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PLANT RESPONSES AND RESILIENCE TOWARDS DROUGHT AND SALINITY STRESS

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Abstract

Drought and salinity are major threats among the abiotic stress to plant growth and agriculture productivity worldwide. However, the plants have developed the adaptation mechanism and respond accordingly to such threats to the extent they can tolerate and they can mitigate the adverse effect of abiotic stresses. Plants respond against stress at several levels which includes at a morphological, physiological, biochemical and molecular level. There are several attributes which extends sufficient tolerance to plants under the stress conditions, such as structural changes, water used efficiency, transpiration, osmotic adjustment, accumulation of compound with low molecular weights, osmolytes i.e., Proline, Glycine betaine, Sugars etc, activation of wide array of antioxidant enzymes, growth regulatory compounds, compatible solutes (osmolytes) accumulation, osmotic adjustment, induction of antioxidant enzymes and free radical quenching system are some of the important and effective strategies to make plants resilient against drought and salinity. The osmoprotection of plant cell through osmotic adjustment could be attributed to an effective abiotic stress defence mean. Furthermore, the plant growth regulators (phytohormones) produced in response to drought and salinity stress impart their effect in very small quantity and exhibit their response by modulating signalling pathways at physiological, biochemical and molecular level to mitigate the adverse effect of stress. The present compilation focussed on the plant responses and adaptation efforts at physiological, biochemical and molecular level to make effective tolerance response against drought and salinity.

Keywords: Drought, Salinity, Osmotic adjustment, Compatible solutes. ROSs, Antioxidants, plant growth regulators.

Introduction

Abiotic stress, especially drought and salinity are known to cause major limiting factor for reduction in the crop yields and economic loss to the farmers. The frequent climate changes and recurrence of abiotic stresses are the major threat to food security and sustainability for the crop production system. Plant responses to drought and salinity are the most intricate phenomenon, which are governed by multiple complex traits. Abiotic stress tolerance in plants mediated through several complex traits involved at various levels (i.e., Physiological, metabolic and molecular) in the plant. Therefore for sustainable agriculture is important to understand the plants' responses under different stress conditions to develop stress tolerant plants, which is the major concern in current agriculture scenario (Ali Raza, 2019).

With a growing population and inflating food demand, food security and production have become a major challenge in current agriculture scenario worldwide. It is estimated that 70% more food crops production required to fulfil the food demand of 2.3 billion additional people by 2050 globally (FAO, 2009).

Salt stress

Salinity, the most critical among abiotic stresses, which strongly influences plant growth, crop production yield and limit the increasing food demand. Salinity is steadily expanding worldwide. It is considered that any soil consisted of high soluble salts concentration equivalent to approximately 40.0 mM NaCl, which can produce osmotic pressure of 0.2 MPa is known as saline soil. Such type of soil can exhibit salt stress effect on plants by reducing plant development and yield (FAO, 2008).

It is calculated, that approximately more than 20% of agricultural land globally is influenced by salinity one or other way. Perhaps most of the crop plants are glycophytes, therefore, cannot withstand the salinity in the soil, which become the major limiting factor for deprived growth, less crop production and eventually die under constant exposure of saline environment. About one third of all irrigated land is considered to be affected by salt due to the secondary salinisation and it is estimated that about 50% of the cultivated land is likely to be salinised by 2050 (Epstein and Emanuel *et al.,* 1980).

Therefore, the current agriculture system needs to develop salt-tolerant crop plants and adopt effective management strategies towards mitigating salt stress in order to meet agricultural production and sustainability (Flowers, 2004, Munns and Tester, 2008). Salinity adversely exhibits its effect on plants in several ways, it could be primarily by high salt concentration in soil, which strongly interferes with the water absorption capacity of plant roots and decline to drastic level making plant more vulnerable. The salt stress also exhibits its adverse effect on plant growth and yield by creating ionic toxicity, which is perhaps, due to an increased cellular concentration of salt within the plants. It leads to depress several physiological and biochemical processes within the plants and impart its toxic effect by reducing nutrient uptake and assimilation, growth, development and production etc. (Hasegawa *et al*., 2000; Munns & Tester, 2008). Salinity is adversely affecting and limiting the crop productivity and yield of cultivated crops globally. It is estimated that salt stress affecting approximately 950 millions ha of land worldwide and creating the major constraint on food crops (Boyer, 1982, Ashraf, 2002). In India, it is estimated about 8.6 million ha of land area is highly susceptible for salinity (Pathak *et al*., 1999), whereas, approximately 20% and more agricultural area worldwide and about 50% of the world's irrigated lands are facing the negative effects of salinity (Katerji *et al.,* 1996). Perhaps, due to continued declined quantity and quality of irrigation water, the problems due to salinity will become even more acute in coming years.

