Chapter 20
Physiological Interventions of Antioxidants in Crop Plants Under Multiple Abiotic Stresses

Ameer Khan, Muhammad A. Hussain, Hummera Nawaz, Gulzar Muhammad, Ingeborg Lang, and Umair Ashraf

Contents

A. Khan (✉) · H. Nawaz · U. Ashraf
Department of Botany, Division of Science and Technology, University of Education,
Lahore, Punjab, Pakistan
e-mail: ameer.khan@ue.edu.pk

M. A. Hussain
Department of Chemistry, University of Sargodha, Sargodha, Pakistan

G. Muhammad
Department of Chemistry, GC University Lahore, Lahore, Pakistan

I. Lang
Department of Functional and Evolutionary Ecology, Faculty of Life Sciences,
University of Vienna, Vienna, Austria

C. S. Prakash et al. (eds.), *Sustainable Agriculture in the Era of the OMICs Revolution*,
https://doi.org/10.1007/978-3-031-15568-0_20

Introduction

The current environmental changes across the globe are serious threats to agriculture and all living organisms (Devendra, 2012). As a result of these environmental changes, global temperature may rise up to 3–4°C (WMO, 2014), which may lead to serious problems such as food shortage and starvation. Owing to these climate changes, plants are persistently facing different stresses such as salinity, heavy metals, drought, chilling, heat, increased sunlight, etc. Due to aforesaid stresses, yield of crops is being dwindled (Lamaoui, 2018; Dhamgaye & Gadre, 2015; Gao et al., 2014) that will certainly affect increasing human population (Poljsak et al., 2013).

From chemistry point of view, oxidative stress on plants due to the abovementioned external stimuli imbalances the ROS-antioxidant interrelations (Fig. 20.1). Excess ROS production in response to various stresses has also been known to speed up peroxidation of lipids, DNA impairment, and carbonylation of proteins (Munns, 2008). Plants produced enzymatic and nonenzymatic antioxidants as a

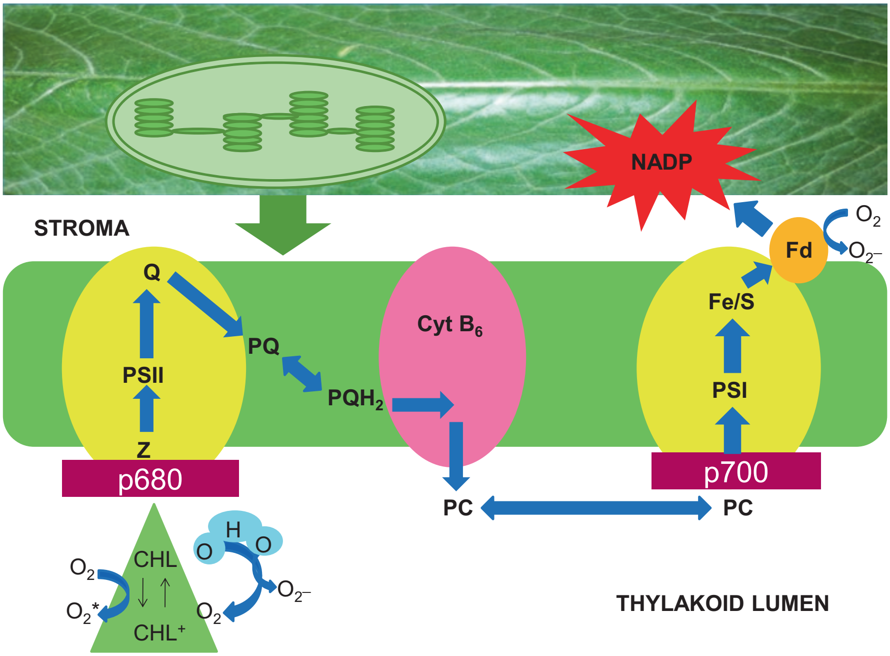


Fig. 20.1 Production of superoxide radical and singlet oxygen in chloroplast at PSII and PSI, respectively

defensive strategy to avoid cytotoxic effects (Shalata et al., 2001) but ultimately hindered plant growth obtained under saline conditions (Taarit et al., 2012a, b). Therefore, there is a need to grow plants under simulated saline conditions using exogenous enzymatic and nonenzymatic antioxidants. In this way, the toxic effects of salinity on the plant growth can be diminished, which is witnessed by various studies (Khan et al., 2013a, b, 2017; Husen et al., 2018).

Strategies of Plants to Cope with Stress

Plants adapted different strategies at cellular, physiological, biochemical, and molecular levels to cope with salinity stress (Gupta & Huang, 2014; Tamang & Fukao, 2015; Wang et al., 2018). For instance, plants respond to salinity by Na^+ selectivity and compartmentalization of Na^+ ions at cellular as well as tissue levels. Mechanisms of salt tolerance thus could be categorized into two major groups, that is, physiological and molecular.

Physiological mechanisms can further be explained by osmotic adjustment and/or water homeostasis, ion exclusion/inclusion and/or ion homeostasis, ROS scavenging, and hormonal biosynthesis (Batool et al., 2015). Among these mechanisms, water and ion homeostasis are mainly thought to counter antagonistic impacts of salinity on plant growth.

Moreover, many transcription factors such as heat shock factors (HSF) or ABA-responsive elements (ABF/ABRE) may induce salinity tolerance in plants (Vinocur & Altman, 2005). Stress-induced activation of molecular networks, signal transduction (starting from the roots toward cellular and whole plant levels), metabolites and specific gene expression are among decisive factors of plants to adapt against environmental stresses (Nguyen et al., 2018; Ismail et al., 2014; Ashraf, 2009; Vinocur & Altman, 2005). In plants, resistance to biotic stresses is usually controlled in a simple way, but salinity tolerance as an abiotic factor is controlled by the interaction of several genes (i.e., a few major genes along with several minor genes) (Ashraf & Harris, 2004; Batool et al., 2015). At the transcriptomic level, genes related to stress signaling, transcription regulation, ion transport mechanism, and biosynthesis of specific metabolites of complex signaling pathways are responsible for salt stress tolerance in plants (Cotsaftis et al., 2011; Kawasaki et al., 2001; Kumar et al., 2013; Walia et al., 2007).

Abiotic Stresses and Plants

Plants growth is significantly affected by various abiotic stresses, which resulted in low crop yields. Abiotic stresses included salinity, heavy metals, drought, chilling, temperature, water logging, and increased exposure to UV radiations (Dhamgaye & Gadre, 2015). Figure 20.2 explained the response of plants to various stresses.

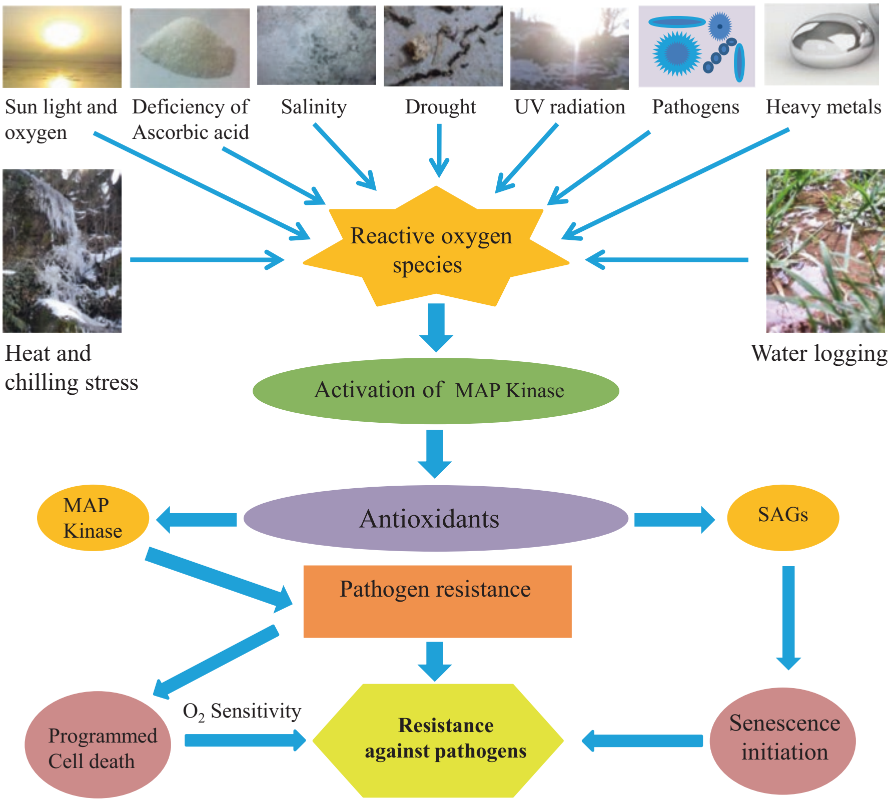


Fig. 20.2 Diagram showing response of plants to various stresses

Among multiple abiotic stresses, salinity is considered the most alarming, which constrained the agricultural production and adversely affected growth and yield of chief crops. Salt stress has affected 25% of the agricultural lands all over the globe due to application of saline irrigation water. Salinity reduced the water availability to crop plants (Taffouo et al., 2010; Ashraf, 2009). High concentrations of salts inhibited the growth of plants due to stumpy osmotic potential of lands, imbalanced nutrition, and selected ion effects (Parvaiz & Satyawati, 2008).

Drought, another abiotic factor, is threatening and has disturbed the economy of the world by reducing crop production (Cenacchi, 2014). Transgenic plants have been prepared to use genes that encoded proteins involved in drought tolerance. Accumulation of osmolytes is also one of the important mechanisms that helped the plants to tolerate drought stress in plants(Bechtold & Field, 2018).

Chilling stress also affects plant metabolism thus hindering plant growth and reproduction. The plants changed their pattern of gene expression to cope with chilling stress, thereby producing a suite of metabolites to protect plants against chilling (Sanghera et al., 2011).

UV radiations also cause a serious threat on the environment and oxidative damage in plants (Du et al., 2011). Due to stress environment, plants switched on their antioxidant system to reduce the toxic effects of stress (Carletti et al., 2013). Although UV-absorbing compounds mainly protected the DNA (Stapleton & Walbot, 1994), these compounds also played a key role in the plant antioxidative defense system and pathogens (Tutejaet al., 2001).

Moreover, heavy metals in the environment is a serious threat to agro-ecosystem and crop plants (Ashraf et al., 2015, 2017a, b; Mani & Kumar, 2014). Toxic levels of heavy metal in plants often result in the oxidative damage and disruption of structural and functionality of plant cells (Ashraf et al., 2018, 2020; Ashraf & Tang, 2017). The oxidative stress disturbs the equilibrium between prooxidant and antioxidant homeostasis (Flora et al., 2008). Waterlogging and salinity go parallel with each other and create severe problems for plant growth. One of the first responses to plant against waterlogging is reduction in stomatal conductance (Folzer et al., 2006). The deficiency of oxygen due to waterlogging generally leads to the substantial decline in photosynthetic efficiency (Kaur et al., 2018a, b; Ashraf et al., 2011; Ashraf & Arfan, 2005) and causes oxidative stress. Due to oxidative stress, reactive oxygen species produced and disturbed the metabolic process of plants (Ashraf et al., 2011; Ashraf, 2009). Excess of water also inhibit electron transport chain, respiration, and ATP formation due to hypoxia (low oxygen concentrations (Ashraf et al., 2011). The nutrient uptake and growth of the plants reduced due to the contrary effects of waterlogging (Ashraf et al., 2011).

Furthermore, the magnitude of temperature stress increased as the ambient temperature increases from a threshold level, which results in alteration in physio-biochemical mechanisms in plants (Kong et al., 2017). The extent of possible damage owing to increased temperature in plants depends on plant developmental stage experiencing the high temperature stress (Slafer & Rawson, 1995; Wollenweber et al., 2003).

Antioxidants Combat Plant Abiotic Stresses

Antioxidant defense system is the best strategy adapted by the plants to ameliorate the abiotic stresses. Plants produce a variety of enzymatic, nonenzymatic antioxidants, and hormones endogenously in response to aforesaid stresses (Albaladejo et al., 2017; Almeselmani et al., 2006; Kandil et al., 2017; Massoud et al., 2018). Enzymatic antioxidants included enzymes such as superoxide dismutase (SOD), peroxidase (POX), ascorbate peroxidase (APX), catalase (CAT), glutathione reductase (GR), and polyphenol oxidase (PPO), whereas α-tocopherol, carotenes, and ascorbic acid (vitamin C) are nonenzymatic antioxidants produced by the plants to alleviate the impacts of abiotic stresses on plants. It is noticed that the abovementioned endogenous production of antioxidant secondary metabolites is the best way but not enough in amount to cope with elevated salinity conditions (Srinieng et al., 2015). It has been reported that antioxidants being supplied exogenously to plants are also fruitful to mitigate plant stresses, particularly salinity (Agada, 2016). Al Kharusi et al. (2019) performed an experiment on date palm to induce salinity tolerance by application of antioxidants.

Ascorbic acid has been found to be involved in cell wall expansion, enhancement of cell division, leaf area, biosynthesis of photosynthetic pigments, and improvement in plant tolerance against multifarious stresses by scavenging ROS (Dey et al., 2016; Kasote et al., 2015). Moreover, salicylic also modulates the important physiological processes such as photosynthesis, osmoregulation, and nitrogen metabolism (Khan et al., 2013a, b). Salicylic acid also plays its role in the tolerance of plants against chilling, drought, salinity, UV radiations, pathogen, heavy metals, waterlogging, and heat stresses (Farheen et al., 2018; Khan et al., 2015; Palma et al., 2013). Exogenous application of trehalose alleviates the adverse effects of salinity stress in wheat by changing the physiological process (Alla et al., 2019; Mervat & Sadak, 2019; NematAlla et al., 2019). Ellagic acid, a natural polyphenolic antioxidant in various vegetables and fruits (Lima et al., 2014), is distributed in the vacuoles as water-soluble ellagitannin and played a vital role in plant defense against a number of stresses by capturing ROS effectively (Nagarani et al., 2014; Priyadarsini et al., 2002; Saul et al., 2011).

In addition, brassinolide captured ROS effectively and protects the plants from oxidative stress. Various literature reports confirmed its oxidative potential when applied exogenously against different stresses (Zhou et al., 2015; Behnamnia 2015; Javid et al., 2011; Li & Chory, 1999). Moreover, tocochromanols are effective and useful group of lipophilic phenolic antioxidants (Housam et al., 2014), which could protect key cell components by scavenging free radicals before prior to lipid peroxidation and/or DNA damage. The tocochromanols break the chain reactions involved in lipid peroxidation and shield the cellular membranes by repair and replacement of lipid in bilayer membranes (Falk and Munnè-Bosch, 2010; Mène-Saffrané & DellaPenna, 2010). On the other hand, exogenous GABA application improved stress tolerance by regulating the physio-biochemical processes and redox balance (Jin et al., 2019; Li et al., 2016). Similarly, carotenoids are important antioxidants used as photosynthetic apparatus in plants, algae, and cyanobacteria, which protected against photooxidative damage and contributed to light harvesting for photosynthesis (Ksas et al., 2015).

Mode of Exogenous Applications of Antioxidants

Folair Applications of Antioxidants

Foliar spray of an antioxidants is considered a shotgun approach to ameliorate the toxic effects of salinity. Foliar application is very economic mode of application to save the nutrients. Previously, Khan et al. (2006) and Athar et al. (2009) have performed experiments on wheat by applying different concentrations (0 and 100 mg

L^{-1}) of ascorbic acid and found substantial improvements in the growth and development of wheat plants. Malik and Ashraf (2012) also performed experiment on wheat by applying different concentration of ascorbic acid and hydrogen peroxide to mitigate the effects of drought. Ahmad et al. (2014) studied the effect of salicylic acid and hydrogen peroxide (each 0, 20, and 40 mgL^{-1}) on maize at low temperature stress. Noreen et al. (2009) reported that exogenous salicylic acid application improved salt stress tolerance in sunflower. Baber et al. (2014) also reported that salicylic acid application improved the performance of fenugreek under saline conditions. Noreen and Ashraf (2008) reported that exogenous salicylic acid application improved the physiology and growth of sunflower under saline conditions. Li et al. (2014a, b) stated that foliar spray of salicylic acid improved the photosynthesis and antioxidant system in *Torreya grandis.* Exogenous salicylic acid application improved the germination and early growth of wheat under salt stress (Sahli et al., 2019). Moreover, Desoky and Merwad (2015) performed an experiment on foliar applications of ascorbic acid and salicylic acid and found that co-application of both resulted in improved the growth and development of wheat under saline conditions (Hamideldin et al., 2017; Morsi et al., 2018; Rihan et al., 2017).

Applications of Antioxidants Through Rooting Media

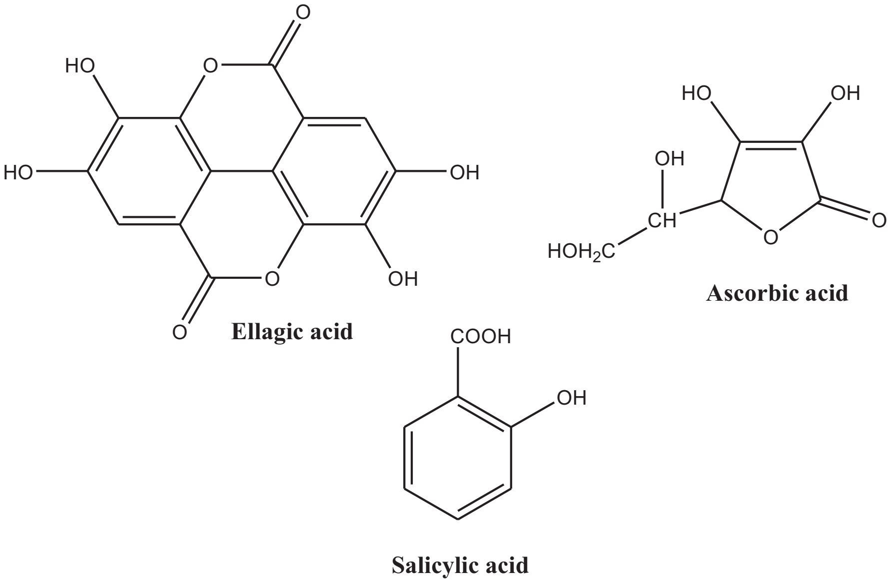
In a number of studies, much attention has been given on stress tolerance by the application of antioxidants through rooting medium. It was observed that antioxidants increased photosynthetic rate via stomatal regulation, which was positively associated with stress tolerance. For example, Athar et al. (2009) found improved growth of wheat when ascorbic acid was applied through rooting medium at vegetative stage under salt stress. Malik and Ashraf (2012) also conducted experiment on wheat and applied ascorbic acid through rooting medium under drought stress and found substantial improvements in growth. In another study, Xu et al. (2015) evaluated the positive effects of ascorbic acid on *Festuca arundinacea* through rooting medium under water stress. Arfan et al. (2007) found improved growth of wheat when applied with the salicylic acid through rooting under saline conditions.

