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REVIEW PAPER

ROLE OF PHYTOHORMONES AS SALT STRESS MITIGATING AGENTS IN CEREALS

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ABSTRACT

When constant exposure of plants to abiotic stress conditions such as drought, salt stress, high temperature, nutrient deficiency and changing light conditions affects plant development. Phytohormones participate in the regulation of developmental processes in plants under adverse condition. Recent research by many scientists has shown that phytohormones play major role in reducing the negative effects of abiotic stress. Phytohormones are natural products and mostly produced in one part then transported to other plant parts. Phytohormones are also known as growth regulators because they regulate plant growth and development. When plants are exposed to water, temperature and salt stress ultimately plant growth reduces. Plant growth under salt stress condition is hindered due to water shortage or exposure to high ion concentration. Plants employ a different tolerance mechanism which help them withstand salt stress condition and overcome stress effect. Among the different strategies for salt tolerance in different crops, salt tolerant genotype production is one of the best way to enhance plant tolerance for stress. But conventional breeding methods depend on existing genetic variables and is quite expensive and laborious. Recently other mechanisms have been adapted. Plant hormones enhance salt tolerance in crops for crop plants to overcome adverse effects of stress and one of such technique is the extrinsic application of phytohormones. In this article review work related to phytohormones role in salt tolerance from 1990 to 2014 will be discussed in detail along with role of the auxin, cytokinin, gibberellic acid, ABA, brassinosteroid and salicylic acid in alleviation of salt stress effects on crop plants.

KEYWORDS: ABA; auxin; cytokinins; salt stress.

INTRODUCTION

Abiotic stress conditions such as water stress, heat, mineral deficiency, low temperature and salt stress affect plant growth and development. Among all abiotic stress conditions high concentration of salt, adversely affect seed

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germination, DNA, RNA, protein synthesis enzyme activity and seedling growth (17, 22). Response of crop plant to saline conditions vary from species to species and some plant species have adapted tolerance mechanism to abiotic stress factors (43). Tolerance mechanism is very complex phenomena either at the organ or organelle level and this complexity of tolerance mechanism might be due to the interdependence of various mechanisms at cellular, biochemical, physiological and morphological level (71, 64). Different scientists are trying to develop tolerance mechanisms, but till no cost-effective has been technically recognized which can help crop plants to withstand unfavorable factors. Improvement of stress tolerance mechanism in cereals is an important way to provide foodstuff for the growing population of the world. When scientist are working for improving plant tolerance under stress conditions requires information about biochemical, physiological processes and genes involved in the development of different traits. Recent advances in biotechnology research have provided substantial information about the tolerance mechanism at the molecular level of plants under abiotic stress tolerance.

Plant hormones enhance salt tolerance in crops tolerance mechanism and even different responses at different developmental stages have been reported which are also very important. Osmotic and ionic stress effect appear when plant exposed to salt stress. Osmotic responses to the high salt concentration can be observed instantly and severely inhibit the cell growth and development. When plants are exposed high salt for a long time its results in ionic stress to plants. Exposure of Crop plant to high ion concentration, promote the death of leaves as a result, photosynthesis rate decline (14). In soil high concentration sodium and chloride affect protein, DNA and RNA synthesis. Plants exposed to salinity adapt various tolerance mechanisms such as; plants may eliminate salt from their cells, compartmentalize salts at the organ and organelle level and osmotic adjustment (71). Recent research has shown that, mostly adapted tolerance mechanism involves the production of osmolytes and these compounds are highly soluble, have low molecular weight and are nontoxic at high cellular concentrations. Growth regulators are responsible for the plant cell division, cell expansion. Recently, scientists are using phytohormones to overcome harmful impacts of high salt concentration on plant development (55). At present scientist demonstrate oppressive consequence of salt stress on seedling growth and plant development related to an endogenous concentration of plant growth regulators. Endogenous level of phytohormones decreases under stress exposure. ABA (Abscisic acid) concentration increases under saline condition, but auxin, salicylic acid decrease in reaction to salt stress. Scientist applied exogenous auxins, gibberellins and cytokinins and it helped overcome the harmful impacts of high salt concentration and also recuperated plant cell division, expansion and seed germination (20). Result of Gomez *et al.*, (25) is depicted that in crop plants if ABA is applied exogenously, it decreases ethylene production as well as foliar demage. High salt levels in the soil cause adverse effect on seed germination of wheat, though the negative impact of high salt was lessened through soaking.