Drought Stress

Among the most prominent abiotic stresses, drought is the one, the agriculture sector is greatly affected. The frequent incidences of the drought and scanty rail fall, perturbed rainfall pattern, limited moisture in the soil, they all are significantly limiting crop productivity and widening the rift between food production and food demand. Presently, due to climate change, the drought-affected land is continuously increasing globally. It is predicted to inflating by from 1-3 per cent of today to 30 per cent by 2090 and incidences of extreme drought and mean drought duration will also increase by factors of two and six respectively (Burke *et al*., 2006, Tekle and Alemu *et al*., 2016). Therefore, in such scenario, there is a need for considerable efforts to mitigate the impact of drought stress to a maximum extent by adopting precision agriculture practices, reduction of water resources and development of crop verities that can tolerate drought or limiting water conditions. (Somerville and Briscoe, 2001). In the last decade, there were considerable efforts have been made to strengthen the understanding of plant physiological, biochemical and molecular components associated with stress response and the underlined mechanism of plants adaptation and their tolerance against drought and salinity. Drought stress is a complex phenomenon governed by several traits. Its magnitude and severity depend on several factors which include, frequency of drought occurrence, rainfall pattern, water holding capacity of soil etc, making it unpredictable to assess the magnitude of drought. Therefore, how plant adopts under such conditions need to be understood at several levels (Hasegawa *et al.,* 2000). The water limitation is a critical factor for crop productivity. Therefore, drought stress can severely decline crop productivity in several important crops like cotton etc (Khan *et al*., 2018). Salt stress among the one which causes most deleterious effect on the plant's growth and yield, it exhibits its major effect on the plant by the accumulation of sodium and chloride ions into the cells of roots when exposed to saline soil type. The excess influx of Na^+ and Cl^- ions inside the cell and their accumulation creates a severe ionic imbalance which leads to the altered physiological processes in the plants. High Na^+ concentration creates ionic toxicity and prevents K^+ ions uptake Therefore, growth and development of the plant are severely inhibited leading to declining yield (James *et al*., 2011).

Abiotic stress like drought and salinity, are multi-dimensional. These stresses affect plants at several stages of development. Prolonged and severe exposure to drought and salt stress plants may eventually lead to death. Plants respond to the abiotic stress through regulation of several metabolic and biochemical pathways. It exhibits several physiological and biochemical and metabolic alterations, which includes alteration in plant-water relations which is characterized by reduced cellular water potential and cellular turgor leading to reduced stomatal aperture or closure of stomata, which limits the gas exchange, nutrient imbalance, increased cellular compatible solutes concentrations. It is studied that drought stress severely inhibits the photosynthesis process in plants perhaps due to the reduced CO_2 diffusion (Pinheiro and Chaves, 2011). Further, several studies revealed that plants respond to abiotic stress by accumulation of compatible solutes or osmolytes like proline, glycinebetaine, polyamines, glutathione's, MDHA and other osmolytes etc. these osmolytes perform a variety of functions like they can stabilize the proteins and help to maintain the water absorption by reducing the cellular osmotic potential (Anjum *et al*., 2017). Several reactive oxygen species (ROS) starts generating in plants when exposed to abiotic stress. The most common ROS induced are, superoxide anions ($O_2.^-$), singlet oxygen ($^1O_2$), hydroxyl radicals (OH^-), hydrogen peroxide (H_2O_2) and alkoxy radicals (RO) etc. such ROSs are very reactive and damage cell membranes integrity by reacting lipid molecules of membrane, they also react with other molecules and negatively affect them (i.e., proteins, lipids and nucleic acids). This may lead reduced plant growth and yield and some time cell death due to prolonged stress exposure (Munné-Bosch and Penuelas, 2003). Moreover, the increased concentration of reactive oxygen species (ROS) and several free radicals with weak or poor ability to scavenge and neutralizing such free radicals and ROS further increase the magnitude of the adverse effect of drought and salt stress on plants, which has a direct detrimental effect on plant growth, development and yield. Plant growth under abiotic stress mainly under drought and salinity is also affected by depressed photosynthesis, ionic nutrients uptakes disturbed metabolism and phytohormones and sunken and closed stomata (Saxena and Chandra *et al*., 2006, Rehnama *et al*., 2010, Osakabe *et al*., 2014, Gupta and Huang 2014, Anjum *et al*., 2017). There are studies which revealed that the plant experiences the increased cellular concentration of several reactive oxygen species and free radicals, when exposed to the abiotic stress (drought and salinity), which exhibit a most destabilizing effect on plants vital processes and subcellular structural integrities (Mahajan and Tuteja, 2005).