Applications of Antioxidants by Seed Soaking

Exogenous application of antioxidant compounds as a pre-sowing treatment has gained a considerable attention in ameliorating the adverse effect of salt stress. In this regard, El-Soud et al. (2013) observed that seed treatment of chickpea seeds with ellagic acid improved seed germination under PEG-induced stress. Seed soaking of soybean and other crops in distilled water or ASC solution for 4 h improved germination under associated physio-biochemical mechanisms under saline conditions (Çavuşoğlu and Bilir 2015; Malik & Ashraf, 2012; Dehghan et al., 2011). Kasim et al. (2016) soaked radish seeds in *Pterocladia capillacea* and *Codium taylorii* extracts and found improved growth under saline conditions. Khan et al. (2006) observed positive effects of pretreatment of wheat seeds with ascorbic acid under saline conditions. Overall, pre-treatment of seeds with antioxidants increased endogenous level of ascorbic acid that had a protective effect on photosynthetic pigments against salt-induced oxidative stress; thus, antioxidants are involved in the regulation of many physiological functions to improve the performance of plants under stress conditions.

Nonenzymatic Antioxidants

To fight against stresses, plants produced antioxidants (Fig. 20.3) that maintained the growth and provided strength under stress and non-stress conditions. Most commonly studied nonenzymatic antioxidants to mitigate the stresses on plant growth included ellagic acid, ascorbic acid, salicylic acid, α-tocopherol, anthocyanins, brassinolides, and carotenes.



Ellagic acid

Ascorbic acid

Salicylic acid

Fig. 20.3 Structures of some important carboxylic acids used as antioxidants against salinity stress

Ellagic Acid

Ellagic acid is a naturally occurring polyphenolic antioxidant that is present in several fruits including grapes, nuts, pomegranate, and a wide variety of berries as well as in vegetables (Malini et al., 2011). However, ellagic acid played several essential roles in plants under stress conditions such as DNA binding, scavenging of ROS, and inhibition of ROS production (Fig. 20.4) and protection of DNA from alkylating injury (Barch et al., 1996). Ellagic acid is also responsible for the restoration of normal functioning of various biomolecules. ROS depolarized cell membranes and hence disturbed the cell metabolism through seepage of essential ingredients from the cell (Hasanuzzaman, 2013). Ellagic acid has displayed antioxidant (Han et al., 2006; Sepúlveda et al., 2011), antibacterial (Han et al., 2006; Sepúlveda et al.,

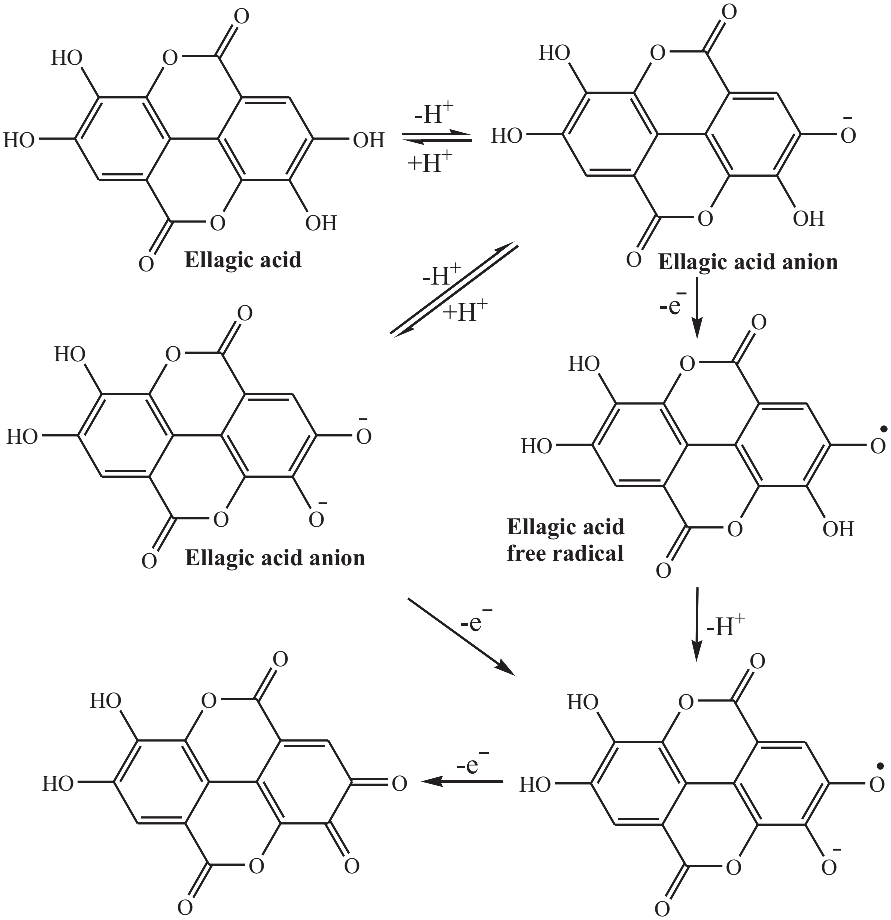


Fig. 20.4 Plausible free radical capturing mechanism of ellagic acid

2011), antiviral (Han et al., 2006; Sepúlveda et al., 2011), anti-inflammatory (Mehan et al., 2015), and anticancerous activities (Han et al., 2006; Mehan et al., 2015; Sepúlveda et al., 2011) in humans and inhibited UV-induced oxidative stress in plants with protection against lipid peroxidation (Bhandari, 2012).

More importantly, it effectively captured ROS at physiological pH to protect cells against toxic effects. Under such conditions, the ellagic acid anion is well known for its protective role, which continuously regenerated after capturing two free radicals, and thus proves more beneficial even at low concentrations (Galano et al., 2014). Moreover, the ellagic acid metabolites have also the ability to scavenge free radicals efficiently showing that its working performance is not reduced after being metabolized. This is an uncommon and constructive characteristic of ellagic acid, which made it particularly valuable against oxidative damage (Galano et al., 2014). Moreover, it has also been reported that ellagic acid provided better protection against oxidative stress and lipid peroxidation than vitamin E.

In another study, it has been investigated that the antioxidant activity of ellagic acid is mainly due to the presence of two pairs of neighboring hydroxyl groups in its structure, and it is very effective in inhibiting lipid peroxidation even at micromolar (low) concentrations. The scavenging activity of ellagic acid resembled those of other antioxidants such as vitamins E and C (Parthasarathi & Park, 2015; Galano, 2014; Indira et al., 2002).

A recent study showed that ellagic acid is bound to DNA by intercalating with the minor groove because of its planar structure. In this function, it activated various signaling pathways such as apoptosis, protected from oxidative DNA damage, and altered growth factor expression (Parthasarathi & Park, 2015). However, detailed investigations are still needed on bioavailability and absorption capacity of ellagic acid.

In a study, ellagic acid (50 ppm) was applied as a pre-seed treatment on chickpea seedlings, and it was found that ellagic acid accelerated the germination and growth with enhanced total antioxidant capacity and contents of compatible components (proline and glycine betaine) and antioxidant enzymes. Furthermore, ellagic acid decreased the lipid peroxidation levels, glutathione content, and seepage of solutes. Thus, the study discovered an improved salt tolerance of gram seedlings under osmotic stress by decreasing contents of H_2O_2 and increasing total antioxidant capacity after ellagic acid treatment (Aguilera-Carbo et al., 2008; El-Soud et al., 2013).

Ascorbic Acid

Ascorbic acid (Fig. 20.3) is a potential antioxidant to scavenge ROS produced under stresses (Kumar et al., 2014). Ascorbic acid possesses antioxidant and cellular reductant abilities, promotes plant growth and development, and regulates plant cellular mechanisms against environmental stresses (Hameed et al., 2015). Generally, ascorbic acid is present in all plant parts, subcellular compartments including the cell wall and vacuole (Fernie & Szilvia, 2015) except dry seeds (Davey et al., 2000), and its concentration varies in different parts of plants (Klause et al., 2016). Ascorbic acid is synthesized by almost all higher plants, while animals capable to oxidize L-gulono-1,4-lactone can synthesize ascorbic acid. It has been discovered that synthesis of ascorbic acid is regulated by the presence of jasmonate, which induced the transcription level and enhanced its production inside the cell (El Hariri et al., 2010; Smirnoff, 2005).

Plants release ascorbic acid in response to stresses. It not only captured free radicals but also activated complex biological defense mechanisms at cellular levels (Conklin & Barth, 2004) (Fig. 20.5). Exogenous ascorbic acid application reduced lipid peroxidation in seedlings of *S. fruticose* (Hameed et al., 2012) and *Brassica napus* (Dolatabadian et al., 2008) and *Phaseolus vulgaris* (Saeidi-Sar et al., 2013) and in perennial halophytes (Hameed et al., 2015) under salinity stress. Shalata and Neumann (2001) described the protective role of exogenous ascorbic acid that appeared to be associated to its antioxidant activity. Ascorbic acid via rooting medium, pre-sowing seed treatment, and foliar spray has been found reliable to reduce the effect of salinity in wheat (Azzedine et al., 2011; Raafat et al., 2011; Athar et al., 2008, 2009; Khan et al., 2006; Shalata & Neumann, 2001; Janda et al., 1999). It can also mitigate the toxic effects of oxidants, inhibit the uptake of sodium, and enhance the uptake of potassium (Conklin & Barth, 2004).

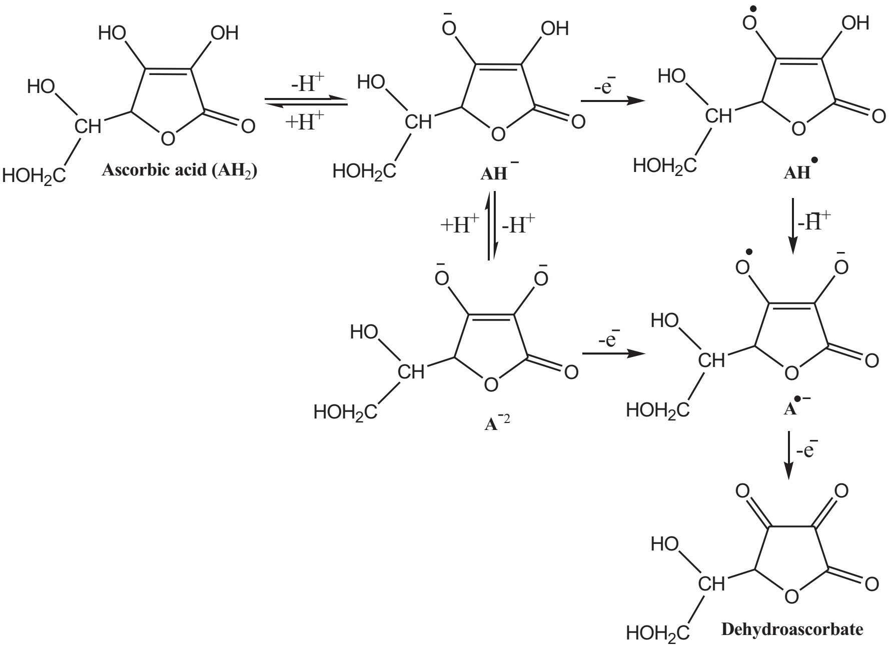


Fig. 20.5 Plausible free radical capturing mechanism of ascorbic acid

It has been indicated that ascorbic acid is centrally correlated with different physiological processes that involved plant growth and production (Hameed et al., 2012; Younis et al., 2010) and rapidly reached the target area owing to its greater solubility in water (Herschbach et al., 2010). Therefore, foliar application of ascorbic acid improved salt tolerance of crop plants in a number of ways (Athar et al., 2008; Dolatabadian et al., 2008; El Hariri et al., 2010; Farahat et al., 2013).

Chemically, ascorbic acid acts as a strong reducing agent and oxidized reversibly to dehydroascorbic acid. The investigation on the interactions of various chemicals with ascorbic acid and metal ions has shown that ascorbic acid, its oxidation product (dehydroascorbic acid), and intermediate, monodehydroascorbic acid free radical might function as cycling redox couples in electron transport and membrane electrochemical potentiation. It quenches oxidizing free radicals and other highly reactive oxygen-derived species such as the hydrogen peroxide, hydroxyl radical, and singlet oxygen by inactivating them in water-soluble compartments such as the plasma, cytosol, and extracellular fluid (Nimse & Pal, 2015).

Exogenous ascorbic acid application induces salt tolerance in wheat and improved Na^+ ions accumulation, leaf chlorophyll contents, and photosynthetic machinery (Akram et al., 2017; Khan et al., 2006). Folair application of ascorbic acid enhanced the plant biomass accumulation, photosynthetic pigments, and absorption of potassium and calcium ions (Khan et al., 2013a, b).

Application of ascorbic acid on roots not only enhanced the root growth, antioxidant activities, and photosynthetic rate but also improved the antioxidant activities (Athar et al., 2009). Ascorbic acid helped in the accumulation of potassium and calcium ions in the leaves; however, application of ascorbic acid on roots did not improve the growth of salt-stressed wheat plants (Athar et al., 2008). The exogenous application of ascorbic acid on leaves or via irrigation accelerated the antioxidant activities with enhanced contents of proline in wheat (Batool et al., 2012). The pre-treatment of barley with ascorbic acid improved seed germination traits, early growth, biomass accumulation, and anatomical features of barley under saline conditions (Çavuşoğlu & Bilir, 2015).

Foliar spray of ascorbic acid on *Cyamopsis tetragonoloba* grown under sea salt irrigation improved plant growth, photosynthetic pigments, protein contents, and potassium contents (Gul et al., 2015). Similarly, ascorbic acid improved seed germination, growth, yield, and ionic composition of eggplant under salt stress (Jan et al., 2016).

Salicylic Acid

Salicylic acid is one of the important antioxidants owing to its involvement in endogenous signal mediating local and systemic plant defense response against stresses. Salicylic acid is a growth regulator that promoted the growth of plants under stress and non-stress conditions (Rivas-San & Plasencia, 2011) (Fig. 20.3). Salicylic acid acts as a potential nonenzymatic antioxidant, which plays a key role in regulations of various physiological processes in crop plants (Jayakannan et al., 2015; Arfanet al., 2007). It has also been found that plants release salicylic acid in response to multiple abiotic stresses such as heavy metal toxicity, water stress or drought, chilling stress, temperature, and osmotic stress (Jayakannan et al., 2015). Some earlier reports showed that exogenous application of salicylic acid could minimize the damaging effect of drought on wheat (Waseem et al., 2006) and heavy metals in rice (Khan et al., 2015).

Salicylic acid is a phenolic compound involved in many physiological and biochemical processes such as nitrogen metabolism, photosynthesis, proline metabolism and production of antioxidant system, glycine betaine, and plant water relations under stress conditions and thereby provided protection in plants against abiotic stresses (Viehweger, 2014; Miura & Tada, 2014; Khan et al., 2013a, b). In another study, salicylic acid was reported to induce salinity tolerance and increased biomass of *Torreya grandis* owing to improved chlorophyll content and antioxidant activity that eventually alleviated the oxidative stress (Li et al., 2014a, b).

The deficiency of salicylic acid in plants could make the effects of salt stress more worse and lead to substantial decline in plant growth (Mirdehghan & Ghotbi, 2014). Salicylic acid-induced pre-adaptation status in plants remained helpful in the acclimation to subsequent salt stress via reducing lipid peroxidation in terms of reduced malondialdehyde (MDA) content (Li et al., 2014a, b; Deng et al., 2012). In wheat, exogenous salicylic acid negated the salt stress-induced growth inhibition (Arfan et al., 2007).

Salicylic acid has variable effects on plants regarding plant adaptation to salt stress; however, the magnitude of protective effects depends on plant species, application dose, application method, and time of application (Metwally et al., 2003). Salicylic acid has obtained special attention owing to its protective effects on plants under NaCl salinity. Several studies have shown that the effects of cytotoxicity induced by salt stress can be overcome by exogenous application of salicylic acid (Dong et al., 2015). Salicylic acid can also act as an endogenic phytohormone, which may regulate various physiological and biochemical processes in plants (Abedini & Hassani, 2015). Foliar application of salicylic acid promoted growth, enzymatic, and photosynthetic activities in salt-stressed sunflower plants (Noreen et al., 2009). Foliarly applied salicylic acid on maize grown in saline soil showed positive effect at the vegetative stage of maize plants. Exogenous salicylic acid application prominently improved sugar, protein, and proline contents and antioxidant enzyme activities. On the other hand, chlorophyll, carotenoids, osmotic potential, and membrane stability index were reduced (Fahad & Bano, 2012).

In addition, exogenous application and salicylic acid concentrations significantly improved plant growth and development (Akhtar et al., 2013). The foliar spray of salicylic acid also protected citrus seedlings subjected to salt stress. Growth, chlorophyll (Chl) contents, relative water contents (RWC), maximal quantum yield of PS-II photochemistry, and gas-exchange attributes were negatively affected by salinity. In addition, cell membrane damage and proline contents were enhanced by salinity. It appeared that the best ameliorative remedies of salicylic acid were obtained when citrus seedlings were sprayed by 0.50 and 1.0 mM salicylic acid solutions (Khoshbakht & Asgharei, 2015). Cucumber seedlings were treated with foliar salicylic acid applications at low concentrations, and it was noted that salt stress negatively affected the growth, chlorophyll content, and mineral uptake of cucumber plants. However, foliar applications of salicylic improved plant biomass accumulation. Moreover, salicylic acid application improved water contents of salt-stressed cucumber plants and reduced electrolyte leakage (Yildirim et al., 2008).

