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Role of ABA on antioxidant mechanism under drought crops

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Abstract

Abscisic acid is a plant growth regulator involved in several development processes as well as environmental responses. Abscisic acid is a plant hormone that regulates plant growth, development, seed germination. ABA has a role in number of physiological functions such as photosynthesis. ABA positively affects stomatal activity under stresses such as abiotic and biotic. ABA analogues and breeding for stress resistant crops for commercial agriculture. The rapid accumulation of ABA in response to stress and their regulation of a wide range of adaptive responses define this phytohormone as the stress hormone helping the plants survival under stresses. Antioxidant is a molecule that inhibits the oxidation of other molecules. Oxidation is a chemical reaction involving the loss of electrons or an increase in oxidation state. We address the global demand aims for the drought resistant crop lines wish and growth penalty. There is a long list of antioxidant plants of which some have been discussed in screening of plants is done by measuring the antioxidant activity. An antioxidant is any substance that, when present at low concentrations significantly delays or prevents oxidation of cell content like proteins, lipids, carbohydrates and DNA. Antioxidants can be classified into three main types: first line defence antioxidants, second line defence antioxidants and third line defence antioxidants. Superoxide dismutase (SOD), catalase (CAT) and peroxidase (POX), GTx, glutathaine reductase and some minerals like Se, Mn, Cu, and Zn come under first line defence.

Key word: Environmental stress, abscicacid, antioxidants and drought.

Introduction

Environmental stress causes significant crop losses. The stresses are numerous and often crop- or location-specific. They include biotic and abiotic stresses such as disease and radiation, drought, water, high salinity, metal toxicity, herbicides, fungicides. Research in this area is driven by the hope of improving crop yield in afflicted areas (Quarrie, 1996). Drought is one of the most universal and significant environmental stress affecting plant growth and productivity worldwide. Therefore, understanding crop response to this stress is the basis for regulating crops appropriately and achieving agricultural water savings (Singh *et al.,* 2012). The phytohormone abscisic acid (ABA) regulates a variety of physiological plant processes, including seed maturation, seed and bud dormancy, root growth, foliar senescence and the transition between the vegetative to reproductive development, among others (Leung and Giraudat, 1998).ABA was reported to be one of the contributing factors which can overcome drought in plants (Hubbard *et al.*, 2010). A number of studies have shown that manipulation of plant antioxidant levels result in cross-tolerance to subsequent exposure of plant to oxidative stress situations (Neill et al. 2002).

Environmental stress

Environmental stress condition such as biotic (insects, bacteria, fungi, and viruses) and abiotic (light, temperature, water availability, nutrients, and soil structure) factors affect the growth in higher plants (Lichtenthaler, 1996,1998). Among these, drought is a major abiotic factor that limits agricultural crop production. Plants experience drought stress either when the water supply to roots becomes difficult or when the transpiration rate becomes very high (Zhu, 2002; Chaitanya et al., 2003; Chaves et al., 2003).

Drought Stress

Water deficit is one of the major abiotic stresses which adversely affect the crop growth and yield. Drought is amorphological term and is commonly defined as a period without significant rainfall. Drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause conditions loss of water by transpiration or evaporation (Shao et al., 2007). Water stress tolerance is seen in almost all plant species but it’s extend varies from species to species. Water deficit stress is a global issue to ensure survival of agricultural crops and sustainable food production (Shao et al., 2006). It is well established that drought stress impairs numerous physiological and biochemical process in pants. Photosynthetic rate is heavily reduced under drought condition due to stomatal closure, so it is assumed to be responsible for decreased dry matter production (Sepheri and modarres Sanavy, 2003; Lower and Teezara, 2009). Plants can response and tolerate water stress by altering their cellular metabolism and evoking various defense mechanisms including stomatal closure, accumulation of solutes, cell wall hardening and production of proteins and enzymes involved in cellular protection and ROS scavenging (Guo et al., 2006; Esfandiari et al., 2008; Omidi, 2010). Drought stress induces various biochemical and physiological responses in plants because of alternation of water content within the plant tissue and oxidative stress such as protein denaturation, lipid peroxidation, MDA accumulation and pigment degradation due to produce reactive oxygen species (ROS) (Chaves et al., 2003; Gill and Tuteja, 2010). Severe drought stress also inhibits the photosynthesis of plants by causing changes in chlorophyll content by affecting chlorophyll components and by damaging the photosynthetic apparatus (Iturbeormaetxe et al., 1998). Plant response to water stress include morphological and biochemical changes and later as water stress become more severe to functional damage and loss of plant parts (Sangtarash, 2010). Grain legumes respond to drought differently and express various drought tolerance strategies (Subbarao *et al*., 1995). Crops are sensitive to water availability though it is sensitive to water stress at all growth stages, flowering and grain development stage (Zubair *et al*., 2002; Thaloot *et al*., 2006).