However, plants have evolved with acquiring certain mechanism at various levels (physiological, biochemical and molecular level) to withstand the adverse conditions and survive under stressful conditions with least impact (Ben Rejeb *et al*., 2014). Plants adapt under stress by developing the mechanism to increase the cellular concentration of antioxidant enzymes (antioxidant system) and scavenging compounds during the exposures of abiotic stress. The plant also builds up stress-responsive protein under stress, moreover, the increased level of associated solutes and antioxidant ratios are also the most important cellular signals raised in response to salinity as well as drought stress. Furthermore, drought and salinity also induce secondary stress (osmotic stress and oxidative stress etc.) in plants which further aggravates the plants growth and development leading to poor productivity (Carvalho *et al*., 2018).

Physiological Response to Drought and Salinity Stress

Leaf water potential, relative water content, water use efficiency etc. are some of the vital attributes that are used to gauge that plant water status under stress. Plant water relationship has a major impact on vital plant functions, cellular processes and adaptive responses in plants under abiotic stress i.e., drought and salt. Maintaining the plant water relationship is a crucial attribute for the plant to withstand the adverse environment, which is mainly exhibited by traits like leaf area, leaf weight, root growth, plant phenology, and leaf surface properties etc. which hold great significance in the adaptive response of plants towards abiotic stress i.e., drought and salinity etc.

The relative water content (RWC) of Leaf is considered as one of the attributes that can be used to measure water status in the plants. Relative water content (RWC) strike the effective balance between transpiration rate and water supply to the leaf (Lugojan and Ciulca 2011). Even the higher relative water content (RWC) as well as more membrane stability index in some of the olive cultivars corroborated to enhanced tolerance and provide an important indicator of drought tolerance (Soheil Karimi *et al*., 2018).

Relative water content provides the important trait to measure the abiotic stress tolerance ability and help to screen comparatively better tolerant crop cultivars i.e. potato (*Solanum tuberosum* L) (Soltys-Kalina Dorota *et al*., 2016) that can help to conserve such cultivars in order to raise the varieties with improved resistance to sustain drought and salinity.

It has been observed that keeping high RWC at low water potential (Ψw), this combination is effective in protecting several cellular metabolic processes from the toxic effect of ion concentrations as tissue water lost. Furthermore, the maintenance of osmotic potential helps to protect chloroplast and maintain photosynthesis preventing from injury due to toxic ionic concentration (Santakumari and Berkowitz, 1991).

Photosynthesis rate and stomatal regulation in plants upon exposure of abiotic stress especially drought and salt key effects. Under limited water stress, photosynthesis is effectively reduced. The quick stomatal closure in order to preserve the moisture is one of the initial strategies of plants to mitigate the adverse effect of stress. This reduces stomatal conductance and reduces CO_2 exchange into the leaves. This may be corroborated to reduced photosynthesis (Zhang *et al*., 2017). It is very obvious from the several studies that abiotic stress influences almost all the vital processes of the plants. Limited water exposure severely hits photosynthetic enzymes and their efficacy, which cause suppressed metabolic processes and damage to photosynthetic machinery in plants.

Compatible Solutes (Osmolytes) Accumulation

The increased cellular concentration of important osmolytes in plants under stressful conditions is leading mechanism through which plants respond to abiotic stress including drought and salinity to cope adverse environment by improving tolerance. Several studies on crop plants revealed the enhanced cellular concentration of osmolytes, which are involved plants endurance to tolerate and survive under harsh environment including drought and salinity. Osmolytes accumulation is widely accepted for playing a key role in maintaining the water-relation in plants through which osmotic adjustment and cell turgor regulation maintained even under adverse conditions. Increased osmolytes concentration is corroborated to reduce water loss, maintenance of the cell turgor, lowered cellular osmotic potential and maintenance of the cellular water uptake capacity, furthermore, osmotic adjustment, activation of antioxidant system, neutralizing the free radicals are some of the vital and important means of abiotic stress tolerance in pants (Anjum *et al*., 2017).