Tocopherols

Tocopherols (Fig. 20.6) are lipophilic antioxidants, which are synthesized in plants and some photosynthetic microorganisms. Four isoforms (*α, β, γ, δ*) of tocopherols and tocotrienols, which vary in the positions and number of methyl groups in the chromanol ring, are found in nature (Eitenmiller et al., 2007). Plants mainly

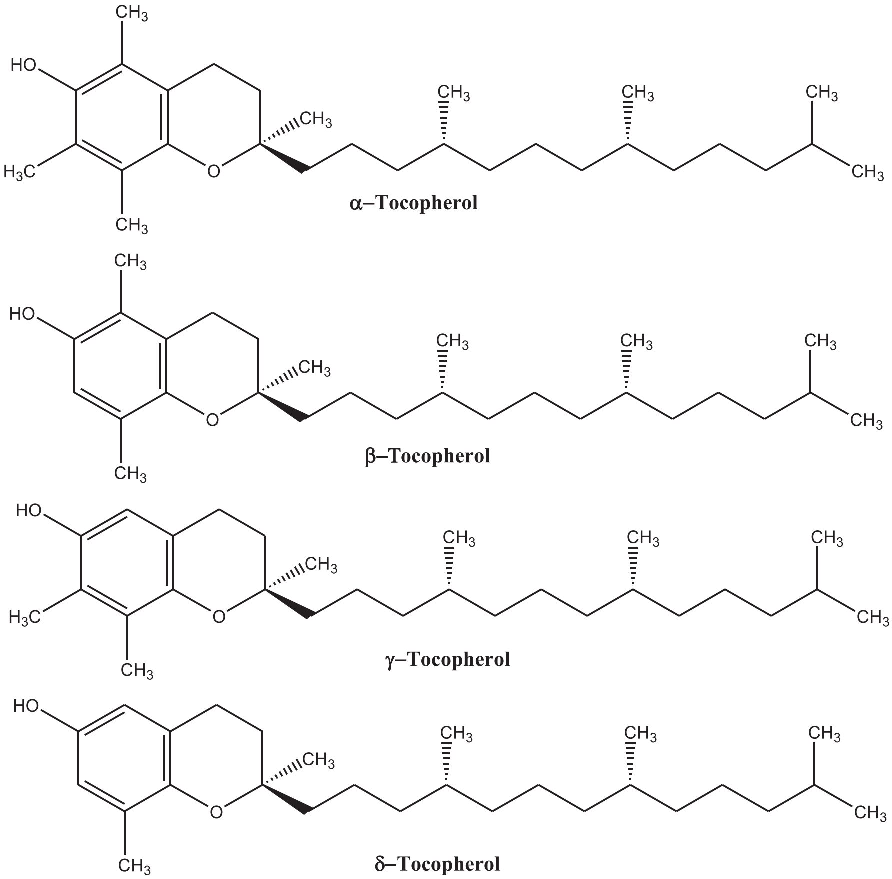


Fig. 20.6 Structures of important tocopherols

accumulated tocochromanols to reduce the lipid oxidation (Falk & Munné-Bosch, 2010). Some evidences suggested that the effectiveness of antioxidant may vary between natural and synthetic source of tocochromanols (Ahsan et al., 2015). To date, little is known about the specific roles of α- and γ-tocopherols in different plant tissues. Tocopherol biosynthesis happens at inner envelope membrane of chloroplasts of photosynthetic organisms (Fritsche et al., 2014), which provides protection to photosynthetic machinery from oxidative damage and lipid peroxidation owing to enhanced ROS production under stress conditions. The important aspect of the biosynthetic pathway of tocopherols in plants has already been identified, whereas the enzyme tocopherol cyclase has been identified as a key enzyme of tocopherol biosynthesis (Ali et al., 2015).

Up to the 1990s, the function of α-tocopherol in plants is believed to be associated only with antioxidant activity and maintenance of membrane integrity. Later on, it was found that α-tocopherol has the ability to transmit cellular signals in plants as well as in animal cells. Experiments performed on mutant plants, which are unable to synthesize tocopherols, have proved this assumption. Tocochromanols are the most effective group of lipophilic phenolic antioxidants, which protect key cell components by neutralizing free radicals before they can cause damage to cellular structures and functions (Espinosa-Diez et al., 2015).

Among tocopherols, α-tocopherols (vitamin E), which contain three methyl groups, have an excellent antioxidant activity (Kamal-Eldin & Appelqvist, 1996). Protective mechanism of vitamin E is the quenching of ROS and removal of the polyunsaturated fatty acid radical species (Fig. 20.7), which are generated during lipid peroxidation (Shin et al., 2016; Raederstorff et al., 2015; Munne-Bosch, 2013; Bramley et al., 2000).

Vitamin E reduced the effect of seawater stress on growth, yield, and physiological and antioxidant responses of faba bean plant. Similarly, foliar application with α-tocopherol on faba bean plants alleviated injuries and caused diluted seawater irrigation. The positive effects are related to the enhancement of protective parameters such as antioxidant enzymes, proline, carotenoids, and inorganic ions ($K^+$and Ca^{2+}). Tocopherols also improved faba bean plant growth, yield, and quality of seeds (Orabi & Abdelhamid, 2016). Foliar application of tocopherols increased relative growth rate, plant nitrogen contents, and net assimilation rate and showed positive changes in all other parameters and productivity of soybean plants when grown under irrigation with moderately saline water (Rady et al., 2015). The antioxidants appraised to alleviate salinity-induced stresses in plants, which has been mentioned in Table 20.1.

Exogenous application of α-tocopherols substantially improved salt stress tolerance in onion plants by inhibiting endogenous H_2O_2 and lipid peroxidation and enhancing enzymatic (i.e., SOD, CAT, APX, and GR) and nonenzymatic (i.e., ascorbic acid and glutathione) antioxidant activities. Moreover, α-tocopherol application improved photosynthetic efficiency and plant water status. Therefore, foliar application of α-tocopherols could be used to induce salt tolerance in plants (Semida et al., 2014).

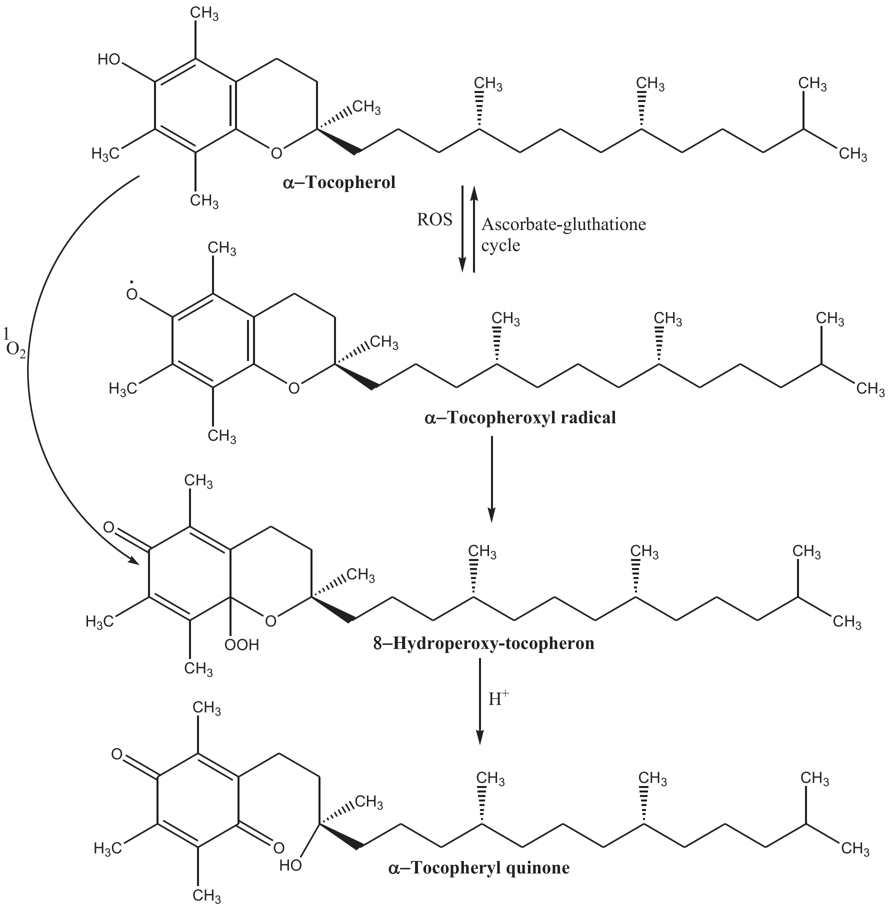


Fig. 20.7 Conversion of α-tocopherol into α-tocopherylquinone by its reaction with ROS

Anthocyanins

Anthocyanins are water-soluble, polar, and pigmented flavonoids (Bendary et al., 2013; Prior, 2006; Harborne, 1998; Holton & Cornish, 1995), which also contributed to the antioxidant properties (Longo & Vasapollo, 2006) in plants grown under saline conditions. Major sources of anthocyanins are cherries, strawberries, blueberries, raspberries, purple grapes, and black currants (Mazza, 2007) and found in the vacuoles of the epidermal and mesophyll cells (Chalker-Scott, 1999). Anthocyanins accumulated in expanding juvenile tissues and autumnal senescing leaves of deciduous species under stress (Amal et al., 2015; Close & Beadle, 2003). Anthocyanin supplementation through foods and beverages plays an important role in the prevention of diverse cardiovascular diseases, cancer, and a plethora of other diseases due to their strong antioxidant, detoxification, anti-proliferation, anti-angiogenic, and anti-inflammatory activities (Ames et al., 1993; Nikkhah et al., 2008).

Table 20.1 Antioxidants used in various crops to alleviate salinity-induced effects

Sr. No.	Antioxidant	Crop	Mode	References
1	Ellagic acid	*Cicer arietinum* (chickpea)	Seed soaking	El-Soud et al. (2013)
2	Ascorbic acid	*Triticum aestivum* (wheat)	Foliar	Khan et al. (2006)
			Rooting	Athar et al. (2008)
			Seed soaking	Athar et al. (2009)
		Helianthus annuus (sunflower)	Foliar	Khan et al. (2013a, b)
		Saccharum spontaneum (wild sugarcane)	Foliar/rooting	Batool et al. (2015)
		Solanum melongena (eggplant)	Foliar	Elwan et al. (2007) and Jan et al. (2016)
		Hordeum vulgare (barley)	Seed soaking	Çavuşoğlu and Bilir (2015)
		Cyamopsis tetragonoloba (guar)	Foliar	Gul et al. (2015)
		Sesamum indicum (sesame)	Seed soaking	Tabatabaei and Naghibalghora (2013)
3	Salicylic acid	*Helianthus annuus* (sunflower)	Foliar	Noreen et al. (2009)
		Zea mays (maize)	Foliar	Fahad and Bano (2012)
		Vigna radiata (mung bean)	Foliar	Akhtar et al. (2013)
		Citrus sinensis (citrus)	Foliar	Khoshbakht and Asgharei (2015)
		Cynara scolymus (artichoke)	Foliar	Bagherifard et al. (2015)
		Cucumis sativus (cucumber)	Foliar	Yildirim et al. (2008)
4	Tocopherols	*Vicia faba* (horsebean)	Foliar	Orabi and Abdelhamid (2016)
		Glycin max (soybean)	Foliar	Rady et al. (2015)
		Mung bean seedling (*Vigna radiata*)	Soaking	Farheen et al. (2018)
		Allium cepa (onion)	Foliar	Semida et al. (2014)
		Linum usitatissimum (Linseed)	Foliar	Sadak and Dawood (2014)
5	Anthocyanin	Role of anthocyanin in plant defense	Endogenous	Lev-Yadun and Gould (2009)
		Higher plants	Endogenous	Eryılmaz (2006)
		Hibiscus esculentus (okra)	Endogenous	Dkhil and Denden (2012)
		Triticum aestivum (wheat)	Endogenous	Tereshchenko et al. (2012)
		The photoprotective role of anthocyanin pigments in leaf tissues	Endogenous	Hughes (2007)
6	Flavonoids	Flavonoids production in plants under stress condition Giovanni	Endogenous	Agati et al. (2013)

(continued)

Table 20.1 (continued)

Sr. No.	Antioxidant	Crop	Mode	References
7	Brassinosteroids	*Triticum aestivum* (wheat)	Foliar spray	Shahbaz and Ashraf (2007) and Eleiwa et al. (2011)
			Seed soaking	El-Feky et al. (2014)
		Lycopersicon esculentum (tomato)	Foliar	Behnamnia et al. (2015)
		Leymus chinensis Trin.	Foliar	Niu et al. (2016)
		Oryza sativa (rice)	Seed soaking	Sharma et al. (2015)
		Citrullus lanatus (water melon)	Spray	Cheng et al. (2015)
		Lycopersicon esculentum (tomato)	Spray	Slathia et al. (2012)
		Leymus chinensis (Chinese lyme grass)	Spray	Jin et al. (2015)
		Zea mays (maize)	Foliar	Anjum et al. (2011)
		Solanum lycopersicum (garden tomato)	Foliar	Hayat et al. (2012)
		Gossypium hirsutum (cotton)	Seed soaking	Fathima et al. (2011)
		Raphanus sativus (radish)	Seed soaking	Mahesh et al. (2013)
8	28-HBL	*Cicer arietinum* (chickpea)	Seed soaking	Ali et al. (2007)
		Zea mays (maize)	Seed soaking	Arora et al. (2008)
		Triticum aestivum (wheat) *Brassica juncea* *Triticum aestivum* (wheat)	Foliar Foliar	Eleiwa et al. (2011) Hayat et al. (2012)
			Foliar	Yusuf et al. (2011)
			Seed soaking	El-Feky (2014)
		Brassica juncea (Chinese mustard)	Foliar	Alyemeni et al. (2013)
9	24-EBL	*Pisum sativum* (garden pea)	Rooting	Fedina (2013)
		Pisum sativum L. (pea)	Seed soaking	Shahid et al. (2011)
		Cucumis sativus (cucumber)	Foliar spray	Fariduddin et al. (2013)
		Solanum melongena (eggplant)	Rooting	Wu et al. (2017)
			Rooting	Ding et al. (2012)
		Cajanus cajan (pigeon pea)	Rooting	Dalio et al. (2013)
		Capsicum annuum (pepper)	Foliar	Abbas et al. (2013)
		Lactuca sativa	Foliar and Seed soaking	Ekinci et al. (2012)
		Brassica juncea	Seed soaking	Kaur et al. (2018a, b)
		Triticum aestivum (wheat) *Triticum aestivum* (wheat)	Foliar	Qayyum et al. (2007) and Shahbaz et al. (2008)
			Foliar	Talaat and Shawky (2013)
		Acacia gerrardii	Foliar	Abd Allaha et al. (2018)
		Cucumis sativus (cucumber)	Foliar	Anwar et al. (2018)
		Phaseolus vulgaris	Foliar	Rady (2011)
		Hordeum vulgare (barley)	Seed soaking	Kartal et al. (2009)
		Cajanus cajan	Rooting	Dalio et al. (2011)
		Fragaria x ananassa	Foliar	Karlidag et al. (2011)
		Grass seedlings	Rooting	Wu et al. (2017)

The promising antioxidant properties of anthocyanins in humans caused also an interest to study their role on plant growth under saline conditions. However, the ecophysiological roles of anthocyanins are manifold as compatible solutes in osmotic regulation, antioxidants, and photoprotectants by masking photosynthetic pigments and capturing ROS (Carletti et al., 2013; Hatier & Gould, 2008; Nakabayashi et al., 2014; Steyn et al., 2002). Anthocyanins are well recognized as an important component of *Quinoa* grains owing to their high nutritional value and health benefits (Alvarez-Suarez et al., 2014). The induced synthesis and accumulation of anthocyanins under stress at grain filling could be an important functional trait for grain nutritional quality of *Quinoa*. Anthocyanin captures free radicals generated from the cyanidin oxidation (Castañeda-Ovando et al. (2009) as well as defends plants against environmental stresses such as ultraviolet radiation, drought, temperature variations, and attraction of pollinators (Chalker-Scott, 1999; Close & Beadle, 2003; Leão et al., 2014; Stone et al., 2001).

Anthocyanins improve drought resistance in plants due to its ability to stabilize the water potential and thus hypothesized to be involved in osmotic regulation (Chalker-Scott, 2002; Oosten et al., 2013). Ploenlap and Pattanagul (2015) suggested that the increase in anthocyanin levels under water stress is mainly due to the photoprotection of chlorophylls by anthocyanins. The anthocyanin level was increased in the juvenile leaves under drought stress, however the accumulation of anthocyanins inhibited under severe stress conditions. Similarly, flavonoids with radical scavenging activity mitigated oxidative and drought stress in *Arabidopsis thaliana* (Nakabayashi et al., 2014). Moreover, it has been demonstrated that anthocyanins are potent antioxidants, displaying up to four times the ROS scavenging potential of trolox (Wang et al., 1997), an industry standard in gauging antioxidant potential. Moreover, in vivo monitoring of an oxidative burst (following mechanical wounding) showed that H_2O_2 decreased more rapidly in red (anthocyanic) *Pseudowintera colorata* leaves than green ones. While the vacuolar storage of anthocyanins was found against their action as direct scavengers of ROS produced in the chloroplast, possibly due to cytoplasmic anthocyanins, which act as antioxidants. For example, Zhang et al. (2012) showed that leaves of an acyanic *Arabidopsis thaliana* mutant subjected to a high irradiance displayed a reduced DPPH (2,2-diphenyl-1-picryl-hydrazylhydrate) scavenging potential and increased oxidative damage (estimated by cell membrane permeability) as compared to wild-type anthocyanic leaves. It was further observed that anthocyanins in *Sambucus* spp. peduncles are responsible for ameliorating light stress during senescence, and anthocyanins may additionally prolonged the senescence period. This dichotomy in anthocyanin research is unwarranted, and its significance is still poorly acknowledged. Identification and exploration of those functions that anthocyanins perform in either reproductive or vegetative organs are necessary to understand the adaptive significance of anthocyanin production in plants.