Phytohormone

Plant hormones are intricately involved in the perception, signalling and downstream response of plant to stressors. Among the most important functions of plant hormones is controlling and coordinating cell division, growth and differentiation (Hooley, 1994). Plant hormones can affect different plant activities including seed dormancy and germination (Graeber *et al.*, 2012). Plant hormones including abscisic acid (ABA), ethylene, gibberellins, auxin (IAA), cytokinins, and brassinosteroids are biochemical substances controlling many physiological and biochemical processes in the plant. These interesting products are produced by plants and also by soil microbes (Finkelstein, 2004; Jimenez, 2005; Santner *et al.,* 2009). The role of plant growth regulators in overcoming the harmful effects of salinity on growth may be due to the change in the endogenous growth regulators which affects plant water balance. The overall development of plant is regulated by the growth hormones, nutrient and environmental factors (Chauhan *et al.,* 2009).Phytohormones create an ability in plants to adapt to abiotic stresses by mediating a wide range of adaptive responses. Cytokinin and ABA cause different manners to encounter the drought stress (Pospisilova *et al*., 2000).

ABA role in drought

Abscisic acid (ABA) has been considered to be one of the main hormone which triggers various acclimations processes under water stress conditions (Zhu, 2002). ABA plays a key role in many physiological and developmental processes such as water relations, seed dormancy and germination (Kermode, 2005).ABA mediates responses to abiotic stresses such as drought, salt, and cold. ABA can induce short-term responses such as stomatal closure minimizing transpirational water loss—or long-term responses involving changes in gene expression (Himmelbach *et al.,* 1998; Finkelstein *et al.,* 2002). Abscisic acid (ABA) has been considered to be one of the main hormones which trigger various acclimations processes under water stress conditions (Zhu, 2002). Under water stress condition exogenously applied ABA stimulated the synthesis of proteins in different species (Riccardi *et al.,* 1998). ABA has been shown to mediate many physiological and developmental processes throughout the life cycle of plants including responses of plants to environmental stresses (Khadri *et al.,* 2006). ABA is known to act as a major signaling molecule involved in the response of plants to drought stress (Liu *et al.,* 2005). Although, it has been shown that ABA can result in an oxidative stress, an enhancement in the capacity of oxidative stress tolerance may imply that plants need to mobilize the whole antioxidant defense systems including enzymatic and non-enzymatic constituents to resist oxidative damage in stressed plant tissues, rather than a few enzymes or metabolites (Guan *et al.,* 2000).

ABA is known to act as a major signaling molecule involved in the response of plant to drought stress. Stress-related responses induced by ABA often occur earlier than the change of plant water status during soil drying and thereby constitute the first line of defense as soil water deficits are encountered (Liu et al., 2005). The hormone triggers stomatal closure to limit water loss through transpiration, as well as mobilizes a battery of genes that presumably serve to protect the cells from ensuing oxidative damage in prolonged stress (Wasilewska et al., 2008). ABA is able to induce changes including synthesis of stress proteins, proline, sugar, alcohol, soluble carbohydrates and glycine betaine in which may involve in stress tolerance (Bagniewska-Zadworna). The involvement of ABA in mediating drought stress has been extensively researched. ABA plays a critical role in regulating plant water status through guard cells and growth as well as by induction of genes that encode enzymes and other proteins involved in cellular dehydration tolerance (Pospisilova *et al*., 2000; Pospisilova, 2003; Ghassemian *et al*., 2008).