Osmolytes are variety of organic compounds belonging to variety of different chemical groups such as polar, nonpolar uncharged etc and even different types, such compound mainly includes proline, glycinebetaine, sugars, polyols etc. they are mostly nitrogen containing organic molecules such as amino acids, amines and betaines etc. but some of them are also sugars, organic acids and polyols etc. (Mansour, 2000). Osmolytes or compatible solutes have a tendency to synthesise and accumulate in plants under stress conditions although their amount and concentration may vary plant to plant. The proline is one of the amino acids which accumulate in most of the plant belonging to the different taxonomic groups under adverse conditions (Saxena *et al*., 2013).

The compatible solutes are categorised into important groups of a compound like amino acids (Proline), Polyamines and quaternary amines mainly consisted of glycinebetaine, dimethylsulfoniopropionate, for example, similarly important polyols are for example are mannitol, trehalose where as important sugars includes sucrose and oligosaccharide. The free proline is a key amino acid, which is most widely studied in plants under abiotic stress. The increased concentration of proline under abiotic stress is attributed to perform an important function in increasing resistance for abiotic stress in many crop plants i.e, Alpha alpha,- *Ziziphus mauritiana* plants. Similarly enhanced cellular sugars concentration also associated with stress tolerance, which provides sufficient osmotic regulation in plants under abiotic stress including drought and salinity (Lisar *et al*., 2012). So far proline and glycine betaine are two well studies and best known compatible solutes whose cellular concentration is known to be increased in plants under drought as well as salt stress, Although, their accumulation has a negative effect on shoot growth due to channelization of most of the energy towards the synthesis of compatible solutes (Munns, 2002, Sakamoto and Murata, 2002).

Compatible solutes synthesis and their accumulation in plants prevents the cellular structure and integrity, maintain the osmotic balance and cell turgor under drought and salt stress by keeping water influx. The magnitude of osmolytes accumulation is usually related to the severity and intensity of stress. The concentration of osmolytes in the cell is maintained by biosynthesis and by and biodegradation. (Hasegawa *et al*., 2000). Compatible solutes are small group of hydrophilic molecules that are water soluble and remain as most inert molecules (irrespective of their cellular concentration) under changing cellular functions and process in response to abiotic stress in plants (Sakamoto & Murata, 2002).

Free proline Amino Acid Accumulation

Several studies revealed that upon the exposure to the drought or salinity stress, concentration of free amino acids like arginine, cysteine, and methionine, which together constitute around 55% of total free amino acids are decrease in plants. However, the increased proline concentration is observed in plants under drought and salinity stress which improves the cell turgor, scavenging of free radicals and maintaining cellular structures and membranes integrity etc (Ashraf and Foolad, 2007). Glutamate is the principal precursor for the synthesis of proline in plant under stress conditions. The proline biosynthesis is mainly governed by two important key regulatory enzymes namely, pyrroline carboxylic acid synthetase and pyrroline carboxylic acid reductase, which overproduce proline under abiotic (drought and salt stress) stress. Therefore, proline accumulation is considered an important parameter to measure the stress tolerance ability of plants under adverse conditions. The intracellular accumulation of proline in response drought salinity stress is important in enhancing plant tolerance and also provide reserve organic nitrogen source from stress recovery (El-Shintinawy and El-Shourbagy, 2001; Bray *et al*., 2002, Matysik, *et al*., 2002, Ben Ahmed *et al*., 2010).

Glycine Betaine (N, N, N trimethylglycine) Accumulation

Glycinebetaine is one of the widely studies quaternary ammonium compound and compatible solutes in the plants. It is non-toxic, water soluble, amphoteric quaternary ammonium compound, GB is accumulated in a wide variety of plants belonging to the different taxonomic groups under abiotic stress and enhance tolerance against adverse environmental conditions (Quan *et al*., 2004). The plant cell synthesizes glycinebetaine either from choline or from glycine as precursor following different metabolic pathways. Glycine betaine is ubiquitously present in microorganisms, higher plants and animals. Glycinebetaine exists as an electrically neutral compound and remain neural over a broad range of pH. It can interact with a both hydrophobic and hydrophilic domain of macromolecules. Therefore, at cellular level Glycinebetaine is nontoxic cellular osmolytes and is accumulated under drought as well as salt stress environment to provide osmotic tolerance and protect the cell from stress by establishing cell-water status through osmotic adjustment (Gadallah, 1999). Glycine beatine is considered to play an important in abiotic stress mitigation by stabilizing several vital enzymes, preventing photosynthetic machinery and scavenging ROS etc (Makela *et al*., 2000; Cha –Um and C. Kirdmanee, 2010, Saxena SC *et al*., 2013). Tian *et al.* (2017) observed the effect of increased concentration of glycine betaine (GB) in wheat (*Triticum aestivum*) on salt tolerance, it was further elaborated that high concentration of glycine betaine in transgenic wheat lines (BADH gene) leads to higher chlorophyll and carotenoids content which is corroborated to protected thylakoid membrane and photosynthetic machinery to provide better salt tolerance. The application of glycine betaine exhibits positive impact on the lipid composition and thylakoid membrane, resulting into intact photosynthetic machinery and better drought tolerance in under drought stress in wheat cultivars (Zhao *et al,* 2007)