Brassinosteroids

Brassinosteroids belong to a group of steroid plant hormones with significant growth promoting potential (Bishop & Yokota, 2001; Clouse & Sasse, 1998; Chory et al., 1989). Brassinosteroids have multiple effects on seed germination, growth, leaf abscission, and senescence (Sasse, 1997) although its mechanism is still obscure (Mathur et al., 1998). Moreover, brassinosteroids exert anti-stress effects on plants such as those caused by cold, heat, drought, and salt (Anuradha & Rao, 2003; Dhaubhadel et al., 2002; El-Feky, 2014; Kagale et al., 2007; Ogweno et al., 2008; Sharma et al., 2018). The brassinosteroids' stress response is an intricate sequence of biochemical reactions such as induction of protein biosynthesis, activation or suppression of key enzymatic reactions, and the production of multiple chemical defense compounds (Bajguz & Hayat, 2009; Jin et al., 2015).

Exogenous applications of brassinosteroids under salinity have long been known to improve growth and yield in many economically useful plant species (Cheng et al., 2015). In cereals, brassinosteroids promoted growth and yield attributes, whereas in leguminous crops, the number of pods per plant and total seed yield remained higher after the exogenous application of brassinosteroids (Rao et al., 2002). Growth and seed yield of rapeseed plants were also promoted by brassinosteroid application (Hayat et al., 2012; Sharma et al., 2018), and the same was reported for seed yield in cotton (Ramraj et al., 1997). Brassinosteroids removed the salinity-induced inhibition of seed germination and seedling growth in rice (*Oryza sativa*) and improved the chlorophyll biosynthesis and enhanced nitrate reductase activity under salt stress(Anuradha & Rao, 2003; Bajguz & Hayat, 2009).

Furthermore, brassinosteroids had no prominent effect on the leaf cell ultrastructure under normal conditions; however, damages imposed by salt stress on nuclei and chloroplasts were significantly reduced by brassinosteroid treatment in barley (Krishna, 2003). When salt solution was supplemented with brassinosteroids, the inhibitory effect of salt on rice seed germination was considerably reduced that is possibly associated with enhanced levels of nucleic acids and soluble proteins (Anuradha & Rao, 2009). The exogenous application of 28-homobrassinolide on *Pusa Basmati*$^{-1}$, a commercially important rice variety, resulted in reduced growth and protein and chlorophyll contents and increased proline and MDA contents of at early growth stages (Sharma et al., 2015).

The plants resulting from the seeds soaked in 28-homobrassinolide exhibited higher activities of nitrate reductase (23%) and carbonic anhydrase (31%), improved dry mass (34%) and nodule number (30%), content of leghemoglobin (28%), and nitrogenase activity (30%), while contents of nodule nitrogen and carbohydrate were decreased by 5% and 6%, respectively, with ultimate increase in yield (26%) in chickpea (Ali et al., 2007). The structures of some important brassinolides are given in Fig. 20.8.

In addition, the activities of antioxidative enzymes and protein contents were promoted in 28-HBL-treated maize plants. Moreover, application of 28-HBL reduced lipid peroxidation in salt-treated maize plants (Arora et al., 2008). Similarly,

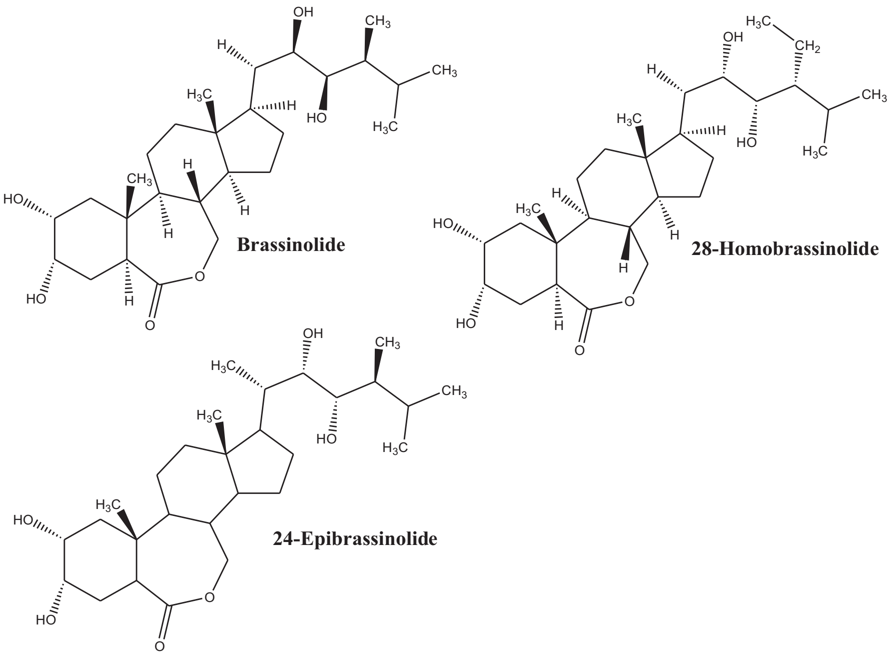


Fig. 20.8 The structures of some selected brassinolides

foliar spray of 28-HBL increased growth and yield attributes and photosynthetic pigments in wheat (Eleiwa et al., 2011). Activities of nitrate reductase and carbonic anhydrase, photosynthetic rate, and seed yield were decreased along with content of chlorophyll under salt stress; however, application of 28-HBL solutions stimulated morpho-physiological attributes in *Brassica juncea* (Alyemeni et al., 2013). Application of 24-epibrassinolide (24-EBL) attenuated the hostile effects of salinity on *Eriobotrya japonica* plants; however, the effect of 24-EBL was significant at 0.5 mgL^{-1} under saline conditions (Sadeghi & Shekafandeh, 2014; Xue, 2012). Similarly, the grass seedlings were treated with 24-EBL and induce salinity tolerance (Wu et al., 2017). In similar studies, foliar spray of 24-EBL improved growth parameters of wheat and *Acacia gerrardii* plants significantly under saline and non-saline conditions; however, there was no prominent increase in the mineral contents of wheat plants (Abd Allaha et al., 2018; Ali et al., 2006; Shahbaz et al., 2008; Shahbaz & Ashraf, 2007). Exogenous application of brassinolide (1.0 mgL^{-1}) enhanced growth, carbohydrate, and total soluble proteins in roots and shoots of wheat and improved the activities of hydrolytic enzymes, amylase, and protease as well under salt stress (El-Fekyl, 2014; Durigan et al., 2011). No doubt, brassinosteroids alleviated the inhibitory effects of salinity on germination, seedling growth, and crop yields; however, further studies are needed to uncover the tolerance mechanism imparted by brassinosteroids under stress conditions.

Carotenoids

Carotenoids are among the most important nutrients in food and found in all plants as natural pigments. They are derived from acyclic C40 isoprenoid lycopene that can be classified as a tetraterpene (Heider et al., 2014). Carotenoids are lipophilic microconstituents that have beneficial effects on human health and provide protection against cancer, cardiovascular diseases, and muscular regeneration (Rao & Rao, 2007; Sommer & Vyas, 2012). Till date, there are approximately 700 known carotenoids that can be categorized as α-carotene, β-carotene, and lycopene and xanthophylls (zeaxanthin, lutein, and β-cryptoxanthin), which denote the oxygenated carotenoids fraction. The α-carotene, β-carotene, and β-cryptoxanthin are promoters of vitamin A and are represented in Fig. 20.9.

In plants, carotenoids function a crucial role in protecting chlorophyll owing to their antioxidant properties, and the endogenous carotenoid contents are affected by several factors such as environmental, genetic, or man-made strategies (Fanciullino et al., 2006). The carotenoid-rich extract is usually used in food supplements, food additives, medicines, and cosmetics (Mezzomo & Ferreira, 2016).

The extent of expression of carotenogenic genes varied with stress conditions. For instance, carotenoid molecules present in the tissues are capable of neutralizing

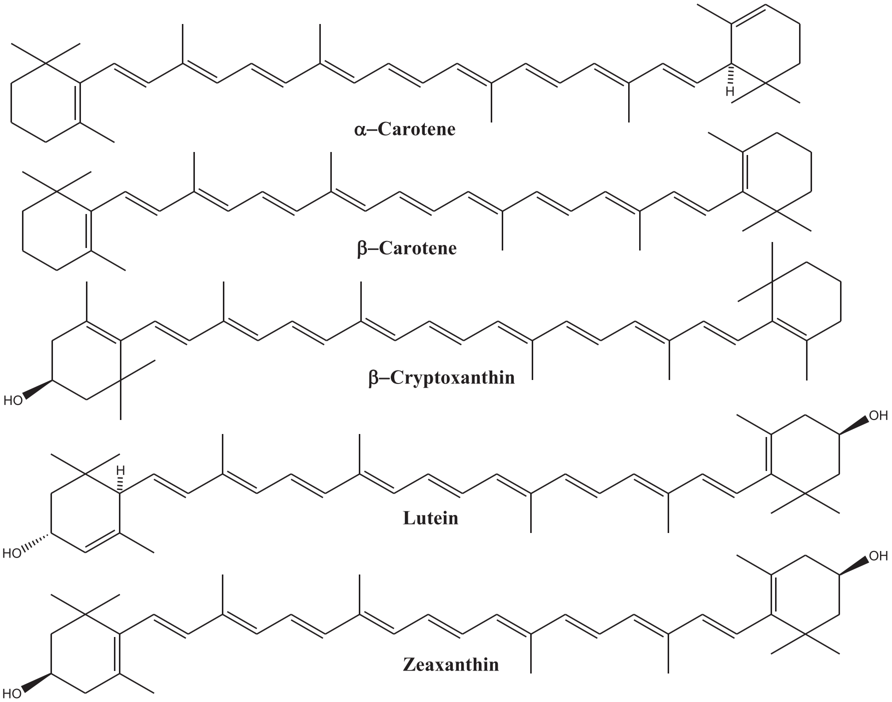


Fig. 20.9 The structures of some selected carotenoids

ROS; however, the mechanism of action of these molecules is based on the modifications of the cell metabolic functions, aimed at interacting with the polyunsaturated acyl groups of lipids to stabilize membranes and playing a protective role against ROS and synergic function with other antioxidants (Raposo et al., 2015). Table 20.2. shows uses and sources of some selected antioxidants.

Table 20.2 Sources and uses of some important antioxidants

Serial No.	Compound	Class	Sources	Uses	References
1	Ellagic acid	Polyphenolic	Vegetables, nuts, grapes, pomegranate, berries	Antioxidant, antiviral, antibacterial, anti-inflammatory, anticancerous	Galano et al. (2014), Bhandari (2012) and Malini et al. (2011)
2	Ascorbic acid	Vitamin	All plant parts except dry seeds, citrus fruit	Antioxidant, growth regulator, anti-saline	Kumar et al. (2014), Hameed et al. (2015) and Klause et al. (2016)
3	Salicylic acid	Phenolic carboxylic acid	Berries, dates, grapes, guavas, apricots, green pepper, olives, tomatoes	Antioxidant, growth regulator, anti-saline	Viehweger (2014), Li et al. (2014a, b) and Abedini and Daie Hassani (2015)
4	Tocopherols	Phenolics	Vegetables and vegetable oils, nuts, grains	Antioxidants	Ahsan et al. (2015), Fritsche et al. (2014) and Raederstorff et al. (2015)
5	Anthocyanins	Flavonoids	Blueberries, cherries, raspberries, strawberries, black currants, purple grapes, red wine	Antioxidant, detoxification activity, anti-proliferation activity, anti-angiogenic activity, anti-inflammatory activity	Chukwu et al. (2012), Leão et al. (2014) and Nakabayashi et al. (2014)
6	Brassinosteroids	Steroid	Plants	Antioxidant, anti-stress, enhanced growth and yield	El-Feky (2014), Cheng et al. (2015) and Jin et al. (2015)
7	Carotenoids	Tetraterpenes	Tomatoes, carrots, and apricots, all fruit or vegetable	Anticancer, cardioprotective, antioxidant	Fanciullino et al. (2006)

Enzymatic Antioxidants

The ROS are the by-products of aerobic metabolism, and their production is generally enhanced under stress conditions (Ashraf & Harris, 2013; Gónmez-Bellot et al., 2013; Mugnai et al., 2009) through enhanced oxidizing metabolic activities occurring in chloroplasts, mitochondria, and microbodies and disruption of electron transport system (Pinheiro & Chaves, 2011). In this context, enzymatic antioxidants, that is, CAT, POX, and SOD, served as efficient ROS scavenging systems to evade the oxidative damage (Mittler et al., 2011; Saisanthosh et al., 2018) in plants under stress conditions.

Catalases (CAT)

The CAT is a tetrameric protein of 244 kDa comprising four identical subunits of 59.7 kDa, and each subunit contains 527 amino acid residues, one haem group, namely, iron (III) protoporphyrin IX, and a tightly bound molecule of NADPH (Sofo et al., 2015). Stress conditions predispose the photosynthetic system of leaves to photoinhibition resulting in a light-dependent inactivation of the primary photochemistry associated with photosystem II (Ashraf & Harris, 2013). At low concentrations, H_2O_2 acts as a signal molecule involved in the regulation of growth and development, specific biological/physiological processes, cell cycle, photosynthetic functions, and plant responses to biotic and abiotic stresses (Kovalchuk, 2010; Seki et al., 2007; Vadez et al., 2012). Oxidative stress and eventual cell death in plants can be caused by excess H_2O_2 accumulation. Since stress factors provoked production of H_2O_2 in plants, severe damage to biomolecules can be possible due to enhanced and non-metabolized cellular H_2O_2 (Sofo et al., 2015;Foyer & Shigeoka, 2011; Apel & Hirt, 2004). Considering the key role of CAT in photorespiration, many authors focused on the role of CAT-catalyzed pathway under both drought and salt stress. Indeed, the maintenance of CAT activity in leaves of drought-stressed plants likely allowed the removal of photorespiratory H_2O_2 produced (De Pinto et al., 2013). Under stress conditions, the photorespiration works as energy sink preventing the over-reduction of the photosynthetic electron transport chain and photo-inhibition (De Pinto et al., 2013). On this basis, photorespiration and CAT pathway cannot be considered wasteful processes but appreciated as a key subsidiary component of photosynthesis and important parts of stress responses in green tissues for preventing ROS accumulation (Bauwe et al., 2012; Voss et al., 2013).

Enzymes, that is, APX, GPX, and CAT, are able to scavenge H_2O_2 with different mechanisms. Regulation of the CAT gene expression played an important role in the levels of CAT activity. The catalase gene expression is regulated by various mechanisms involving peroxisome proliferator-activated receptors (Ford et al., 2011; Sofo et al., 2015).

Peroxidases

Peroxidases (POXs) having molecular weight ranging from 30 to 150 kDa are widely distributed in nature. The POXs are involved in the detoxification of toxic pollutants, and its detoxification ability is dependent upon the reduction of peroxides such as H_2O_2 (Saxena et al., 2011). These enzymes are produced by a variety of sources including plants, animals, and microbes, whereas POXs have the potential for bioremediation of wastewater contaminated with phenols, cresols, and chlorinated phenols used for biopulping and biobleaching in paper industry (Malar et al., 2014). Moreover, the POXs are also used as biosensors. The term POX represents a group of specific enzymes such as NADH-POX, glutathione-POX, and iodine-POX as well as a variety of nonspecific enzymes that are simply known as POXs. These oxidases and POXs have been reported as excellent antioxidants to degrade dyes (Caverzan et al., 2012). Specifically, the POX activity involved donating electrons that are bound to other substrates such as ferricyanide and ascorbate to break them into harmless components. Moreover, the POX donates two electrons to reduce peroxides by forming selenols and eliminates peroxides as potential substrate for the Fenton reaction (Liochev & Fridovich, 2003, 2010).

In addition, the use of POX for the degradation of pollutants has thrown more light on sustainable bioremediation strategies for polluting compounds and environmental protection using different enzymes. Environmental protection is influenced by interwoven factors such as environmental legislation, ethics, and education. Each of these factors played an important role in influencing national-level environmental decisions and personal-level environmental values and behaviors. For environmental protection to become a reality, it is important for societies and the nations to develop each of these areas that together will inform and drive environmental decisions.

Superoxide Dismutase (SOD)

Plant-antioxidant defense machinery comprising antioxidant enzymes and nonenzymatic antioxidant components metabolized ROS and their reaction products to avert oxidative stress conditions (Gill & Tuteja, 2010; Hasanuzzaman et al., 2012). The SOD is a metalloenzyme and one of the most effective components of the antioxidant defense system in plant cells against ROS toxicity. The SODs catalyzed the dismutation of $O_2^{\bullet -}$ to H_2O_2 and O_2 in all subcellular compartments such as chloroplasts, peroxisomes, mitochondria, cytoplasm, nuclei, and the apoplast (Alscher et al., 2002; Gill & Tuteja, 2010). Moreover, the SODs are available at an intracellular concentration of 10^{-5} M and occur in all oxygen-metabolizing cells and all subcellular compartments (Alscher et al., 2002; Fink & Scandalios, 2002). The SODs constituted the first-line defense against abiotic stress-induced enhanced ROS production and its reaction products. Nevertheless, all the SOD isoforms are nuclear coded and, where necessary, transported to their subcellular targets by means of NH_2-terminal targeting sequences (Pan et al., 2006).

Four different isoforms of SODs have been distinguished depending on the metal at the active center, which is manganese, iron, copper, and zinc (Miller & Sorkin, 1997). Previous studies denoted that most of the SODs are intracellular enzymes; these are Cu/Zn SOD (which is also extracellular), Mn-SOD, and Fe-SOD. Cu/Zn-SODs are generally found in the cytosol of eukaryotic cells and chloroplasts. The Mn-SODs are found in mitochondria and reported in chloroplasts and peroxisomes in some plants. The dimeric Fe-SODs, which are not found in animals, have been reported in chloroplasts of some plants (Gomez et al., 2003; Droillard & Paulin, 1990; Camp et al., 1994; Fridovich, 1995; Salin & Bridges, 1980).

