.,* 1992; Iqbal *et al.,* 2013). This raise in yield is accredited to the GA-induced priming modulation of ions uptake and partitioning under salinity-stressed conditions.

Morphological and physiological traits such as plant height, fresh and dry weights of shoots and roots, leaf area, osmotic potential and rate of photosynthesis were reduced with rising salt concentrations, but GA treatment induced a significant alleviating effect in wheat on account to these growth characteristics (Ashraf et al., 2002; Colebrook et al., 2014; Fahad *et al.,* 2015).

Wheat crop exposures to the adverse environmental condition such as salinity stress increases the formation of reactive oxygen species (ROS) (Sairam *et al.*, 2002; Wimmer *et al.*, 2003; Wahid *et al.*, 2007). Generally ROS are produced in thalakaloid, mitochondria and peroxisomes during photosynthetic process, electron transport chain and glyoxylate cycle respectively (Reddy *et al.*, 2004, Moller, 2001, Fazeli *et al.*, 2007). The plants have enzymatic mechanisms intended for scavenging of salinity-induced ROS. The enzymatic systems are established to curtail the meditation of ROS. So far, the enzymes which are overproduced comprise of superoxide dismutase (SOD), glutathione reductase (GR), glutathione synthetase and ascorbate peroxidase (APX). Increase SOD, GR and APX activities under salinity stress and relatively higher activity in salinity-tolerant wheat varieties have also been accounted by Sairam *et al.*, (2002). Furthermore, studies by Sairam and Srivastava (2002), Manjili *et al.* (2012) exhibited that salinity-stress declined the catalase, carboxylase, rubisco, but increased superoxide dismutase and peroxidase activities and proline concentration, while, GA caused significant increased in rubisco and carboxylase activities and resulted in improved growth and yield.

Salicylic acid

Salicylic acid (SA) is a pivotal plant hormone and acts as endogenous signaling molecule which is conscientious for stirring up salinity-tolerance in plants (Arfan *et al.,* 2007; Ashraf *et al.,* 2010). SA plays a key role in the regulation of wheat plants growth, development and resistance responses against salinity stress (AM, 2011; Hasanuzzaman *et al.,* 2014). It was found that SA is not necessary for seed germination in normal sowing environments, though, it plays a significant role in promoting seed germination in a wheat system under elevated salinity by means of retarding oxidative damages (Miura and Tada, 2014). Exogenous SA applications led to improved growth and increased salt-tolerance in seedlings of wheat (Afzal *et al.,* 2006). When wheat cultivars grown in salinity-induced conditions were foliar-spray of SA, it alleviated the depressing shocks of salinity stress through increasing phosphorous, nitrogen potassium (P, N, K) and Ca2+ ions content, also improved the photosynthesis, antioxidant enzymes activities, glutathione content and yield as well as yield components (Li *et al.,* 2010; Manjili *et al.,* 2012; Barakat *et al.,* 2013). Agami *et al.* (2013) reported that exogenous appliance of SA allayed the harmful effects of salinity stress in wheat plants and better the physiological and molecular processes allied with plant growth and expansion. Similarly, supplementation of SA also improved the biochemical characteristics (total soluble sugar, proline content and Antioxidants activity) of wheat subjected to elevated salinity stress (Chetana *et al.*, 2014). Ameliorative results of SA in extenuating the phytotoxicity of salt-stress in wheat plants by regulating the growth attributes, photosynthetic pigments content, relative water content, proline, electrolyte leakage and antioxidatant enzymes activities were observed (Al-Whaibi *et al.*, 2012; Siddiqui *et al.,* 2013).

Cytokinins

Cytokinins (Cks) are the endogenously produced plant hormones which regulate growth and development of plant. Cks play salient functions in plant through triggering cell division and expansion. CKs have been premeditated extensively for their applications in alleviating abiotic stresses attacks. The well-designed investigations with CKs-deficit plants to make available evidences that CKs depressingly adjust salinity stress signaling have been reported. Cks play a pivotal role on plant growth and establishment processes such as cell division, apical dominance, nutrients uptake, chlorophyll biosynthesis, shoot, leaf and vascular differentiation, leaf senescence and photomorphogenic improvement (Jameson *et al.*, 1982, Hare *et al.,* 1997; Nishiyama *et al.,* 2011; Fahad *et al.,* 2015). Cks in wheat reap enhance salinity tolerance through interacting with auxin as well as ABA and improve membrane plasticity to for ions homeostasis (Iqbal *et al.* 2006).