The compatible solutes accumulation in the cytoplasm on the onset of salt or drought stress, they protect the vital cellular functions by acting as an osmoprotectant and preventing denaturation of enzymes, stabilizing important cellular structures, membranes and macromolecules. Therefore, compatible solutes play an effective role in providing osmoprotection to the plants and bolster stress tolerance to plants under abiotic stress (Ashraf and Foolad, 2007).

The functions of osmolytes are not limited to only providing osmotic protection by creating optimum osmotic balance within the cell, but also act as low molecular weight molecules that are involved in the protection of subcellular structures, membranes and proteins etc and acts chaperones, they also protect cellular structures by neutralizing several reactive oxygen species that are produced in response to the abiotic stress (Hasegawa *et al.,* 2000).

Sugar Accumulation

In the last decade, the role of sugars and carbohydrates in improving abiotic stress tolerance in plants has been emerged as an important factor. Sugars being, chemically diverse exists in different categories. The available studies indicated the enhanced accumulation of different groups of important sugars and sugar alcohols molecules like glucose, fructose, fructans (polymer of fructose), Sucrose and trehalose (disaccharide) starch, mannitol and sorbitol etc. in response to abiotic stress, whose increased cellular concentration potentially strengthen the plant tolerance against drought and salinity (Singh *et al.,* 2015; Slama *et al.,* 2015). These sugars are involved in osmoprotection, ROS scavenging and stabilizing the quaternary structures of proteins (Parida *et al*., 2004). It was revealed that under salinity stress plants experience increased cellular accumulation of reducing sugars like sucrose and fructans to enhance stress tolerance (Kerepesi and Galiba, 2000). In one of the study sucrose content was noted to be increased under salt stress in tomato (*Solanum lycopersicum*). Further, it was attributed to induced sucrose phosphate synthase enzyme activity leading to increased cellular concentration of sucrose (Gao *et al*., 1998). The plants containing the transgene of Trehalose- 6-phosphate and phosphatase and Mannitol-1-phosphate dehydrogenase revealed the better tolerance in rice (*Oryza sativa*) under drought and salinity stress conditions (Jang *et al.,* 2003, Pujnai *et al*., 2007), which is attributed to the increased concentration of trehalose and mannitol.

Polyamines Accumulation

Polyamines are an important group of compatible solutes, which play a vital role in abiotic stress mitigation in plant including drought and salinity. Polyamines are small, low molecular weight compounds, which are polycationic aliphatic molecules. Polyamines exist in large number of different varieties of plants species occupy the different taxonomic groups. The increased level Polyamines in plants under abiotic stress indicate its involvement in enhancing tolerance against abiotic stress (Yang *et al*., 2007; Groppa and Benavides, 2008, Kov´acs *et al*., 2010). Some of the polyamine like diamine putrescine (PUT), triamine spermidine (SPD), and tetra-amine spermine (SPM) are among the most common polyamines that are present within the plant system (Alc´azar *et al*., 2011).