In summary, to detoxify ROS, enzymatic and nonenzymatic antioxidant systems become upregulated, whereas H_2O_2 is scavenged by CAT and POX. The SOD plays a determinant role in the protection against the toxic effects of oxidative stress by scavenging superoxide radicals and providing their conversion into O_2 and H_2O_2 (Verma et al., 2003; Bowler et al., 1992). Overall, the enzymatic antioxidants are first-line defense of plants against oxidative stress owing to multiple biotic and abiotic factors.

Conclusion

Throughout the world, environmental stresses are proved to be a fatal threat for agricultural productivity. Plants being sessile in nature have to face multiple abiotic stresses. Crops in arid and semiarid regions have to face uncertain periods of drought and extreme weather conditions. Thus, improving crop yields under such climatic conditions yield is vital to satisfy the increasing food demand. Phytohormones and plant growth regulators could play important role in this regard owing to their stress alleviatory role. Exogenous application of some phytohormones and plant growth regulators could substantially improve the enzymatic and nonenzymatic antioxidants to scavenge ROS and brought promising results regarding growth and productivity of crops under stress conditions. Moreover, the antioxidants play a diverse role in inducing abiotic stress tolerance in plants. Till now, a number of exogenous antioxidants have been reported, but still there is a need to discover more economical antioxidants so that they can be used for beneficial purposes.

References

Abbas, S., Latif, H. H., & Elsherbiny, E. A. (2013). Effect of 24-epibrassinolide on the physiological and genetic changes on two varieties of pepper under salt stress conditions. *Pakistan Journal of Botany, 45*(4), 1273–1284.

Abd Allaha, E. F., Alqarawia, A. A., Hashem, A., Wirthe, S., & Egamberdievae, D. (2018). Regulatory roles of 24-epibrassinolide in tolerance of Acacia gerrardii Benth to salt stress. *Bioengineered, 9*, 61–71.

Abedini, M., & Hassani, B. D. (2015). Salicylic acid affects wheat cultivars antioxidant system under saline and non-saline condition. *Russian Journal of Plant Physiology, 62*, 604–610.

Agada, O. O. (2016). Abiotic stress, antioxidants and crop productivity: The mitigating role of exogenous substances. *Greener Journal of Agricultural Science, 6*(2), 79–86.

Agati, G., Brunetti, C., Di Ferdinando, M., Ferrini, F., Pollastri, S., & Tattini, M. (2013). Functional roles of flavonoids in photoprotection: New evidence, lessons from the past. *Plant Physiology and Biochemistry, 72*, 35–45.

Aguilera-Carbo, A. F., Augur, C., Prado-Barragan, L. A., Aguilar, C. N., & Favela-Torres, E. (2008). Extraction and analysis of ellagic acid from novel complex sources. *Chemical Papers, 62*(4), 440–444.

Ahmad, I., Basra, S. M. A., & Wahid, A. (2014). Exogenous application of ascorbic acid, salicylic acid and hydrogen peroxide improves the productivity of hybrid maize at low temperature stress. *International Journal of Agriculture and Biology, 16*(4), 825–830.

Ahsan, H., Ahad, A., & Siddiqui, W. A. (2015). A review of characterization of tocotrienols from plant oils and foods. *Journal of Chemical Biology, 8*(2), 45–59.

Akhtar, J., Ahmad, R., Ashraf, M. Y., Tanveer, A., Waraich, E. A., & Oraby, H. (2013). Influence of exogenous application of salicylic acid on salt-stressed mungbean (Vignaradiata): growth and nitrogen metabolism. *Pakistan Journal of Botany, 45*(1), 119–125.

Akram, N. A., Shafiq, F., & Ashraf, M. (2017). Ascorbic acid-a potential oxidant scavenger and its role in plant development and abiotic stress tolerance. *Frontiers in Plant Science*. https://doi.org/10.3389/fpls.2017.00613

Al Kharusi, L., Al Yahyai, R., & Mahmoud Yaish, W. (2019). Antioxidant response to salinity in salt-tolerant and salt-susceptible cultivars of date palm. *Agriculture, 9*, 8. https://doi.org/10.3390/agriculture9010008

Albaladejo, I., Meco, V., Plasencia, F., Flores, F. B., Bolarin, M. C. A. N. D., & Egea, I. (2017). Unravelling the strategies used by the wild tomato species Solanum pennellii to confront salt stress: from leaf anatomical adaptations to molecular responses. *Environmental and Experimental Botany, 135*, 1–12.

Ali, Q., Athar, H. R., & Ashraf, M. (2006). Influence of exogenously applied brassinosteroids on the mineral nutrient status of two wheat cultivars grown under saline conditions. *Pakistan Journal of Botany, 38*, 1621–1632.

Ali, B., Hayat, S., & Ahmad, A. (2007). 28-Homobrassinolide ameliorates the saline stress in chickpea (Cicer arietinum L.). *Environmental and Experimental Botany, 59*(2), 217–223.

Ali, E., Kaleem Ullah, K., Jawad, M. S., Mumtaz, A. S., Nazim, H., Xue, D., et al. (2015). Bioinformatics study of tocopherol biosynthesis pathway genes in Brassicarapa. *International Journal of Current Microbiology and Applied Sciences, 4*(3), 721–732.

Alla, M. N., Badrani, E., & Mohammed, F. (2019). Exogenous trehalose alleviates the adverse effects of salinity stress in wheat. *Turkish Journal of Botany, 43*, 48–57. https://doi.org/10.3906/bot-1803-36

Almeselmani, M., Deshmukh, P. S., Sairam, R. K., Kushwaha, S. R., & Singh, T. P. (2006). Protective role of antioxidant enzymes under high temperature stress. *Plant Science, 171*, 382–388.

Alscher, R. G., Erturk, N., & Heath, L. S. (2002). Role of superoxide dismutases (SODs) in controlling oxidative stress in plants. *Journal of Experimental Botany, 53*(372), 1331–1341.

Alvarez-Suarez, J. M., Giampieri, F., Tulipani, S., Casoli, T., Di Stefano, G., Gonzalez-Paramas, A. M., et al. (2014). One month strawberry-rich anthocyanin supplementation ameliorates cardiovascular risk, oxidative stress markers and platelet activation in humans. *The Journal of Nutritional Biochemistry, 25*, 289–294.

Alyemeni, M. N., Hayat, S., Wijaya, L., & Anaji, A. (2013). Foliar application of 28-homobrassinolide mitigates salinity stress by increasing the efficiency of photosynthesis in Brassicajuncea. *Acta Botânica Brasílica, 27*(3), 502–505.

Amal, F. M., Eldina, Z., & Ibrahim, A. H. (2015). Some biochemical changes and activities of antioxidant enzymes in developing date palm somatic and zygotic embryos in vitro. *Annals of Agricultural Science, 60*, 121–130.

Ames, B. N., Shigenaga, M. K., & Hagen, T. M. (1993). Oxidants, antioxidants, and the degenerative diseases of aging. *Proceedings of the National Academy of Sciences, 90*(17), 7915–7922.

Anjum, S. A., Wang, L. C., Farooq, M., Hussain, M., Xue, L. L., & Zou, C. M. (2011). Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. *Journal of Agronomy and Crop Science, 197*(3), 177–185.

Anuradha, S., & Rao, S. S. R. (2003). Application of brassinosteroids to rice seeds (Oryzasativa L.) reduced the impact of salt stress on growth, prevented photosynthetic pigment loss and increased nitrate reductase activity. *Plant Growth Regulation, 40*(1), 29–32.

Anuradha, S., & Rao, S. S. R. (2009). Effect of 24-epibrassinolide on the photosynthetic activity of radish plants under cadmium stress. *Photosynthetica, 47*(2), 317–320.

Anwar, A., Bai, L., Miao, L., Liu, Y., Li, S., Yu, X., & Li, Y. (2018). 24-Epibrassinolide ameliorates endogenous hormone levels to enhance low-temperature stress tolerance in cucumber seedlings. *International Journal of Molecular Sciences, 19*. https://doi.org/10.3390/ijms19092497

Apel, K., & Hirt, H. (2004). Reactive oxygen species: metabolism, oxidative stress, and signal transduction. *Annual Review of Plant Biology, 55*, 373–399.

Arfan, M., Athar, H. R., & Ashraf, M. (2007). Does exogenous application of salicylic acid through the rooting medium modulate growth and photosynthetic capacity in two differently adapted spring wheat cultivars under salt stress? *Journal of Plant Physiology, 6*(4), 685–694.

Arora, N., Bhardwaj, R., Sharma, P., & Arora, H. K. (2008). Effects of 28-homobrassinolide on growth, lipid peroxidation and antioxidative enzyme activities in seedlings of Zea mays L. under salinity stress. *Acta Physiologiae Plantarum, 30*(6), 833–839.

Ashraf, M. (2009). Biotechnological approach of improving plant salt tolerance using antioxidants as markers. *Biotechnology Advances, 27*, 84–93.

Ashraf, M., & Arfan, M. (2005). Gas exchange characteristics and water relations in two cultivars of Hibiscus esculentus under waterlogging. *Biologia Plantarum, 49*, 459–462.

Ashraf, M., & Harris, P. J. C. (2004). Potential biochemical indicators of salinity tolerance in plants. *Plant Science, 166*, 3–16.

Ashraf, M., & Harris, P. J. C. (2013). Photosynthesis under stressful environments: An overview. *Photosynthetica, 51*, 163–190.

Ashraf, U., & Tang, X. (2017). Yield and quality responses, plant metabolism and metal distribution pattern in aromatic rice under lead (Pb) toxicity. *Chemosphere, 176*, 141–155.

Ashraf, M. A., Ashraf, M., & Ali, Q. (2010). Response of two genetically diverse wheat cultivars to salt stress at different growth stages: Leaf lipid peroxidation and phenolic contents. *Pakistan Journal of Botany, 42*, 559–565.

Ashraf, M. A., Ahmad, M. S. A., Ashraf, M., Al-Qurainy, F., & Ashraf, M. Y. (2011). Alleviation of waterlogging stress in upland cotton (Gossypium hirsutum L.) by exogenous application of potassium in soil and as a foliar spray. *Crop & Pasture Science, 62*(1), 25–38.

Ashraf, U., Kanu, A. S., Mo, Z., Hussain, S., Anjum, S. A., Khan, I., Abbas, R. N., & Tang, X. (2015). Lead toxicity in rice: effects, mechanisms, and mitigation strategies—a mini review. *Environmental Science and Pollution Research, 22*(23), 18318–18332.

Ashraf, U., Kanu, A. S., Deng, Q., Mo, Z., Pan, S., Tian, H., & Tang, X. (2017a). Lead (Pb) toxicity; physio-biochemical mechanisms, grain yield, quality, and Pb distribution proportions in scented rice. *Frontiers in Plant Science, 8*, 259.

Ashraf, U., Hussain, S., Anjum, S. A., Abbas, F., Tanveer, M., Noor, M. A., & Tang, X. (2017b). Alterations in growth, oxidative damage, and metal uptake of five aromatic rice cultivars under lead toxicity. *Plant Physiology and Biochemistry, 115*, 461–471.

Ashraf, U., Hussain, S., Akbar, N., Anjum, S. A., Hassan, W., & Tang, X. (2018). Water management regimes alter Pb uptake and translocation in fragrant rice. *Ecotoxicology and Environmental Safety, 149*, 128–134.

Ashraf, U., Mahmood, M. H. U. R., Hussain, S., Abbas, F., Anjum, S. A., & Tang, X. (2020). Lead (Pb) distribution and accumulation in different plant parts and its associations with grain Pb contents in fragrant rice. *Chemosphere, 248*, 126003.

Athar, H. R., Khan, A., & Ashraf, M. (2008). Exogenously applied ascorbic acid alleviates salt-induced oxidative stress in wheat. *Environmental and Experimental Botany, 63*(1–3), 224–231.

Athar, H. R., Khan, A., & Ashraf, M. (2009). Inducing salt tolerance in wheat by exogenously applied ascorbic acid through different modes. *Journal of Plant Nutrition, 32*(11), 1799–1817.

Avalbaev, A. M., Yuldashev, R. A., Fatkhutdinova, R. A., Urusov, F. A., Safutdinova, Y. V., & Shakirova, F. M. (2010). The influence of 24-epibrassinolide on the hormonal status of wheat plants under sodium chloride. *Applied Biochemistry and Microbiology, 46*, 99–102.

Azzedine, F., Gherroucha, H., & Baka, M. (2011). Improvement of salt tolerance in durum wheat by ascorbic acid application. *Stress: the International Journal on Biology of Stress, 7*, 27–37.

Babar, S., Siddiqi, E. H., Hussain, I., Bhatti, K. H., & Rasheed, R. (2014). Mittigating the effects of salinity by foliar application of salicylic acid in fenugreek. *Physiology Journal, 2014*, 1–6.

Bagherifard, A., Bagheri, A., Sabourifard, H., Bagherifard, G., & Najar, M. (2015). The effect of salicylic acid on some morphological and biochemistry parameters under salt stress in herb artichoke (CynaraScolymus L.). *Research Journal of Fisheries and Hydrobiology, 10*, 745–750.

Bajguz, A., & Hayat, S. (2009). Effects of brassinosteroids on the plant responses to environmental stresses. *Plant Physiology and Biochemistry, 47*(1), 1–8. https://doi.org/10.1016/j.plaphy.2008.10.002

Barch, D. H., Rundhaugen, L. M., Stoner, G. D., Pillay, N. S., & Rosche, W. A. (1996). Structure-function relationships of the dietary anticarcinogen ellagic acid. *Carcinogenesis, 17*(2), 265–269. https://doi.org/10.1093/carcin/17.2.265

Batool, E. J., Ahmad, Z., & Faheem, A. F. T. (2012). Effect of exogenous application of ascorbic acid on antioxidant enzyme activities, proline contents and growth parameters of Saccharum spp. Hybrid cv. HSF-240 under salt stress. *Turkish Journal of Biology, 36*, 630–640.

Batool, N., Noor, T., Ilyas, N., & Shahzad, A. (2015). Molecular basis of salt stress tolerance in crop plants. *Pure and Applied Biology, 4*(1), 80–88.

Bauwe, H., Hagemann, M., Kern, R., & Timm, S. (2012). Photorespiration has a dual origin and manifold links to central metabolism. *Current Opinion in Plant Biology, 15*, 269–275.

Bechtold, U., & Field, B. (2018). Molecular mechanisms controlling plant growth during abiotic stress. *Journal of Experimental Botany, 69*, 2753–2758.

Behnamnia, M. (2015). Protective roles of brassinolide on tomato seedlings under drought stress. *International Journal of Agricultural Sciences, 8*, 552–559.

Bendary, E. R. R., Francis, H. M. G., Ali, M. I., Sarwat, S., & El-Hady. (2013). Antioxidant and structure–activity relationships (SARs) of some phenolic and anilines compounds. *Annals of Agricultural Science, 58*, 173–181.

Bhandari, P. R., & Kamdod, M. A. (2012). Emblica officinalis (Amla): A review of potential therapeutic applications. *International Journal of Green Pharmacy, 6*, 257–269.

Bishop, G. J., & Yakota, T. (2001). Plants steroid hormones, brassinosteroids: Current highlights of molecular aspects on their synthesis/metabolism, transport, perception and response. *Plant & Cell Physiology, 42*(2), 114–120.

Bowler, C., Montagu, M. V., & Inze, D. (1992). Superoxide dismutase and stress tolerance. *Annual Review of Plant Physiology and Plant Molecular Biology, 43*(1), 83–116. https://doi.org/10.1146/annurev.pp.43.060192.000503

Bramley, P. M., Elmadfa, I., Kafatos, A., Kelly, F. J., Manios, Y., Roxborough, H. E., et al. (2000). Review: Vitamin E. *Journal of the Science of Food and Agriculture, 80*, 913–938.

Camp, W. V., Willekens, H., Bowler, C., Montagu, M. V., Inzé, D., Reupold-Popp, P., et al. (1994). Elevated levels of superoxide dismutase protect transgenic plants against ozone damage. *BioTechnol, 12*(2), 165–168.

Carletti, G., Lucini, L., Busconi, M., Marocco, A., & Bernardi, J. (2013). Insight into the role of anthocyanin biosynthesis-related genes in Medicagotruncatula mutants impaired in pigmentation in leaves. *Plant Physiology and Biochemistry, 70*, 123–132. https://doi.org/10.1016/j.plaphy.2013.05.030

Castañeda-Ovando, A., Pacheco-Hernández, M. L., Páez-Hernández, M. E., Rodríguez, J. A., & Galán-Vidal, C. (2009). Chemical studies of anthocyanins: a review. *Food Chemistry, 113*, 859–871.

Caverzan, A., Passaia, G., Rosa, S. B., Ribeiro, C. W., Lazzarotto, F., & Margis-Pinheiro, M. (2012). Plant responses to stresses: role of ascorbate peroxidase in the antioxidant protection. *Genetics and Molecular Biology, 35*, 1011–1019.

Cavusoglu, K., & Bilir, G. (2015). Effects of ascorbic acid on the seed germination, seedling growth and leaf anatomy of barley under salt stress. *APRN Journal of Agricultural and Biological Science, 10*(4), 124–129.

Cenacchi, N. (2014). Drought risk reduction in agriculture: A review of adaptive strategies in East Africa and the Indo-Gangtic Plain of South Asia IFPRI discussion paper series. *Washington: International Food Policy Research Ins, 46*.

Chalker-Scott, L. (1999). Environmental significance of anthocyanins in plant Stress responses. *Photochemistry and Photobiology, 70*(1), 1.

Chalker-Scott, L. (2002). Do anthocyanins function as osmoregulators in leaf tissues? *Advances in Botanical Research, 37*, 103–127.

Cheng, Y., Zhu, W., Chen, Y., Ito, S., Asami, T., & Wang, X. (2014). Brassinosteroids control root epidermal cell fate via direct regulation of a MYB-bHLH-WD40 complex by GSK3-like kinases. *eLife, 3*. https://doi.org/10.7554/elife.02525

Cheng, W., Huang, Y., Meng, C., Zhang, N., Zeng, H., Ren, J., Li, Y., & Sun, Y. (2015). *Effect of exogenous 24-epibrassinolide on salt resistance of watermelon (Citrulluslanatus L.) under salinity stress* (p. 68). 5th International Conference on Advanced Design and Manufacturing Engineering.