In his research, Gadallah (1999) showed that kinetin (A cytokinin) application improved soluble sugar content in salinity stressed wheat plants. Also, early kinetin treatment enhanced chlorophyll pigments content due to which total carbohydrates content was greatly increased. Exogenous Cks applications improved seedling growth, water relations, CO2 assimilation, ions homeostasis (Na+ and Cl−) and grain yield in two wheat cultivars under salinity stress (Iqbal *et al.,* 2005).

Ethylene

Ethylene is an endogenous plant hormone which plays a well-known role in ripening of fruits and senescence (Iqbal *et al.,* 2011; Tao *et al.,* 2015). Ethylene role to alleviate several abiotic stresses is one of prime ongoing investigation. Ethylene application improved salinity tolerance through triggering photosynthetic pigments (chlorophyll a, b and carotenoids), photosystem I and II functions (Fv/Fm), maintenance of K^+ ions and redox status, hence, led to enhanced growth and yield percentage (Wright, 1977; Yang *et al.,* 2006; Arshad and Frankenberger, 2012; Chen *et al.,* 2013). Moreover, literature study revealed that ethylene induced salinity tolerance was mediated by triggering the increase of root growth, osmotically bioactive solutes, soluble sugar and protein content and amino acid in wheat plants (Varty *et al.,*1983; Huang *et al.,* 1997; El-Samad, 2013). Beltrano *et al.* (1994) reported that ethylene produced in wheat during ear development and that application of ethylene hastens the growth process of grains maturation.

Abscisic acid

Abscisic acid (ABA) is a critical plant hormone which was discovered in 1960s for its function in stimulating seed dormancy and leaf abscission (Shafi *et al.*, 2011). Several studies exposed that ABA possesses a main role during several phases of the plant life-cycle, including seed dormancy and development, and intervenes wheat plants responses to salinity stress and it also functions as endogenous signaling molecule responsible for enhancing salinity stress tolerance in plants (Afzal, *et al.,* 2006; Egawa *et al.,* 2006; Yousaf *et al.,* 2011).

ABA has been anticipated to contribute an imperative role in salt-stress responses and plant adjustment. Under elevated salinity, there is a significant and swift accretion of ABA which indeed is critical to plant defensive systems (Sauter *et al.,* 2002). The production and re-distribution of abscisic acid is one among the best responses of wheat plants to salinity stress inducing closure of stomata, thereby dropping off water-loss through transpiration and ultimately controlling cellular growth.

Exogenous application of ABA during the salinity stress stage provoked salt-tolerance in wheat (Agarwal *et al.,* 2005). ABA applications diminished the hydrogen peroxide as well as thiobarbituric acid (reactive substance produced as a measure of lipid peroxidation) contents as compared with un-sprayed plants. ABA increased the antioxidant enzymatic activity and reduced the oxidative stress and reflected in increased in total chlorophyll content, leaf area, relative water content, membrane stability index and total biomass. Furthermore, it also enhances the endurance rate and triggers the osmoprotectants accumulation such as proline which have supporting a role for induction of osmotic adjustment in wheat genotypes (Bakht *et al.,* 2012). Osmotic adjustment is precised an important process in plant adjustment to salinity stress because of maintaining cellular metabolic processes and assists in re-growing upon confiscating the salt-stress (Mutlu & Buzcuk, 2007; Bakht *et al.,* 2011). Consequently, exogenous applications of ABA play a critical role in signals transducing and eliciting the downstream responses in a wheat system.