Osmotic Adjustment

Osmotic adjustment is considered an important trait, through which plants enhance their tolerance under stress condition by maintaining cell water balance, cell turgor and cellular hydration and delayed wilting. Osmotic adjustment is one of the strategy plant adopted in the early response to abiotic stress (drought and salinity) that help plant sustainability under adversity (Singh *et al.,* 2015). The primary aim of plant reactions to abiotic stress especially drought and salinity is to maintain the homeostasis of the cell which includes osmotic adjustment and ionic balance. The osmotic adjustment is achieved through the intracellular accumulation of osmolytes which results in lowering of osmotic potential of the cell. Therefore the vital function of intracellular solute accumulation is an osmotic adjustment that helps to maintain the cellular turgor and cellular hydration. There are of a wide range of compatible solutes or osmolytes i.e., soluble sugars, sugar alcohols, proline, glycine betaines, sorbitol, mannitol, ions and organic acids etc exists in the cytosol. Osmolytes decreases the cellular water potential, which causes more influx of water into the cell and maintains cell turgor. Proline is the most important and common osmolyte that accumulate in crop plants under abiotic stress (Subbarao *et al,* 2000; Bray *et al*., 2002). It helps plants to be protected from the damaging effect of water deficit and salt stress by keeping higher tissue water potential and also reduces the harmful effects of abiotic stress. Thus osmotic adjustment is considered as important stress tolerant trait under stress conditions to maintain the cellular turgor and vital physiological functions of the cell to sustain normal photosynthetic rate, growth yield even under adverse conditions (Ludlow and Machou, 1990, Taiz and Zeiger, 2006). Osmotic adjustment is considered as one the important trait in providing drought and salt stress tolerance under the adverse environment. Variation in osmotic adjustment in different crops under drought stress is studied in several crops, however some of the studies revealed that osmotic adjustment does not provide a yield advantage (Serraj and Sinclair, 2002).

Reactive Oxygen Species (ROS) and Antioxidant Activity

In response to the drought and salt stress etc. plants experienced an increased concentration of reactive oxygen species (ROS) and production of several free radicals such as singlet oxygen, superoxide radical, hydrogen peroxide, and hydroxyl radical etc., which are the most common effect plants experience. The production of ROS and increased cellular concentration of free radicals in response to the abiotic stress in plants cause oxidative damage to the vital cell structure which includes cell membrane, proteins, lipids etc. Reactive oxygen species further interferes with vital cellular functions of the plants leading to cellular damage and cell death (Kissoudis *et al*., 2014).

Plants inherently possess antioxidant defence system which gets activated under stress conditions, although the magnitude of response varies species to species and severity of the stress. The antioxidant (Enzymatic and Nonenzymatic) defence system in the plants consisted of variety of antioxidant enzymes i.e., Superoxide dismutase (SOD), Catalase (CAT), Ascorbate peroxidase (APX), Peroxidase (POD), and Glutathione reductase (GR) and Monodehydroascorbate reductase (MDAR) etc., parallel to antioxidant enzymes, several antioxidant molecules for example ascorbic acid (AA), glutathione, tocopherols, flavanones, carotenoids and anthocyanins etc. are produced, which are involved in reducing oxidative damage to the plant cell induced in response to the abiotic stress . The superoxide radical are frequently synthesized in cellular organelles i.e., Mitochondria and chloroplast, Where they are effectively neutralized by superoxide dismutase leading to production of hydrogen peroxide that later on further break down by catalase and peroxidase (Sairam and Aruna, 2004).

Similarly, the nonenzymatic component of antioxidant defence system also strengthens the defence response of the plant under adverse conditions; this system includes cysteine, ascorbic acid and glutathione etc. (Gong *et al*., 2005; Farooq *et al*., 2009; Sharma *et al*., 2012). Therefore, elevated concentration of certain antioxidant agents has normally been considered as plant response against abiotic stress and it is coupled with stress mitigation in plants for better survival under harsh environment. The variety of antioxidant enzymes and a non-enzymatic component of the oxidative defence system of plants together effectively neutralize the reactive oxygen species generated in the response of abiotic stress especially drought and salt. Quenching of ROS (i.e., singlet oxygen, per hydroxyl radicals, hydroxyl radicals etc.) is an effective mechanism of plant defences to attenuate the oxidative stress induced in response to abiotic stress (Farooq *et al*., 2009; Rejeb *et al*., 2014; Kissoudis, *et al*., 2014). The fast and quick generation of ROS in the plant in response to abiotic stress act as an important signalling molecule to trigger defence response. (Kissoudis, *et al*., 2014). The plant initiate responses to the drought stress at several levels (i.e., physiological, biochemical and molecular) which includes activation of several pathways, interaction with each other and modification of target proteins leading to cellular response against abiotic stress at various levels. However, plant responses at molecular under abiotic stress mainly due to altered expression of genes. (Sreenivasulu, *et al*., 2007; Tani *et al*., 2019). Glutathione is one of the important antioxidants which is involved in stress resilience by scavenging free radicals generated in response to drought and salinity. Glutathione act as a potent antioxidant to neutralize superoxide radical, hydroxyl radical, and hydrogen peroxide etc. Glutathione is also involved in the production of ascorbate via ascorbate-glutathione cycle (Foyer *et al*., 1997), some of the studies indicated that, exogenous application of glutathione helped to induce salinity tolerance in plants (i.e. *Allium cepa*) *by* maintaining cell membrane permeability during stress (Aly-Salama and Al-Mutawa, 2009). The induced SOD activity was observed in white clover (*Trifolium repens* L.) and exhibits better tolerance under PEG induced water stress (Wang, 2008).