Chory, J., Peto, C., Feinbaum, R., Pratt, L., & Ausubel, F. (1989). Arabidopsis thaliana mutant that develops as a light-grown plant in the absence of light. *Cell, 58*(5), 991–999.

Chukwu, O. O. C. (2012). Carrot (Daucuscarrota), garlic (Alliumsativum) and ginger (Zingiberfficinale) extracts as bacteria selective agents in culture media. *African Journal of Microbiology Research, 6*(2), 219–224.

Close, D. C., & Beadle, C. L. (2003). The ecophysiology of foliar anthocyanin. *The Botanical Review, 69*(2), 149–161.

Clouse, S. D., & Sasse, J. M. (1998). Brassinosteroids: Essential regulators of plant growth and development. *Annual Review of Plant Physiology and Plant Molecular Biology, 49*(1), 427–451. https://doi.org/10.1146/annurev.arplant.49.1.427

Conklin, P. L., & Barth, C. (2004). Ascorbic acid, a familiar small molecule intertwined in the response of plants to ozone, pathogens, and the onset of senescence. *Plant, Cell & Environment, 27*(8), 959–970.

Cotsaftis, O., Plett, D., Johnson, A. A., Walia, H., Wilson, C., Ismail, A. M., Close, T. J., Tester, M., & Baumann, U. (2011). Root-specific transcript profiling of contrasting rice genotypes in response to salinity stress. *Molecular Plant, 4*, 25–41.

Dalio, R. J. D., Pinheiro, H. P., Sodek, L., & Haddad, C. R. B. (2011). The effect of 24-epibrassinolide and clotrimazole on the adaptation of Cajanuscajan (L.) Millsp. to salinity. Act. *Physiologia Plantarum, 33*(5), 1887–1896.

Dalio, R. J., Pinheiro, H., Sodek, L., & Haddad, C. R. (2013). 24-epibrassinolide restores nitrogen metabolism of pigeon pea under saline stress. *Botanical Studies, 54*(1), 9.

Davey, M. W., Montagu, M. V., Inzé, D., Sanmartin, M., Kanellis, A., Smirnoff, N., et al. (2000). Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *Journal of the Science of Food and Agriculture, 80*(7), 825–860.

De Pinto, M. C., Locato, V., Sgobba, A., Romero-Puertas, M. D. C., Gadaleta, C., Delledonne, M., & de Gara, L. (2013). S-nitrosylation of ascorbate peroxidase is part of programmed cell death signaling in tobacco Bright Yellow-cells. *Plant Physiology, 163*, 1766–1775.

Dehghan, G., Rezazadeh, L., & Habibi, G. (2011). Exogenous ascorbate improves antioxidant defense system and induces salinity tolerance in soybean seedlings. *Acta Biologica Szegediensis, 55*(2), 261–264.

Deng, X. P., Cheng, Y. J., Wu, X. B., Kwak, S. S., Chen, W., & Egrinya, A. (2012). Exogenous hydrogen peroxide positively influences root growth and metabolism in leaves of sweet potato seedlings. *Australian Journal of Crop Science, 6*, 1572–1578.

Desoky, E.-S. M., & Merwad, A.-R. M. (2015). Improving the salinity tolerance in wheat plants using salicylic and ascorbic acids. *The Journal of Agricultural Science, 7*(10), 203–217.

Devendra, C. (2012). Climate Change Threats and effects: challenges for agriculture and food security. ASM series on climate change. *Academy of Sciences Malaysia, 56*, ISBN 978-983-9445-82-4.

Dey, S., Sidor, A. O., & Rourke, B. (2016). Compartment-specific control of reactive oxygen species scavenging by antioxidant pathway enzymes. *The Journal of Biological Chemistry, 291*(21), 11185–11197.

Dhamgaye, S., & Gadre, R. (2015). Salinity stress effects on growth and nitrate assimilation in bean seedlings likely to be mediated via nitric oxide. *Stress: The International Journal on Biology of Stress, 11*, 137–146.

Dhaubhadel, S., Browning, K. S., Gallie, D. R., & Krishna, P. (2002). Brassinosteroid functions to protect the translational machinery and heat-shock protein synthesis following thermal stress. *The Plant Journal, 29*(6), 681–691.

Ding, H. D., Zhu, X. H., Zhu, Z. W., Yang, S. J., Zha, D. S., & Wu, X. X. (2012). Amelioration of salt-induced oxidative stress in eggplant by application of 24-epibrassinolide. *Biologia Plantarum, 56*, 767–770.

Dkhil, B. B., & Denden, M. (2012). Effect of salt stress on growth, anthocyanins, membrane permeability and chlorophyll fluorescence of Okra (Abelmoschusesculentus L.) seedlings. *Journal of Plant Physiology, 7*(4), 174–183.

Dolatabadian, A., Sanavy, S. A. M. M., & Chashmi, N. A. (2008). The effects of foliar application of ascorbic acid (Vitamin C) on antioxidant enzymes activities, lipid peroxidation and proline accumulation of canola (Brassica napus L.) under conditions of salt stress. *Journal of Agronomy and Crop Science, 194*(3), 206–213.

Dong, Y. J., Wang, Z. L., Zhang, J. W., Liu, S., He, Z. L., & He, M. R. (2015). Interaction effects of nitric oxide and salicylic acid in alleviating salt stress of Gossypium hirsutum L. *Journal of Soil Science and Plant Nutrition, 15*(3), 561–573.

Droillard, M. J., & Paulin, A. (1990). Isozymes of superoxide dismutase in mitochondria and peroxisomes isolated from petals of carnation (Dianthuscaryophyllus) during senescence. *Plant Physiology, 94*(3), 1187–1192.

Du, H., Liang, Y., Pei, K., & Ma, K. (2011). UV radiation-responsive proteins in rice leaves: a proteomic analysis. *Plant & Cell Physiology, 52*(2), 306–316.

Durigan, D. R. J., Pinheiro, H. P., Sodek, L., & Haddad, C. R. B. (2011). The effect of 24-epibrassinolide and clotrimazole on the adaptation of Cajanus cajan (L.) Mill sp to salinity. *Acta Physiologiae Plantarum, 33*, 1887–1896.

Eitenmiller, R. R., Landen, W. O., & Ye, L. (2007). *Vitamin analysis for the health and food sciences* (p. 664). CRC Press. ISBN 9780849397714 - CAT# 9771.

Ekinci, M., Yildirim, E., Dursun, A., & Turan, M. (2012). Mitigation of salt stress in lettuce (Lactuca sativa L. var. Crispa) by seed and foliar 24-epibrassinolide treatments. *Horticultural Science, 47*, 631–663.

El Hariri, D. M., Sadak, M. S., & El-Bassiouny, H. M. S. (2010). Response of flax cultivars to ascorbic acid and? – Tocopherol under salinity stress conditions. *International Journal of Academic Research, 2*(6), 101–109.

Eleiwa, M. E., Bafeel, S. O., & Ibrahim, S. A. (2011). Influence of brassinosteroids on wheat plant (Triticum aestivum L.) production under salinity stress conditions. I. Growth parameters and photosynthetic pigments. *Australian Journal of Basic and Applied Sciences, 5*, 58–65.

El-Feky, S. (2014). Effect of exogenous application of brassinolide on growth and metabolic activity of wheat seedlings under normal and salt stress conditions. *Annual Research and Review in Biology, 4*(24), 3687–3698.

El-Soud, W. A., Hegab, M. M., AbdElgawad, H., Zinta, G., & Asard, H. (2013). Ability of ellagic acid to alleviate osmotic stress on chickpea seedlings. *Plant Physiology and Biochemistry, 71*, 173–183.

Elwan, M. W. M., Shaban, W. I., Mohammed, A. I., & Hossein, H. E. A. (2007). Effect of foliar application of Ascorbic acid on plant growth, powdery meldow disease, chemical composition, fruit yield. *The Journal of Agricultural Science, 32*, 10359–10378.

Epstein, E. (1972). *Mineral nutrition of plants: Principles and perspectives*. Wiley.

Eryılmaz, F. (2006). The relationships between salt stress and anthocyanin content in higher plants. *Biotechnology and Biotechnological Equipment, 20*(1), 47–52.

Espinosa-Diez, C., Miguel, V., Mennerich, D., Kietzmann, T., Sánchez-Pérez, P., Cadenas, S., & Lamas, S. (2015). Antioxidant responses and cellular adjustments to oxidative stress. *Redox Biology, 6*, 183–197.

Fahad, S., & Bano, A. (2012). Effect of salicylic acid on physiological and biochemical characterization of maize grown in saline area. *Pakistan Journal of Botany, 44*(4), 1433–1438.

Falk, J., & Munné-Bosch, S. (2010). Tocochromanol functions in plants: antioxidation and beyond. *Journal of Experimental Botany, 61*(6), 1549–1566.

Fanciullino, A. L., Dhuique-Mayer, C., Luro, F., Casanova, J., Morillon, R., & Ollitrault, P. (2006). Carotenoid diversity in cultivated citrus is highly influenced by genetic factors. *Journal of Agricultural and Food Chemistry, 54*, 4397–4406. https://doi.org/10.1021/jf0526644

Farahat, M. M., Mazhar, A. A. M., Mahgoub, M. H., & Zaghloul, S. M. (2013). Salt tolerance in Grevillea robusta seedlings via foliar application of ascorbic acid. *Middle-East Journal of Scientific Research, 14*, 9–15.

Farheen, J., Mansoor, S., & Abideen, Z. (2018). Exogenously applied salicylic acid improved growth, photosynthetic pigments and oxidative stability in Mungbean seedling (Vigna radiata) at salt stress. *Pakistan Journal of Botany, 50*(3), 901–912.

Fariduddin, Q., Mir, B. A., Yusuf, M., & Ahmad, A. (2013). Comparative roles of brassinosteroids and polyamines in salt stress tolerance. *Acta Physiologiae Plantarum, 35*(7), 2037–2053.

Fathima, S. A. M., Johnson, M., & Lingakumar, K. (2011). Effect of crude brassinosteroid extract on growth and biochemical changes of GosssypiumhirsutumL. and Vigna mungo L. *Stress: the International Journal on Biology of Stress, 7*, 324–334.

Fedina, E. O. (2013). Effect of 24-epibrassinolide on pea protein tyrosine phosphorylation after salinity action. *Russian Journal of Plant Physiology, 60*, 351–358.

Fernie, A. R., & Szilvia, Z. T. (2015). Identification of the elusive chloroplast ascorbate transporter extends the substrate specificity of the PHT family. *Molecular Plant, 8*, 674–676.

Fink, R. C., & Scandalios, J. G. (2002). Molecular evolution and structure–function relationships of the superoxide dismutase gene families in angiosperms and their relationship to other eukaryotic and prokaryotic superoxide dismutases. *Archives of Biochemistry and Biophysics, 399*(1), 19–36.

Flora, S. J., Mittal, M., & Mehta, A. (2008). Heavy metal induced oxidative stress and its possible reversal by chelation therapy. *The Indian Journal of Medical Research, 4*, 501–523.

Folzer, H., Dat, J., Capelli, N., Rieffel, D., & Badot, P. M. (2006). Response to flooding of sessile oak: An integrative study. *Tree Physiology, 26*, 759766.

Ford, K. L., Cassin, A., & Bacic, A. (2011). Quantitative proteomic analysis of wheat cultivars with differing drought stress tolerance. *Frontiers in Plant Science, 2*. https://doi.org/10.3389/fpls.2011.00044

Foyer, C. H., & Shigeoka, S. (2011). Understanding oxidative stress and antioxidant functions to enhance photosynthesis. *Plant Physiology, 155*, 93–100.

Fridovich, I. (1995). Superoxide radical and superoxide dismutases. *Annual Review of Biochemistry, 64*(1), 97–112.

Fritsche, S., Xingxing, W., Lars, N. I., Ida, S., Silke, H., Jessica, E., et al. (2014). Genetic and functional analysis of tocopherol biosynthesis pathway genes from rapeseed (Brassica napus L.). *Plant Breeding, 133*(4), 470–479.

Galano, A., Marquez, M. F., & Lez, A. G. (2014). Ellagic Acid: An Unusually Versatile Protector against Oxidative Stress. *Chemical Research in Toxicology, 27*, 904–918.

Gao, H. J., Yang, H. Y., Bai, J. P., Liang, X. Y., Lou, Y., Zhang, J. L., et al. (2014). Ultrastructural and physiological responses of potato (Solanumtuberosum) plantlets to gradient saline stress. *Frontiers in Plant Science, 5*, 1–14.

Gill, S. S., & Tuteja, N. (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry, 48*, 909–930.

Gomez, J. M. (2003). Location and effects of long-term NaCl stress on superoxide dismutase and ascorbate peroxidase isoenzymes of pea (Pisum sativum cv. Puget) chloroplasts. *Journal of Experimental Botany, 55*(394), 119–130.

Gónmez-Bellot, M. J., Álvarez, S., Bañón, S., Ortuño, M. F., & Sánchez-Blanco, M. J. (2013). Physiological mechanisms involved in the recovery of euonymus and laurustinus subjected to saline waters. *Agricultural Water Management, 128*, 131–139. https://doi.org/10.1016/j.agwat.2013.06.017

Gul, H., Rafiq, A., & Muhammad, H. (2015). Impact of exogenously applied ascorbic acid on growth, some biochemical constituents and ionic composition of guar (Cymopsistetragonoloba) Subjected to salinity stress. *Journal of Life Science, 03*(01), 22–40.

Gupta, B. I., & Huang, B. (2014). Mechanism of salinity tolerance in plants: physiological, biochemical, and molecular characterization. *International Journal of Plant Genomics, 2014*. https://doi.org/10.1155/2014/701596

Hameed, A., Hussain, T., Gulzar, S., Aziz, I., Gul, B., & Khan, M. A. (2012). Salt tolerance of a cash crop halophyte Suaedafruticosa: Biochemical responses to salt and exogenous chemical treatments. *Acta Physiologiae Plantarum, 34*, 2331–2340.

Hameed, A., Gulzar, S., Aziz, I., Hussain, T., Gul, B., & Khan, M. A. (2015). Effects of salinity and ascorbic acid on growth, water status and antioxidant system in a perennial halophyte. *AoB Plants, 7*. https://doi.org/10.1093/aobpla/plv004

Hamideldin, N., Eliwa, N. E., & Hussein, O. S. (2017). Role of jasmonic acid and gamma radiation in alleviating salt stress in Moringa. *International Journal of Agriculture and Biology, 19*(1). https://doi.org/10.17957/IJAB/15.0245

Han, D. H., Lee, M. J., & Kim, J. H. (2006). Antioxidant and apoptosis-inducing activities of ellagic acid. *Anticancer Research, 26*, 3601–3606.

Harborne, J. B. (1998). *Phytochemical methods* (pp. 60–66). Chapman Hall.

Hasanuzzaman, M., Hossain, M. A., Teixeira, da Silva, J. A., & Fujita, M. (2012). Plant response and tolerance to abiotic oxidative stress: Antioxidant defense is a key factor. *Crop Stress Manag. Persp. Strat*, 261–315.

Hasanuzzaman, M., Nahar, K., Alam, M. M., Roychowdhury, R., & Fujita, M. (2013). Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. *International Journal of Molecular Sciences, 14*, 9643–9684.

Hatier, J.-H. B., & Gould, K. S. (2008). Foliar anthocyanins as modulators of stress signals. *Journal of Theoretical Biology, 253*(3), 625–627.

Hayat, S., Hasan, S. A., Yusuf, M., Hayat, Q., & Ahmad, A. (2010). Effect of 28 homobrassinolide on photosynthesis, fluorescence and antioxidant system in the presence or absence of salinity and temperature in Vigna radiata. *Environmental and Experimental Botany, 69*, 105–112.

Hayat, S., Alyemeni, M. N., & Hasan, S. A. (2012). Foliar spray of brassinosteroid enhances yield and quality of Solanumlycopersicum under cadmium stress. *Saudi Journal of Biological Sciences, 19*(3), 325–335.

Heider, S. A. E., Peters-Wendisch, P., Wendisch, V. F., Beekwilder, J., & Brautaset, T. (2014). Metabolic engineering for the microbial production of carotenoids and related products with a focus on the rare C50 carotenoids. *Applied Microbiology and Biotechnology, 98*(10), 4355–4368.

Herschbach, C., Scheerer, U., & Rennenberg, H. (2010). Redox states of glutathione and ascorbate in root tips of poplar (Populustremula3 P. alba) depend on phloem transport from the shoot to the roots. *Journal of Experimental Botany, 61*, 1065–1074.

Holton, T. A., & Cornish, E. C. (1995). Genetics and biochemistry of anthocyanin biosynthesis. *Plant Cell, 7*(7), 1071. https://doi.org/10.2307/3870058

Housam, H., Wari, K., & Zaid, A. A. (2014). Estimating the antioxidant activity for natural antioxidants (tocochromanol) and synthetic one by DPPH. *International Journal of Pharmacy and Pharmaceutical Sciences, 6*, 441–444.

Hughes, N. M., & Smith, W. K. (2007). Attenuation of incident light in Galaxurceolata (Diapensiaceae): concerted influence of adaxial and abaxial anthocyanic layers on photoprotection. *American Journal of Botany, 94*(5), 784–790.

Husen, A., Iqbal, M., Sohrab, S. S., & Ansari, M. K. A. (2018). Salicylic acid alleviates salinity-caused damage to foliar functions, plant growth and antioxidant system in Ethiopian mustard (Brassica carinata A. Br.). *Agricultural and Food Science*. https://doi.org/10.1186/s40066-018-0194-0

Indira, K. P. A., Sujata, M., Khopde, S., Santosh, K., & Hari, M. (2002). Free radical studies of ellagic acid, a natural phenolic antioxidant. *Journal of Agricultural and Food Chemistry, 50*, 2200–2206.