Plant hormones enhance salt tolerance in crops seed with IAA. Egamberdieva (20) explained that if wheat seedlings were exposed to a high salt level, root and shoot length increased considerably due to auxin applied exogenously. Zahir *et al.* (69) results showed that rice plant development is enhanced when CKs is applied in salt stress. In this review paper focus to discuss the role of phytohormones as mitigating agent and this tolerance mechanism helps plants to withstand stress.

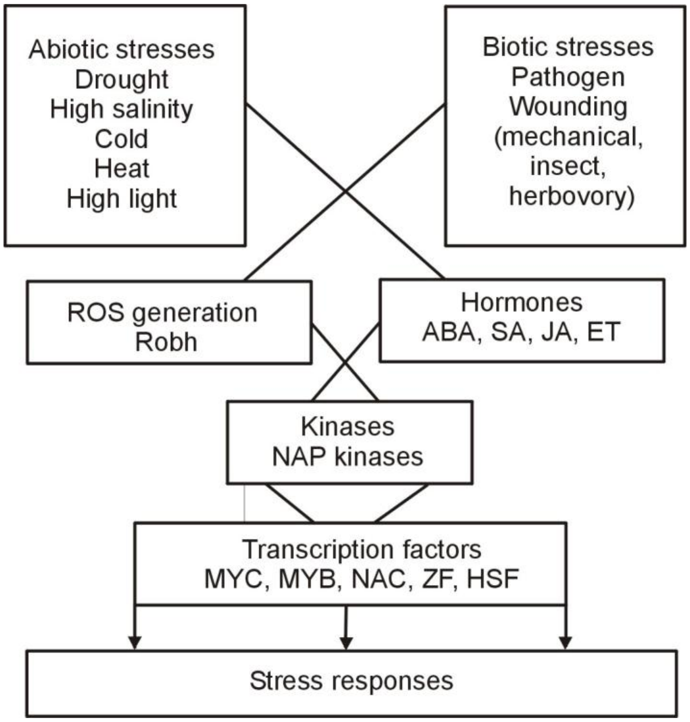
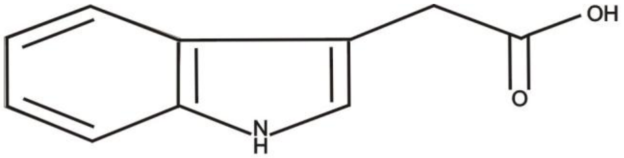


Fig. 1. A generalized model for phytoharmone production in plants, when plants exposed to stress condition (Fujita *et al.*, (24).

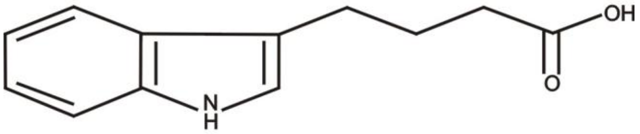
Auxin (IAA)

IAA is responsible to promote plant growth and development. In plants, auxin mainly regulates cell elongation, development of vascular tissue and apical dominance.

Plant hormones enhance salt tolerance in crops abiotic stress conditions in crop plants, but limited knowledge is available about stress condition and auxin level relationship. IAA concentration shows variability under stress conditions and reduction in plant growth is due to distortion in hormonal level (67). So, external application of the phytohormones provides a striking mechanism to overcome the stress effect. High sodium chloride concentration considerably reduces the auxin level in rice plants and it was found that GA3 application overcomes the adverse effects of salinity on auxin. Scientist explained that high salt concentration affect plant hormones and in rice seedlings IAA concentration decreased after sodium chloride application (49, 51). Externally applied auxin showed positive effect on shoot growth, shoot weight and seedling weight of wheat varieties exposed to salt stress (5). Wheat seeds priming with Auxin helped in overcoming the growth inhibiting effect of salinity (3, 58). Gulnaz *et al.* (27) showed that wheat seed germination slowed down when salinity level increased, but the negative impact of salt was overcome by IAA application.



Indole-3-acetic acid (IAA)



Indole-3-butyric acid (IBA)

Fig. 2. IAA structure

If we study at molecular level IAA regulates expression of genes which are known as primary auxin response genes. Hagen and Guilfoyle (35) stated that in Arabidopsis a huge number of ARG (auxin responsive genes) have been recognized and characterized. IAA activated genes are categorized into three groups, such as Aux/IAA, GH3 and small auxin-up RNA (SAUR) gene families. In *Oryza sativa* L. auxin inhibits tiller formation and cytokine biosynthesis by down regulating OsIPT expression (44). A novel gene playing main role in the salinity response identification provides information to the scientist for further genetic engineering strategies (71).