Plant Growth Regulators Under Abiotic Stress

Plants are often exposed to the wide variety of stresses including biotic as well as abiotic, abiotic stress severely hits the important cellular processes of plants leading to growth inhibition and slow down many other important physiological processes. Plant growth regulators are a very crucial group of endogenous signal molecules that are involved in sensing and response to the adverse environment by regulation of several important cell signalling pathways and cross talk other hormones to impart tolerance to plants. Abscisic acid (ABA), salicylic acid, jasmonate and ethylene are the important plant growth regulators, whose response to mitigate drought and salt stress are well studied. Phytohormones play a critical role in helping the plants to adapt to adverse conditions; therefore they offer tremendous opportunities in stress tolerance in plants (Horvath *et al*., 2007; Kurepin *et al*., 2017). Abscisic acid (ABA) played a major role in abiotic stress mediated responses by signalling and regulation by interacting with other hormones. Several studies indicated that ABA plays an important role in several processes in different developmental stages of plant and especially regulation of stomatal opening and closing, seed germination and dormancy, inducing stress-responsive genes, which provide sufficient tolerance to the plants under drought stress (Dong *et al*., 2018; Kuromori *et al*., 2018). There are studies available, which indicated the role plant growth regulators in plant defence against abiotic stresses (drought and salt etc.) it is revealed that salicylic acid (SA), Jasmonic acid and ethylene impart stress tolerance in plants, the phytohormones communicate by modulating plant defence response signalling pathways and impart defence response in plants (Verma *et al*., 2016). The increased drought and salinity tolerance was observed in several crop plants i.e. Maize (*Zea mays* L.), Barley (*Hordeum vulgare*), Mustard (*Brassica sp.*) Wheat (*Triticum aestivum*) etc. in response to application of plant growth regulators (Salicylic acid, Jasmonic acid) in appropriate concentrations, (Fayez and Bazaid, 2014; Qui *et al*., 2014; Singh *et al*., 2015; Nazar *et al*., 2015; Ahmad Mir *et al*., 2018). There are several ways through which phytohormones interact and regulate several metabolic processes in order to modulate plant growth and development, yet their role in abiotic stress defence response in the plants depends on the severity and duration of stress exposure on the plants, SA and JA are linked biochemically and trigger necessary signalling pathways to induce response in plants under abiotic stress (Khan MIR *et al*., 2012). Recently the study conducted by Noshin Ilyas *et al*. (2017) revealed the drought resilience impact of salicylic acid and jasmonic on the wheat. The results indicated that application of SA (10mM) and JA (100µM) not only increased the seed germination percentage but also involved in increased water potential and enhanced proline accumulation and sugars, which indicated that both of these plant growth regulators have a potential to mitigate drought stress and maintain the plant growth. Although the impact of SA well studied in biotic stress tolerance in plants and is considered as effective tool in inducing tolerance against pathogens attack in crop plants i.e., cowpea (Chandra *et al.,* 2007). However, its role in biotic stress tolerance is equally studied. The foliar application of SA on Maize (*Zea mays*) attributed the improved drought tolerance by increased cellular concentration of total soluble and cell-bound phenolics (Farzana *et al*., 2016). Khan *et al.* (2014) conducted the study on *Vigna radiata, L.* under salinity stress. It was reported that SA application on salt-stressed plants revealed the reduction in endogenous levels of ethylene due to SA application further it was observed that SA application allows the effective portioning and sequestration of toxic ions (Na^+) in the cell. Another important gaseous hormone ethylene, which performs several functions including seed germination, fruit ripening, leaf growth etc. ethylene also involved in the regulation of signalling pathways leading to modulate plant responses under abiotic stress i.e., drought, salinity high temperature etc. (Dubois *et al*., 2018). There is an evidence that, increased ABA and SA level in plants in response to abiotic stress leads to activation of several physiological pathways to mitigate stress, increase tolerance and reduced growth hormones, mean while plants which accumulate more Glycine betaine offers better interaction with plant hormones, improved growth and photosynthesis hence provide better stress tolerance (Kurepin *et al.,* 2017).