Ismail, A., Takeda, S., & Nick, P. (2014). Life and death under salt stress: same players, different timing. *Journal of Experimental Botany, 65*(12), 2963–2979.

Jan, S., Hamayun, M., Wali, S., Bibi, A., Gul, H., & Rahim, F. (2016). Foliar application of ascorbic acid mitigates sodium chloride induced stress in eggplant (Solanummelongena L.). *Pakistan Journal of Botany, 48*(3), 869–876.

Janda, T., Szalai, G., Tari, I., & Páldi, E. (1999). Hydroponic treatment with salicylic acid decreases the effects of chilling injury in maize (Zeamays L.) plants. *Planta, 208*(2), 175–180.

Javid, M., Ali, G. S., Foad, M., Seyed, A. M. M. S., & Iraj, A. (2011). The role of phytohormones in alleviating salt stress in crop plants. *Australian Journal of Crop Science, 5*(6), 726–734.

Jayakannan, M. J., Bose, O., Babourina, Z., & Shabala, S. (2015). Salicylic acid in plant salinity stress signalling and tolerance. *Plant Growth Regulation, 76*, 25–40.

Jin, S. H., Li, X. Q., Wang, G. G., & Zhu, X. T. (2015). Brassinosteroids alleviate high-temperature injury in Ficusconcinna seedlings via maintaining higher antioxidant defence and glyoxalase systems. *AoB ANTS, 7*. https://doi.org/10.1093/aobpla/plv009

Jin, X., Liu, T., Xu, J., Gao, Z., & Hu, X. (2019). Exogenous GABA enhances muskmelon tolerance to salinity-alkalinity stress by regulating redox balance and chlorophyll biosynthesis. *BMC Plant Biology, 19*, 48. https://doi.org/10.1186/s12870-019-1660

Kagale, S., Divi, U. K., Krochko, J. E., Keller, W. A., & Krishna, P. (2007). Brassinosteroid confers tolerance in Arabidopsisthaliana and Brassicanapus to a range of abiotic stresses. *Planta, 225*(2), 353–364.

Kamal-Eldin, A., & Appelqvist, L. A. (1996). The chemistry and antioxidant properties of tocopherols and tocotrienols. *Lipids, 31*(7), 671–701.

Kandil, A. A., Sharief, A. E., & Alkhamsa, A. K. D. (2017). Influence of antioxidants and salinity stress on seed viability characters of some wheat cultivars. *Res. Plant Biol, 7*, 13–20.

Karlidag, H., Yildirim, E., & Turan, M. (2011). Role of 24-epibrassinolide in mitigating the adverse effects of salt stress on stomatal conductance, membrane permeability, and leaf water content, ionic composition in salt stressed strawberry (Fragariaananassa). *Scientia Horticulturae, 130*(1), 133–140.

Kartal, G., Temel, A., Arican, E., & Gozukirmizi, N. (2009). Effects of brassinosteroids on barley root growth, antioxidant system and cell division. *Plant Growth Regulation, 58*(3), 261–267.

Kasim, W. A. E. A., Saad-Allah, K. M., & Hamouda, M. (2016). Seed priming with extracts of two seaweeds alleviates the physiological and molecular impacts of salinity stress on Radish (Raphanussativus). *International Journal of Agriculture and Biology, 18*(3), 653–660.

Kasote, D. M., Katyare, S. S., Hegde, M. V., & Bae, H. (2015). Significance of antioxidant potential of plants and its relevance to therapeutic applications. *International Journal of Biological Sciences, 11*(8), 982–991.

Kaur, G., Nelson, K. A., & Motavalli, P. P. (2018a). Early-season soil waterlogging and N fertilizer sources impacts on corn N uptake and apparent N recovery efficiency. *Agranomy, 102*. https://doi.org/10.3390/agronomy8070102

Kaur, H., Sirhindi, G., Bhardwaj, R., Alyemeni, M. N., Kadambot, H. M. S., & Ahmad, P. (2018b). 28-homobrassinolide regulates antioxidant enzyme activities and gene expression in response to salt- and temperature-induced oxidative stress in Brassica juncea. *Scientific Reports, 8*, 8735.

Kawasaki, S., Borchert, C., Deyholos, M., Wang, H., Brazille, S., Kawai, K., Galbraith, D., & Bohnert, H. J. (2001). Gene expression profiles during the initial phase of salt stress in rice. *The Plant Cell, 13*, 889–905.

Khan, A., Ahmed, M. S. A., Athar, H. R., & Ashraf, M. (2006). Interactive effect of foliarly applied ascorbic acid and salt stress on wheat (Triticum aestivum L.) at the seedling stage. *Pakistan Journal of Botany, 38*, 1407–1414.

Khan, A., Lang, I., Amjid, M., Shah, A., Ahmad, I., & Nawaz, H. (2013a). Inducing salt tolerance on growth and yield of sunflower by applying different levels of ascorbic acid. *Journal of Plant Nutrition, 36*(8), 1180–1190.

Khan, M. I. R., Iqbal, N., Masood, A., Per, T. S., & Khan, N. A. (2013b). Salicylic acid alleviates adverse effects of heat stress on photosynthesis through changes in proline production and ethylene formation. *Plant Signaling & Behavior*, 263–274.

Khan, M. I. R., Fatma, M., Per, T. S., Anjum, N. A., & Khan, N. A. (2015). Salicylic acid-induced abiotic stress tolerance and underlying mechanisms in plants. *Frontiers in Plant Science, 6*. https://doi.org/10.3389/fpls.2015.00462

Khan, A., Nazar, S., Lang, I., Nawaz, H., & Hussain, M. A. H. (2017). Effect of ellagic acid on growth and physiologyofcanola (Brassica napus L.) under saline conditions. *Journal of Plant Interactions*. https://doi.org/10.1080/17429145.2017.1400122

Khoshbakht, D., & Asgharei, M. R. (2015). Influence of foliar-applied salicylic acid on growth, gas-exchange characteristics, and chlorophyll fluorescence in citrus under saline conditions. *Photosynthetica, 53*(3), 410–418.

Klause, A. W., Gerd, B., & Michael, T. (2016). The concentration of ascorbic acid and glutathione in13 provenances of Acaciamelanoxylon. *Tree Physiology, 36*(4), 524–532.

Kong, L., Ashraf, U., Cheng, S., Rao, G., Mo, Z., Tian, H., Pan, S., & Tang, X. (2017). Short-term water management at early filling stage improves early-season rice performance under high temperature stress in South China. *European Journal of Agronomy, 90*, 117–126.

Kovalchuk, I. (2010). Multiple roles of radicals in plants. In S. D. Gupta (Ed.), *Reactive oxygen species and antioxidants in higher plants* (1st ed., pp. 31–44). CRC Press.

Krishna, P. (2003). Brassinosteroid-mediated stress responses. *Journal of Plant Growth Regulation, 22*(4), 289–297.

Ksas, B., Becuwe, N., Chevalier, A., & Havaux, M. (2015). Plant tolerance to excess light energy and photooxidative damage relies on plastoquinone biosynthesis. *Scientific Reports, 5*. https://doi.org/10.1038/srep10919

Kumar, K., Kumar, M., Kim, S. R., Ryu, H., & Cho, Y. G. (2013). Insights into genomics of salt stress response in rice. *Rice, 6*, 27. https://doi.org/10.1186/1939-8433-6-27

Kumar, A., Rahal, A., Zoheb, S. M., Prakash, A., & Mandil, R. (2014). Antioxidant role of ascorbic acid on oxidative stress induced by sub-acute exposure of lead and cypermethrin in erythrocytes of Wistar rats. *Toxicological and Environmental Chemistry, 96*, 1248–1259.

Lamaoui, M., Jemo, M., Datla, R., & Faouzi, B. (2018). Heat and drought stresses in crops and approaches for their mitigation. *Frontiers in Chemistry, 6*. https://doi.org/10.3389/fchem.2018.00026

Leão, G. A., Oliveira, J. O., Felipe, R. A., Farnese, F. S., & Soares, G. G. (2014). Anthocyanins, thiols, and antioxidant scavenging enzymes are involved in Lemnagibba tolerance to arsenic. *Journal of Plant Interactions, 9*, 143–151.

Lev-Yadun, S., & Gould, K. S. (2009). Role of anthocyanins in plant defence. In S. Secondary Lev-Yadun & K. S. Gould (Eds.), *Anthocyanins* (pp. 22–28). Springer.

Li, J., & Chory, J. (1999). Brassinosteroid actions in plants. *Journal of Experimental Botany, 50*(332), 275–282.

Li, T., Hu, Y., Dux, Tang, H., Shen, C., & Wu, J. (2014a). Salicylic acid alleviates the adverse effects of salt stress in Torreya grandis cv. Merrillii seedlings by activating photosynthesis and enhancing antioxidant systems. *PLoS One, 9*(10), e109492.

Li, X., Cai, J., Liu, F., Dai, T., Cao, W., & Jiang, D. (2014b). Cold priming drives the sub-cellular antioxidant systems to protect photosynthetic electron transport against subsequent low temperature stress in winter wheat. *Plant Physiology and Biochemistry, 82*, 34–43.

Li, W., Liu, J., Ashraf, U., Li, G., Li, Y., Lu, W., Gao, L., Han, F., & Hu, J. (2016). Exogenous γ-aminobutyric acid (GABA) application improved early growth, net photosynthesis, and associated physio-biochemical events in maize. *Frontiers in Plant Science, 7*, 919.

Lima, G. P. P., Vianello, F., Corrêa, C. R., Campos, R. A. S., Milena, G., & Borguini, M. G. (2014). Polyphenols in fruits and vegetables and its effect on human health. *Food and Nutrition Sciences, 5*. https://doi.org/10.4236/fns.2014.511117

Liochev, S. I., & Fridovich, I. (2003). Reversal of the superoxide dismutase reaction revisited. *Free Radical Biology & Medicine, 34*, 908–910.

Liochev, S. I., & Fridovich, I. (2010). Mechanism of the peroxidase activity of Cu, Zn superoxide dismutase.Free Rad. *Biologie et Médecine, 48*, 1565–1569.

Longo, L., & Vasapollo, G. (2006). Extraction and identification of anthocyanins from Smilaxaspera L. berries. *Food Chemistry, 94*, 226–231.

Mahesh, K., Balaraju, P., Ramakrishna, B., & Rao, S. S. R. (2013). Effect of brassinosteroids on germination and seedling growth of radish (Raphanussativus L.) under PEG-6000 induced water stress. *American Journal of Plant Sciences, 4*(12), 2305–2313.

Malar, S., Vikram, S. S., Favas, P. J. C., & Perumal, V. (2014). Lead heavy metal toxicity induced changes on growth and antioxidative enzymes level in water hyacinths [Eichhornia crassipes (Mart.)]. *Botanical Studies, 55*, 54.

Malik, S., & Ashraf, M. (2012). Exogenous application of ascorbic acid stimulates growth and photosynthesis of wheat (Triticum aestivum L.) under drought. *Soil and Environment, 31*(1), 72–77.

Malini, P., Kanchana, G., & Rajadurai, M. (2011). Antidiabetic efficacy of ellagic acid in streptozotocin-induced Diabetes mellitus in Albino Wistar Rats. *Asian Journal of Pharmaceutical and Clinical Research, 4*, 124–128.

Mani, D., & Kumar, C. (2014). Biotechnological advances in bioremediation of heavy metals contaminated ecosystems: An overview with special reference to phytoremediation. *International journal of Environmental Science and Technology, 11*, 843–872.

Massoud, M. B., Karmous, I., El Ferjani, E., & Chaoui, A. (2018). Alleviation of copper toxicity in germinating pea seeds by IAA, GA3, Ca and citric acid. *Journal of Plant Interactions, 13*, 21–29.

Mathur, J., Molnar, G., Fujioka, S., Takatsuto, S., Sakurai, A., Yokota, T., et al. (1998). Transcription of the Arabidopsis CPD gene, encoding a steroidogenic cytochrome P450, is negatively controlled by brassinosteroids. *The Plant Journal, 14*(5), 593–602.

Mazza, G. (2007). Anthocyanins and heart health. *Annali dell'Istituto Superiore di Sanità, 243*(4), 369–374.

Mehan, S., Kaur, R., Parveen, S., Khanna, D., & Kalra, S. (2015). Polyphenol ellagic acid-targeting to brain: a hidden treasure. *International Journal Neurology Research, 1*, 141–152.

Mène-Saffrané, L., & DellaPenna, D. (2010). Biosynthesis, regulation and functions of tocochromanols in plants. *Plant Physiology and Biochemistry, 48*(5), 301–309.

Mervat, S. H., & Sadak, M. S. (2019). Physiological role of trehalose on enhancing salinity tolerance of wheat plant. *Sadak Bulletin of the National Research Centre, 43*, 53. https://doi.org/10.1186/s42269-019-0098-6

Metwally, A. (2003). Salicylic acid alleviates the aadmium toxicity in barley seedlings. *Plant Physiology, 132*(1), 272–281.

Mezzomo, N., & Ferreira, S. R. S. (2016). Carotenoids Functionality, Sources, and Processing by Supercritical Technology. *Journal of Chemistry, 16*. https://doi.org/10.1155/2016/3164312

Miller, A. F., & Sorkin, D. L. (1997). Superoxide dismutases: A molecular perspective. *Comments on Molecular and Cellular Biology, 9*(1), 1–48.

Mirdehghan, S. H., & Ghotbi, F. (2014). Effects of salicylic acid, jasmonic acid, and calcium chloride on reducing chilling injury of pomegranate (Punica granatum L.) fruit. *Journal of Agricultural Science and Technology, 16*, 163–173.

Mittler, R., Vanderauwera, S., Suzuki, N., Miller, G., Tognetti, V. B., Vandepoele, K., et al. (2011). ROS signaling: The new wave? *Trends in Plant Science, 16*, 300–309.

Miura, K., & Tada, Y. (2014). Regulation of water, salinity, and cold stress responses by salicylic acid. *Frontiers in Plant Science, 5*, 4.

Morsi, M. M. M., Abdelmigid, H. M., & Aljoudi, N. G. S. (2018). Exogenous salicylic acid ameliorates the adverse effects of salt stress on antioxidant system in Rosmarinus officinalis L. *Egyptian Journal of Botany, 58*, 249–263.

Mugnai, S., Ferrante, A., Petrognani, L., Serra, G., & Vernieri, P. (2009). Stress-induced variation in leaf gas exchange and chlorophyll a fluorescence in Callistemon plants. *Research Journal of Biological Sciences, 4*, 913–921.

Munné-Bosch, S., Queval, G., & Foyer, C. H. (2013). The impact of global change factors on redox signaling underpinning stress tolerance. *Plant Physiology, 161*, 5–19.

Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology, 59*, 651–681.

Nagarani, G., Abirami, A., & Siddhuraju, P. (2014). A comparative study on antioxidant potentials, inhibitory activities against key enzymes related to metabolic syndrome, and anti-inflammatory activity of leaf extract from different Momordica species. *Food Science and Human Wellness, 3*(1), 36–46.

Nakabayashi, R., Urano, K. Y., Kaoru, Suzuki, M., Yamada, Y., Nishizawa, T., Matsuda, F., et al. (2014). Enhancement of oxidative and drought tolerance in Arabidopsis by overaccumulation of antioxidant flavonoids. *The Plant Journal, 3*, 367–379.

Nematalla, M., Badrani, E., & Mohammed, F. (2019). Exogenous trehalose alleviates the adverse effects of salinity stress in wheat. *Turkish Journal of Botany, 43*, 48–57. https://doi.org/10.3906/bot-1803-36

Nguyen, H. C., Lin, K. H., Ho, S. L., Chiang, C. M., & Yang, C. M. (2018). Enhancing the abiotic stress tolerance of plants: from chemical treatment to biotechnological approaches. *Physiologia Plantarum, 164*(4), 452–466. https://doi.org/10.1111/ppl.12812

Nikkhah, E., Khayami, M., & Heidari, R. (2008). In vitro screening for antioxidant activity and cancer suppressive effect on blackberry (Morus nigra). *Iranian Journal of Cancer Prevention, 1*, 167–172.

Nimse, S. B., & Pal, D. (2015). Free radicals, natural antioxidants, and their reaction mechanisms. *RSC Advances, 5*(35), 27986–28006.

Niu, J.-H., Anjum, S. A., Wang, R., Li, J.-H., Liu, M.-R., Song, J.-X., et al. (2016). Exogenous application of brassinolide can alter morphological and physiological traits of Leymuschinensis (Trin.) Tzvelev under room and high temperatures. *Chilean Journal of Agricultural Research, 76*(1), 27–33.

Noreen, S., & Ashraf, M. (2008). Alleviation of adverse effects of salt stress on sunflower (Helianthus annuus L.) by exogenous application of salicylic acid: Growth and photosynthesis. *Pakistan Journal of Botany, 40*(4), 1657–1663.

Noreen, S., Ashraf, M., Hussain, M., & Jamil, A. (2009). Exogenous application of salicylic acid enhances antioxidative capacity in salt stressed sunflower (Helianthus annuus L.) plants. *Pakistan Journal of Botany, 41*, 473–479.

Ogweno, J. O., Song, X. S., Shi, K., Hu, W. H., Mao, W. H., Zhou, Y. H., et al. (2008). Brassinosteroids alleviate heat-induced inhibition of photosynthesis by increasing carboxylation efficiency and enhancing antioxidant systems in Lycopersiconesculentum. *Journal of Plant Growth Regulation, 27*(1), 49–57.

Oosten, M. J. V., Sharkhuu, A., Batelli, G., Bressan, R. A., & Maggio, A. (2013). The Arabidopsisthaliana mutant air1 implicates SOS3 in the regulation of anthocyanins under salt stress. *Plant Molecular Biology, 83*, 405–415.

Orabi, S. A., & Abdelhamid, M. T. (2016). Protective role of α-tocopherol on two Viciafaba cultivars against seawater-induced lipid peroxidation by enhancing capacity of anti-oxidative system. *Journal of the Saudi Society of Agricultural Sciences, 15*(2), 145–154.

Palma, F., López-Gómez, M., Tejera, N. A., & Lluch, C. (2013). Salicylic acid improves the salinity tolerance of Medicagosativa in symbiosis with Sinorhizobiummeliloti by preventing nitrogen fixation inhibition. *Plant Science, 208*, 75–82.