Gibberellic acid (GA)

Gibberellic acid generally regulates seedling growth, cell expansion, stem growth and flower formation. Zhu *et al.* (71) identified gibberelin homeostasis and metabolism in which EUI gene encodes a cytochrome P450 monooxygenase, epoxidizes GA1 and GA4. Findings by different scientists suggest that there is a link among GA production and abiotic stress effects on plant development. Recent studies showed that the destabilization of DELLA protein is promoted by gibberellic acid, but is altered by the high salt concentration and light. GA also regulates other plant hormone signaling (50, 45) and environmental and plant internal stimuli regulate synthesis of Gibberellic acid (6). In biotic and abiotic stress condition GA accumulates rapidly in plants and overcome the lethal effects of high salt in soil. In wheat and rice grown under saline conditions GA3 has been considered helpful in removal of harmful impacts of salt stress (31, 51). Seed germination, plant growth and grain yield declined with increasing salt concentration, but plant growth relatively increased when seed priming with GA3 was done. Iqbal and Ashraf (36) reported that wheat seed priming with GA3 increase yield.

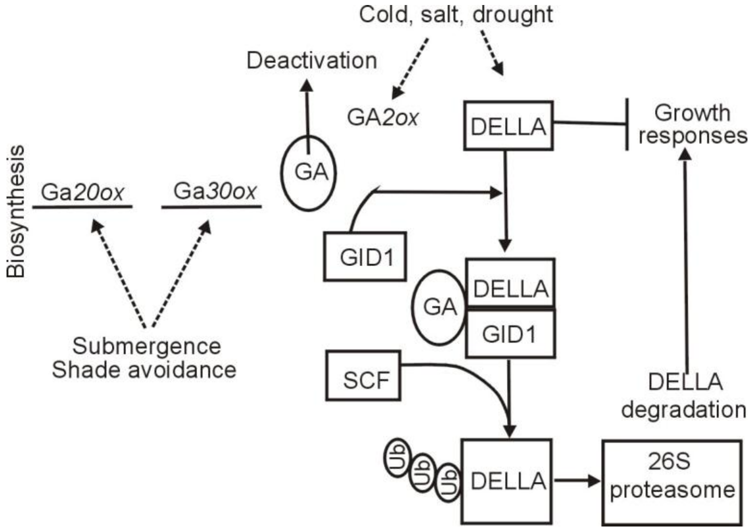


Fig. 3. GA production in response to stress conditions.

Plant hormones enhance salt tolerance in crops uptake and compartmentalization of ions within plant parts. Another scientist also reported that wheat seed treatment with different phytohormones including Gibberellins showed increased rates of germination. Salt stress caused oxidative stress, lipid peroxidation but Gibberellic acid can overcome the effects of free radicals. Gibberellins external application could recover crop plant growth under saline condition and Gibberellins can work with other plant growth regulators to enhance metabolic processes in plants (39). A scientist recently discovered that the GA biosynthesis increased by auxin and when GA was exogenusly applied Gonai *et al.* (28) observed increase in catabolism of ABA. How GA3 priming help overcome the effect of high salt in plants is not yet clear.

Cytokinins (CKs)

Various aspects of plant growth are regulated by cytokinins such as chloroplast formation, vascular bundle differentiation, pigment formation mainly anthcyanin, nutrient accumulation and cell division. CKs can also increase resistance in plants to salinity and high temperature and CKs seed priming increases plant salt tolerance (19, 52). Cytokinin in wheat enhance salt tolerance by interacting with auxins and ABA and increase membrane stability for mono and divalent ions (37). Hare *et al.* (32) explained that CKs supply, reduces from the root during stress condition that could alter shoot gene expression and elicits suitable responses that helps plants to tolerate stress. Kinetin application can help break dormancy of barley and cotton seeds which has been induced due to stress conditions. A number of scientists observed reductions in endogenous levels of CKs under stress conditions and this prospect shows that CKs concentration is a restraining factor under stress. In salt sensitive crop plants CKs are not acting as ameliorating agent. Cks are formed on the growing root tips, developing seeds of crop plants and transported to shoot through xylem where they activate plant growth and aging mechanism (69). Rice yield and yield components increased in response to the cytokinin application (Mathew and Rayan, (47) and when CKs applied in a *Oryza sativa* field an increase of 45.8 percent rice yield was observed (69). When wheat seedlings are exposed to a high salt level, the external application of kinetin helps overcome harmful impacts of high salt level (1) and the addition of benzyl adenine reduces growth of barley salt sensitive varieties during stress condition but increases CKs level in salt tolerant varieties. Chakrabarti and Mukherji (16) stated that kinetin may also involve in anti-oxidative processes and gene’s potential to be involved in stress mechanism is observed for changes in the transcript product in response to adverse condition.