Conclusion

Plants respond to abiotic stress by activation of a cascade of physiological and metabolic reactions that are required to provide sufficient tolerance under the adverse situation. Better understanding and elucidation of the regulatory mechanism of metabolic and biochemical pathways need a continuous effort in this direction to develop better tolerance in plants and will hold key toward the identification and selection of tolerant crops. The identification of stress tolerant traits could offer a plausible approach to select and develop tolerant cultivars, biotechnological interventions could be another approach to develop tolerant crop by introducing the stress responsive traits. Accumulation of compatible solutes in plant acts as a vital factor to reduce the impact of drought and salt stress by maintaining the plant water relation and osmotic adjustment. Activation of the antioxidant system further enhances tolerance by preventing and subcellular structural damage and other vital reactions. Furthermore, plant growth regulators could be a potential solution in order to strengthen the defence response of plants against abiotic stress. The drought and salt stress could be effectively mitigated by developing the suitable cultivars. The exogenous application of plant growth regulators and appropriate osmolytes, enhancing cell signalling to induce the antioxidant system to modulate the plant stress response. However, this need an extensive research to fine tune the optimum concentration that coincides with appropriate developmental stage of plants to harness the maximum tolerance. Furthermore, understanding at molecular level and deciphering the mechanisms plant exhibit for abiotic stress tolerance still not sufficient and put forward the major challenge towards abiotic stress tolerance.

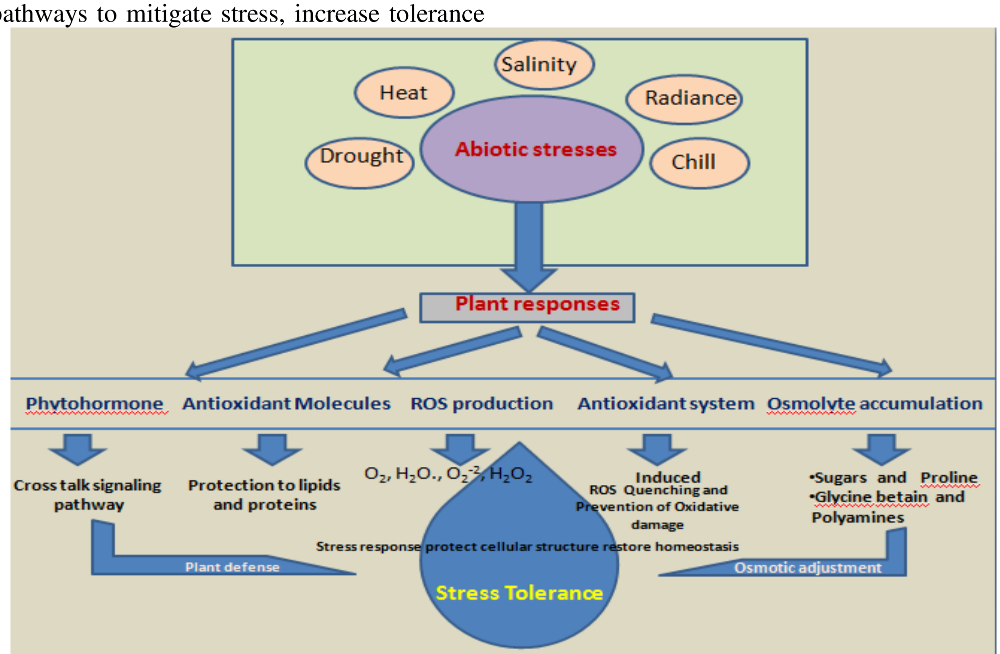

Fig. 1 : Explains the plant responses when exposed to abiotic stress, it generates free radicals and activation of enzymatic as a well as nonenzymatic antioxidant system, which detoxify the free radicals and prevent damage of proteins, lipid molecules etc. Induction of different groups of osmolytes and their cellular accumulations further maintain cellular osmotic potential through osmotic adjustment. Synthesis several phytohormones like, Abscisic Acid (ABA), Salicylic Acid (SA), Jasmonic acid (JA) and Ethylene (ET) etc. modulate defence response through cell signalling and metabolic pathways regulation at different levels and maximize the overall defence response.

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