Pan, Y., Wu, L. J., & Yu, Z. L. (2006). Effect of salt and drought stress on antioxidant enzymes activities and SOD isoenzymes of liquorice (Glycyrrhizauralensis Fisch). *Plant Growth Regulation, 49*(2–3), 157–165.

Parthasarathi, S., & Park, Y. K. (2015). Determination of total phenolics, flavonoid contents and antioxidant activity of different mBHT fractions: A polyherbal medicine. *Pakistan Journal of Pharmaceutical Sciences, 28*, 2161–2166.

Parvaiz, A., & Satyawati, S. (2008). Salt stress and phytochemical responses of plants – a review. *Plant, Soil and Environment, 54*, 89–99.

Pinheiro, C., & Chaves, M. M. (2011). Photosynthesis and drought: Can we make metabolic connections from available data? *Journal of Experimental Botany, 62*, 869–882.

Ploenlap, P., & Pattanagul, W. (2015). Effects of exogenous abscisic acid on foliar anthocyanin accumulation and drought tolerance in purple rice. *Biologia, 70*, 915–921.

Poljsak, B., Šuput, D., & Milisav, I. (2013). Achieving the balance between ROS and antioxidants: When to use the synthetic antioxidants. *Oxidative Medicine and Cellular Longevity, 2013*. https://doi.org/10.1155/2013/956792

Prior, R. L., & Wu, X. (2006). Anthocyanins: Structural characteristics that result in unique metabolic patterns and biological activities. *Free Radical Research, 40*, 1014–1028.

Priyadarsini, K. I., Sujata, M., Khopde, S., Santosh, K., & Mohan, H. (2002). Free radical studies of ellagic acid, a natural phenolic antioxidant. *Journal of Agricultural and Food Chemistry, 50*, 2200–2206.

Qayyum, B., Shahbaz, M., & Akram, N. A. (2007). Interactive effect of foliar applicationof 24-epibrassinolide and root zone salinity on morpho-physiological attributes of wheat (Triticumaestivum L.). *International Journal of Agriculture and Biology, 9*, 584–589.

Raafat, N., & Radwan, T. E. E. (2011). Improving wheat grain yield and its quality under salinity conditions at a newly reclaimed soil by using different organic sources as soil or by foliar applications. *Journal of Applied Sciences Research, 7*, 42–55.

Rady, M. M. (2011). Effect of 24-epibrassinolide on growth, yield, antioxidant system and cadmium content of bean (Phaseolus vulgaris L.) plants under salinity and cadmium stress. *Scientia Horticulturae, 129*, 232–237.

Rady, M. M., Sadak, M., El-Lethy, S. R., Abd Elhamid, E. M., & Abdelhamid, M. T. (2015). Exogenous ɑ-tocopherol has a beneficial effect on Glycine max (L.) plants irrigated with diluted sea water. *The Journal of Horticultural Science and Biotechnology, 90*, 195–202.

Raederstorff, D. W., Adrian, Philip, C. C., Weber, P., & Eggersdorfer, M. (2015). Vitamin E function and requirements in relation to PUFA. *British Journal of Nutrition, 114*, 1113–1122.

Ramraj, V. M., Vyas, B. N., Godrej, N. B., Mistry, K. B., Swami, B. N., & Singh, N. (1997). Effects of 28-homobrassinolide on yields of wheat, rice, groundnut, mustard, potato and cotton. *The Journal of Agricultural Science, 128*(4), 405–413.

Rao, A. V., & Rao, L. G. (2007). Carotenoids and human health. *Pharmacological Research, 55*, 207–216.

Rao, S. S. R., Vardhini, B. V., Sujatha, E., & Anuradha, S. (2002). Brassinosteroids – New class of phytohormones. *Current Science, 82*, 1239–1245.

Raposo, M., de Morais, A., & de Morais, R. (2015). Carotenoids from marine microalgae: A valuable natural source for the prevention of chronic diseases. *Marine Drugs, 13*(8), 5128–5155.

Rihan, H., Kareem, F., & Fuller, M. (2017). The effect of exogenous applications of salicylic acid and molybdenum on the tolerance of drought in wheat. *Journal of Agricultural Science and Technology, 9*(4), 555768. https://doi.org/10.19080/ARTOAJ.2017.09.555768

Rivas-San, V. M., & Plasencia, J. (2011). Salicylic acid beyond defence: Its role in plant growth and development. *Journal of Experimental Botany, 62*(10), 3321–3338.

Sadak, M. S., & Dawood, M. G. (2014). Role of ascorbic acid and α tocopherol in alleviating salinity stress on flax plant (Linum usitatissimum L.). *Stress: The International Journal on Biology of Stress, 10*, 93–111.

Sadeghi, F., & Shekafandeh, A. (2014). Effect of 24-epibrassinolide on salinity-induced changes in loquat (Eriobotrya japonica Lindl). *Journal of Applied Botany and Food Quality, 87*, 182–189. DOI: 10.5073/JABFQ.2014.087.026

Saeidi-Sar, S., Abbaspour, H., Afshari, H., & Yaghoobi, S. R. (2013). Effects of ascorbic acid and gibberellin A3 on alleviation of salt stress in common bean (Phaseolusvulgaris L.) seedlings. *Acta Physiologiae Plantarum, 35*, 667–677.

Sahli, A. A., Mohamed, A. K., Alaraidi, I., Al-Ghamdi, A., Al-Watban, A., El-Zaidy, M., & Alzahrani, S. M. (2019). Salicylic acid alleviates salinity stress through the modulation of biochemical attributes and some key antioxidants in wheat seedlings. *Pakistan Journal of Botany, 51*(5), 1551–1559. https://doi.org/10.30848/PJB2019-5(12)

Saisanthosh, K., Sumalatha, G. M., Shuba, A. C., Komala, N. T., Biradar, P. N., & K. (2018). Role of enzymatic antioxidants defense system in seeds. *International Journal of Current Microbiology and Applied Sciences, 7*, 584–594.

Salin, M. L., & Bridges, S. M. (1980). In J. V. Bannister & H. A. O. Hill (Eds.), *Chemical and biochemical aspects of superoxide and superoxide dismutase* (pp. 176–284). Elsevier.

Sanghera, G. S., Wani, S. H., Hussain, W., & Singh, N. B. (2011). Engineering cold stress tolerance in crop plants. *Current Genomics, 12*(1), 30–43.

Sasse, J. M. (1997). Recent progress in brassinosteroid research. *Physiologia Plantarum, 100*(3), 696–701.

Saul, N., Pietsch, K., Stürzenbaum, S. R., Menzel, R., & Steinberg, C. E. (2011). Diversity of polyphenol action in Caenorhabditis elegans: Between toxicity and longevity. *Journal of Natural Products, 74*, 1713–1720.

Saxena, S. C., Joshi, P., Grimm, B., & Arora, S. (2011). Alleviation of ultraviolet-C induced oxidative through overexpression of cytosolic ascorbate peroxidase. *Biologia, 66*, 1052–1059.

Seki, M., Umezawa, T., Urano, K., & Shinozaki, K. (2007). Regulatory metabolic networks in drought stress responses. *Current Opinion in Plant Biology, 10*, 296–302.

Semida, W. M., Taha, R. S., Abdelhamid, M. T., & Rady, M. M. (2014). Foliar-applied α-tocopherol enhances salt-tolerance in Viciafaba L. plants grown under saline conditions. *South African Journal of Botany, 95*, 24–31.

Sepúlveda, L., Ascacio, A., Rodriguez-Herrera, R., Aguilera-Carbó, A., & Aguilar, C. N. (2011). Ellagic acid: biological properties and biotechnological development for production processes. *African Journal of Biotechnology, 10*, 4518–4523.

Shahbaz, M., & Ashraf, M. (2007). Influence of exogenous application of brassinosteroids on growth and mineral nutrients of wheat (Triticum aestivum L.) under saline conditions. *Pakistan Journal of Botany, 39*, 513–522.

Shahbaz, M., Ashraf, M., & Athar, H. (2008). Does exogenous application of 24-epibrassinolide ameliorate salt induced growth inhibition in wheat (Triticumaestivum L.)? *Plant Growth Regulation, 55*(1), 51–64.

Shahid, M. A., Pervez, M. A., Balal, R. M., Mattson, N. S., Rashid, A., Ahmad, R., et al. (2011). Brassinosteroid (24-epibrassinolide) enhances growth and alleviates the deleterious effects induced by salt stress in pea (Pisum sativum L.). *Australian Journal of Crop Science, 5*, 500–510.

Shalata, A., & Neumann, P. M. (2001). Exogenous ascorbic acid (vitamin C) increases resistance to salt stress and reduces lipid peroxidation. *Journal of Experimental Botany, 52*(364), 2207–2211.

Shalata, A., Mittova, V., Volokita, M., Guy, M., & Tal, M. (2001). Response of cultivated tomato and its wild salt-tolerant relative Lycopersicon pennelii to salt-dependent oxidative stress. The root antioxidative system. *Physiologia Plantarum, 112*, 487–494.

Sharma, I., Bhardwaj, R., & Pati, P. K. (2015). Exogenous application of 28-Homobrassinolide modulates the dynamics of salt and pesticides induced stress responses in an elite rice variety pusa basmati-1. *Journal of Plant Growth Regulation, 34*(3), 509–518.

Sharma, I., Kaur, N., & Pati, P. K. (2018). Brassinosteroids: A promising option in deciphering remedial strategies for abiotic stress tolerance in rice. *Frontiers in Plant Science, 8*, 2151.

Shin, H., Hyeyoon, E. O., & Lim, Y. (2016). Similarities and differences between alpha-tocopherol and gamma-tocopherol in amelioration of inflammation, oxidative stress and pre-fibrosis in hyperglycemia induced acute kidney inflammation. *Nutrition Research and Practice, 10*, 33–41.

Slafer, G. A., & Rawson, H. M. (1995). Base and optimum temperatures vary with genotype and stage of development in wheat. *Plant, Cell & Environment, 18*, 671–679.

Slathia, S., Sharma, A., & Choudhary, S. P. (2012). Influence of exogenously applied epi-brassinolide and putrescine on protein content, antioxidant enzymes and lipid peroxidation in Lycopersiconesculentum under salinity stress. *American Journal of Plant Sciences, 3*(6), 714–720.

Smirnoff, N. (2005). Ascorbate, tocopherol and carotenoids: metabolism, pathway engineering and functions. In N. Smirnoff (Ed.), *Antioxidants and reactive oxygen species in plants* (pp. 53–86). Blackwell Publishing.

Sofo, A., Scopa, A., Nuzzaci, M., & Vitti, A. (2015). Ascorbate Peroxidase and Catalase Activities and Their Genetic Regulation in Plants Subjected to Drought and Salinity Stresses. *International Journal of Molecular Sciences, 2015*(16), 13561–13578.

Sommer, A., & Vyas, K. S. (2012). A global clinical view on vitamin A and carotenoids. *The American Journal of Clinical Nutrition, 96*, 1204S–1206S.

Srinieng, K., Tanatorn, S., & Aphichart, K. (2015). Effect of salinity stress on antioxidative enzyme activities in tomato cultured in vitro. *Pakistan Journal of Botany, 47*(1), 1–10.

Stapleton, A. E., & Walbot, V. (1994). Flavonoids can protect maize DNA from the induction of ultraviolet radiation damage. *Plant Physiology, 105*, 881–889.

Steyn, W. J., Wand, S. J. E., Holcroft, D. M., & Jacobs, G. (2002). Anthocyanins in vegetative tissues: A proposed unified function in photoprotection. *The New Phytologist, 155*(3), 349–361.

Stone, C. L., Chisholm, L., & Coops, N. (2001). Spectral reflectance characteristics of eucalypt foliage damaged by insects. *Australian Journal of Botany, 49*, 687–698.

Taârit, M. B., Msaada, K., Hosni, K., & Marzouk, B. (2012a). Physiological changes, phenolic content and antioxidant activity of Salvia officinalis L. grown under saline conditions. *Journal of the Science of Food and Agriculture, 92*, 1614–1619.

Taârit, M., Msaada, K., Hosni, K., & Marzouk, B. (2012b). Physiological changes, phenolic content and antioxidant activityofSalviaofficinalisL.grownundersalineconditions. *Journal of the Science of Food and Agriculture, 92*, 1614–1619.

Tabatabaei, S. A., & Naghibalghora, S. M. (2013). The effect of ascorbic acid on germination characteristics and proline of sesame seeds under drought stress. *International Journal of Agriculture and Crop Sciences, 6*, 208–212.

Taffouo, V. D., Nouck, A. H., Dibong, S. D., & Amougou, A. (2010). Effects of salinity stress on seedling growth, numeral nutrients, and total chlorophyll of some tomato (Lycopersicum esculentum L.) cultivars. *African Journal of Biotechnology, 9*(33), 5366–5372.

Talaat, N. B., & Shawky, B. T. (2013). 24-Epibrassinolide alleviates salt-induced inhibition of productivity by increasing nutrients and compatible solutes accumulation and enhancing antioxidant system in wheat (Triticumaestivum L.). *Acta Physiologiae Plantarum, 35*(3), 729–740.

Tamang, B. G., & Fukao, T. (2015). Plant adaptation to multiple stresses during submergence and following desubmergence. *International Journal of Molecular Sciences, 16*, 30164–30180.

Tereshchenko, O., Gordeeva, E., Arbuzova, V., Börner, A., & Khlestkina, E. (2012). The D genome carries a gene determining purple grain colour in wheat. *Cereal Research Communications, 40*(3), 334–341.

Tuteja, A. N., Singh, M. B., Misra, M. K., Bhalla, P. L., & Tuteja, R. (2001). Molecular mechanisms of DNA damage and repair: progress in plants. *Critical Reviews in Biochemistry and Molecular Biology, 4*, 337–397.

Vadez, V., Berger, J. D., Warkentin, T., Asseng, S., Ratnakumar, P., & Rao, K. P. C. (2012). Adaptation of grain legumes to climate change: a review. *Agronomy for Sustainable Development, 32*, 31–44.

Verma, S., & Dubey, R. S. (2003). Lead toxicity induces lipid peroxidation and alters the activities of antioxidant enzymes in growing rice plants. *Plant Science, 164*(4), 645–655.

Viehweger, K. (2014). How plants cope with heavy metals. *Botany Studies International Journal, 55*, 1–12. https://doi.org/10.1186/1999-3110-55-35

Vinocur, B., & Altman, A. (2005). Recent advances in engineering plant tolerance to abiotic stress: achievements and limitations. *Current Opinion in Biotechnology, 16*, 123–132.

Voss, I., Suni, B., Scheibe, R., & Raghavendra, S. (2013). Emerging concept for the role of photorespiration as an important part of abiotic stress response. *Plant Biology, 15*, 713–722.

Walia, H., Wilson, C., Zeng, L., Ismail, A. M., Condamine, P., & Close, T. J. (2007). Genome-wide transcriptional analysis of salinity stressed japonica and indica rice genotypes during panicle initiation stage. *Plant Molecular Biology, 63*, 609–623.

Wang, H., Cao, G., & Prior, R. L. (1997). Oxygen radical absorbing capacity of anthocyanins. *Journal of Agricultural and Food Chemistry, 45*, 304–309.

Wang, M., Lee, J., Choi, B., Park, Y., Sim, H. J., Kim, H., & Hwang, I. (2018). Physiological and molecular processes associated with long duration of ABA treatment. *Frontiers in Plant Science, 21*. https://doi.org/10.3389/fpls.2018.00176

Waseem, M., Athar, H., & Ashraf, M. (2006). Effect of salicylic acid applied through rooting medium on drought tolerance of wheat. *Pakistan Journal of Botany, 38*(4), 1127–1136.

WMO. (2014). *The State of greenhouse gases in the atmosphere based on global observations through 2013*. Greenhouse Gas Bulletin No. 10, World Meteorological Organization.

Wollenweber, B., Porter, J. R., & Schellberg, J. (2003). Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. *Journal of Agronomy and Crop Science, 189*, 142–150.

Wu, W., Zhang, Q., Ervin, E. H., Yang, Z., & Zhang, X. (2017). Physiological mechanism of enhancing salt stress tolerance of perennial ryegrass by 24-Epibrassinolide. *Frontiers in Plant Science, 8*. https://doi.org/10.3389/fpls.2017.01017

Xu, Y., Xu, Q., & Huang, B. (2015). Ascorbic acid mitigation of water stress-inhibition of root growth in association with oxidative defense in tall fescue (Festucaarundinacea Schreb). *Frontiers in Plant Science, 6*, 807.

Xue-Xia, W. (2012). Effects of 24-epibrassinolide on photosynthesis of eggplant (Solanummelongena L.) seedlings under salt stress. African. *Journal of Biotechnology, 11*(35), 8665–8671.

Yildirim, E., Turan, M., & Guvenc, I. (2008). Effect of foliar salicylic acid applications on growth, chlorophyll, and mineral content of cucumber grown under salt stress. *Journal of Plant Nutrition, 31*(3), 593–612.

Younis, M. E., Hasaneen, M. N. A., & Kazamel, A. M. S. (2010). Exogenously applied ascorbic acid ameliorates detrimental effects of NaCl and mannitol stress in Viciafaba seedlings. *Protoplasma, 239*, 39–48.

Yusuf, M., Fariduddin, Q., & Ahmad, A. (2011). 28-Homobrassinolide mitigates boron induced toxicity through enhanced antioxidant system in Vignaradiata plants. *Chemosphere, 85*(10), 1574–1584.

Zhang, D., Yu, B., Bai, J., Qian, M., Shu, Q., Su, J., et al. (2012). Effects of high temperatures on UV-B/visible irradiation induced postharvest anthocyanin accumulation in ‘Yunhongli No. 1’ (Pyruspyrifolia Nakai) pears. *Scientia Horticulturae, 134*, 53–59.

Zhou, Y., Xia, X., Yu, G., Wang, J., Wu, J., Wang, M., et al. (2015). Brassinosteroids play a critical role in the regulation of pesticide metabolism in crop plants. *Scientific Reports, 5*(1). https://doi.org/10.1038/srep09018