Plant hormones enhance salt tolerance in crops stress. CRE1/AHK4 cytokinin dependence was studied by cytokinin receptor mutant analysis and it showed that in arabidopsis all three cytokinin receptors act as negative regulators (65). Merchan *et al.*, (48) demonstrate that CKs gene receptor is active when changes occur in the osmotic conditions even though the mechanism is not well implicit.

Abscisic acid

Abscisic acid (ABA) is known as stress signal and major functions of ABA is to regulate plant water relation and helps plants tolerate stress conditions. Abscisic acid plays main role in seed germination, promote stomatal closure, synthesis of storage proteins, leaf senescence and seed dormancy. Scientists suggested that Abscisic acid (ABA) is a fundamental cellular signal that increase the expression of salt and drought responsive genes but still direct relation among stress tolerance and increased levels of ABA is not clear. Swamy and Smith (62) reported that ABA deficient mutants such as ABA1, ABA2 and ABA3 in Arabidopsis, *Zea mays* and ABA mutant in saline condition showed poor growth and development (68). Crop plants exposure to the high salt concentration shows increase in ABA level, which is linked with water potential of leaf and soil (21). Babu *et al.* (13) reported that endogenous levels of ABA increased in leaf tissue of many plants under high salt condition. The increase in ABA level in the leaf xylem is interrelated with reduced leaf conductance and decrease in leaf growth. ABA synthesis is enhanced in lower parts of plants, mainly in roots and is transported in the water conducting tissue xylem under higher salt level and ABA stimulates sodium chloride ion accumulation in vacuoles. ABA production in plants exposed to saline conditions increase xylem water potential and water uptake (23). *Oryza Sativa* tolerance to salt stress was usually improved by ABA application and leaf sodium content reduced (Saeedipour, 2011).

Plant hormones enhance salt tolerance in crops tolerant crop plant varieties than in sensitive varieties. ABA synthesis inhibition has shown opposite effect and *O. sativa* tolerance to saline conditions increased due to application of ABA. Absicic acid was considered to be efficient in decreasing sodium and chloride levels and sodium/potassium ratio and accumulation of soluble sugar content (26).

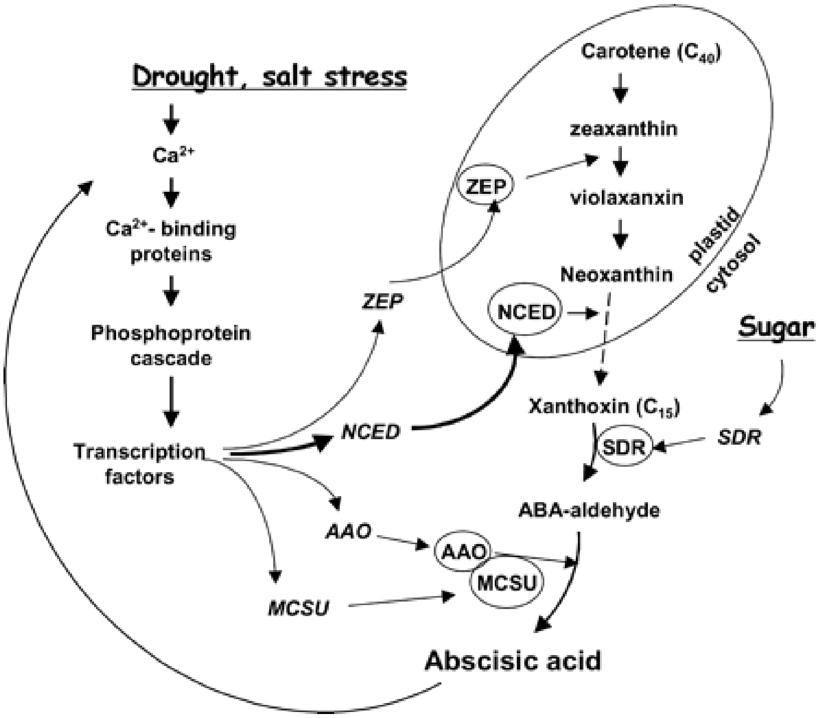


Fig. 4. ABA production in response to abiotic stress conditions.