Brassinosteroids

Brassinosteroids (BRs) are a new kind of plant hormones (polyhydroxy steroidal) with noteworthy growth- improving influence (Vardhini and Anjum, 2015). BRs, 24-epibrassinolide (24-EpiBL), brassinolide (BL), 28-homobrassinolide (28-HomoBL), castasterone (CS) and 24-epicatasterone (24-EpiCS) are generally used. BRs play significant roles to monitor the stress-protecting possessions in plants in opposition to salinity stress (Vardhini, 2014). BRs confer salinity tolerance by diminishing its harmful effects on the physiology and biochemistry of plants (Ashraf *et al.,* 2010). Eleiwa *et al.* (2011) conducted a research and applied 28-HomoBL as foliar-spray and found that 28-HomoBL notably increased not only all the growth attributes, photosynthetic pigments content, but also yield and yield attributes of wheat plants and considerably prevailed over the negative effects of salinity compared with plants grown in normal condition. Foliar application of BRs induced tolerance to salinity stress by shifting stress-responses in wheat plant through improving physiological characteristics (Braun and Wild, 1984). BRs improved the physiological traits (photosynthetic pigments, water relations and CO2 conductance) for improving the tolerance in wheat plants against salinity stress (Abd-El Hamid *et al.,* 2009). Further, the ameliorative effect of 24-EpiBL on two wheat genotypes S-24 (salt-tolerant) and MH-97 (moderately salt-sensitive) in the incidence of NaCl stress was reported (GROWN, 2006). Shahbaz and Ashraf (2007) also reported the improved effects of brassinolides (24-EpiBL) on two wheat cultivars (S-24 and MH-97) established under salinity. BL induced a major increase in growth factors, carbohydrate content, total soluble proteins in shoot and root and the hydrolytic enzymes such as amylase and protease of wheat seedlings developed in saline condition (El-Feky *et al.,* 2014).

Methyl-jasmonate

Methyl-jasmonate (MeJA) or jasmonic acid (JA); a MeJA deesterified acid, is hormone which regulates a broad range of metabolic processes in plants, varying from growth, development and photosynthesis to reproductive enhancement (Wasternack, 2014; Dar *et al.,* 2015; Kazan, 2015). Particularly, jasmonic acid plays crucial roles for plant resistance against responses to poor environmental challenges. Foliar application of JA used for 3 days appreciably improved salt-stress tolerance in wheat plants by lessening the concentration of malondialdehyde (MDA) and Hydrogen peroxide (H_2O_2) and enhanced the activities of antioxidant enzymes (SOD, POD, CAT and APX), that, in turn, improved the growth and development of salinity-stressed seedlings (Qiu *et al.,* 2014).

However, the molecular measures leading to salinity stress in incidence of JA has not until now been well elucidated in wheat plants.

Strigolactones

Strigolactones (SLs) were first secluded from the root exudates of plant and recognized as germination and seedlings growth stimulant (Besserer *et al.,* 2006; Brewer *et al.,* 2013). SLs are produced in two types (Exogenous plant hormone and Root secretion) and play critical role during plant growth and development in changing environment. They are involved in cell expansion, Light capturing process and root growth (Boyer *et al.,* 2014; Al-Babili and Bouwmeester, 2015). Since SLS are still quite unknown plant hormones, their mechanism of action in retortion to salinity stress have been studied primarily through exogenous applications. Seed treatment (pre-sowing) with GR24 (a SLs) showed significant enhanced Co2 assimilation rate and chlorophyll fluorescence in two wheat genotypes (Kausar and Shahbaz, 2017). Strigolactones are suggested to have biological influence on rhizosphere interactions during plant seedling and development. The potential of SLs to mitigate elevated salinity stress is one of the considerable ongoing investigations.

Conclusion

1. Salinity stress adversely interrupts wheat various traits including germination rate, plant height, fresh and dry weight, photosynthetic pigments, total carbohydrates, total proteins and antioxidants content.
2. Plant hormones protect the wheat plants from the attack of salinity stress.
3. Plant hormones when applied exogenously to wheat reap, result in improved growth, development and other physio-biochemical characteristics.
4. Plant hormones scavenge the reactive oxygen species generated due to elevate salt concentration.
5. Exogenous applications of plant hormones mediate water- relations via sustaining cell turgidity under salinity stress.
6. Under salinity stress induced wheat plants, exogenous applied plant hormones enhance antioxidants activities which assist plants to withstand the attack of salinity stress.

Despite the various morpho-physiological and biochemical effects of plant hormones on wheat plants, a good deal of work is still considered necessary for inclusive understanding of their role in plants cellular response to salinity stress. In view of exogenous plant hormones potential as a reactive oxygen species scavenger, plant hormones may overtake a positive tool to counteract the detrimental effects of salinity, thereby improving annual wheat yield.

Acknowledgement

The authors are thankful to Dr. Muhammad Ahsan (Assistant Professor of Horticulture, University College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur) for his inspiration and support during research.

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