Brassinosteroids (BRs)

Brassino steroid is a group of plant hormones with considerable capability to promote growth and have pleiotropic effects. Brassinosteroids are drawn in a plant in responses to salinity, drought and heat stress (Bishop and Yokota, (15). In Arabidopsis CPD gene encodes a cytochrome P450 protein that shows resemblance with mammalian steroid hydroxylases. Krishna, (42) observed in his feeding trial that CYP90 acts as C-23 in hydroxylation step. Plant hormones enhance salt tolerance in crops the BRs synthesis. Responses to stress condition regulated by BRs are a multifarious biochemical reaction which may include protein synthesis, activation, suppression of key enzymatic reactions and the production of osmolytes (59). Externally applied BRs in high salt condition is known to enhance plant cell division and expansion. BRs support the number of ears formation, increase length and weight of ears (7, 53). *Oryza sativa* high salt level induced inhibition in seed germination was removed through BRs application and restored photosynthetic activity. In cereals, BRs application promotes nitrogen transport, growth and productivity (12). One leaf segment *Hordeum vulgare* were incubated in BRs solution and another leaf segment was soaked in 0.5 mM sodium chloride with BRs solution. In control conditions BRs had no effect on the leaf cell ultrastructure but the damage through high salt on nuclei and chloroplasts were considerably decreased by the BRs application (42). *Oryza sativa* seeds were soaked in 150 mM sodium chloride and later BRs were added and tested for seed germination and after germination seedling growth parameter. BRs promote growth under high salt concentrations which was connected with increased in concentration of different chemicals such as soluble proteins (9). Number of scientific findings clearly explained that brassinosteroids are capable to overcome the adverse effects of high salt concentration on seed germination, plant growth and yield.

Salicylic acid

Salicylic acid (SA) is a plant hormone which is phenolic nature. SA mainly participates in photosynthesis, nutrient metabolism, flowering and also helps plant overcome adverse biotic and abiotic stress effects (30). Acidic pathogen related gene expression is induced by SA but expression of basic PR gene is inhibited (67).

Plant hormones enhance salt tolerance in crops treatment enhances gene expression mostly related to stress and signaling pathways. This may include heat shock proteins (HSPs), antioxidants and genes involved in synthesis of secondary metabolite such as sinapyl alcohol dehydrogenas and Cytochrome P450 (CYP 450). Numerous ways for application of SA such as soaking the seeds prior to sowing, adding to the hydroponic solution, irrigating and spraying which may induce a variety of mechanisms allowing salt stress tolerance (33). SA ameliorative effects have been well studied in many crop plants (11). Sakhabutdinova *et al.* (58) explained that wheat seed priming with 0.05 mM SA improved growth and increase accumulation of ABA and proline under salt stress. This exogenous application of SA may increase cell division within the apical meristem of wheat seedling roots (57). If salicylic acid exogenously applied it enhanced the barley plants photosynthetic rate, maintained membrane stability and improved the growth. Horvath *et al.* (33) stated that when SA was added into the soil it had a beneficial effect on the survival of maize plants and decreased the accumulation of sodium chloride at organelle and organ level. Oxidative damage caused by salt stress can be overcome by a transient increase in the H_2O_2 level in wheat plants and this increase in H_2O_2 can be achieved by application of SA (66). Tomatos roots were exposed with 0.1 mM SA under 200 mm NaCl stress, this SA exposure promotes root growth, increased photosynthetic rate and membrane stability. In rice seedlings endogenous levels of SA increased under saline condition (61). It was clear from the literature that the salicylic acid treatment increased the level of auxin and ABA in crop plants under salinity. SA induces the development of anti-stress programs and acceleration of normalization of growth processes (58). Salicylic acid is capable to reduce harmful impacts of abiotic stress on crop plants.

CONCLUSION

Auxin, cytokinin, gibberellins salicylic acid concentrations decrease and a considerable increase in ABA is observed in different plant parts when exposed to high concentration. Many scientists explain fluctuations in concentration of plant growth regulators as plant tolerance mechanism under salinity. So, salt induced adverse effects on plant can be overcome by the application of phytohormones. Salt tolerance is a multifaceted phenomenon in plants and a variety of research methodologies and genetic approaches are used for tolerance mechanism. Expression of a number of functionally related genes enhance, the activities of antioxidant enzymes, which may help plants overcome oxidative stress damages. Plant hormone serves as a main determinant for showing salt tolerance. In addition an improved information on the fundamental mechanisms of action of exogenously applied phytohormones is helpful to return metabolic activities to their normal levels under salt stress conditions.

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