In vegetative tissues, ABA levels increase when plants encounter adverse environmental conditions such as drought, salt, and to a lesser extent, low temperatures. Although a higher level of exogenous ABA inhibits plant growth under non-stressful conditions, an increased ABA content is beneficial for plants under environmental stress as a result of ABA induced changes at the cellular and whole-plant levels. ABA promotes the closure of stomata to minimize transpirational water loss. It also mitigates stress damage through the activation of many stress responsive genes that encode enzymes for the biosynthesis of compatible osmolytes and LEA-like proteins, which collectively increase plant stress tolerance (Hasegawa et al., 2000; Bray, 2002; Finkelstein et al., 2002). ABA seems to play an important role in plant response to water stress by decreasing water loss and thereby increasing the efficiency of water use by the plant (Thompson et al., 1997). The similarity between ABA effects and water stress response suggests the exogenous ABA added to nutrient solutions should produce responses similar to that of water stress (Blum and Sinmena, 1995).Of various plant responses to water shortage, enhanced accumulation of ABA is one of key mechanism of adaptation to water stress (Esther *et al*., 2000).

Reactive oxygen species scavenging enzymes

Plants are interminably exposed to unfavourable environmental conditions such as temperature extremes, high light intensities, drought, salinity, air pollution and pathogen attack, all known to increase the rate of ROS generation. When ROS production over whelms the cellular scavenging capacity suspending cellular redox homeostasis, the results is a rapid and transient excess of ROS, known as oxidative stress (Scandalios et al. 1997).ROS, namely singlet oxygen , superoxide radical , hydrogen peroxide and hydroxyl radical are by-products of the energy-generating processes of photosynthetic and respiratory electron transport chains (ETC). Consequently, chloroplasts, mitochondria and peroxisomes are the main organelles of ROS producers in plant cells. ROS are highly reactive and toxic based on their ability to react indiscriminately with almost all biomolecules provoking destructive protein modifications, DNA strand breaks, purine oxidations, protein-DNA crosslinks and ß-oxidation of lipids (Van Breusegem and Dat 2006). Abiotic and biotic stresses which induce ROS production through the activation of NADPH oxidase, can trigger a plant denfece response against different stress conditions, thus enhancing tolerance of plants to multiple stresses and pathogen (Alvarez et al., 1998; Torres et al., 2002).

Antioxidant enzymes	**Function**	**Subcellular location**
Superoxide dismutase (SOD)	$O_2^- + O_2^- + 2H^+ \rightarrow O_2 + H_2O_2$	chloroplast, mitochondria organelle, cytoplasm membrane
Catalase (CAT)	$2H_2O_2 \rightarrow 2H_2O + O_2$	peroxisomes
Ascorbate peroxidase (APX)	$H_2O_2 + 2AsA \rightarrow 2H_2O + 2MDA$	plastids, mitochondria, peroxisomes, cytosol
Peroxidase (POD)	$H_2O_2 + (ROH)_2 \rightarrow 2H_2O + R(O)_2$	Cytosol, cell wall bound
Alternative oxidase (AOX)	$2e^- + 2H^+ + O_2 \rightarrow H_2O$	Mitochondria, chloroplast
Glutathione peroxidase (GPX)	$H_2O_2 + 2GSH \rightarrow H_2O + GSSG$	(chloro) plastids, mitochondria organelle, cytosol
Peroxiredoxin (Prx)	$2P\text{-}SH + H_2O_2 \rightarrow P\text{-}S\text{-}S\text{-}P + 2H_2O$	plastids, mitochondria, cytoplasm membrane
Glutathione S-transferase (GST)	$ROO^- + 2GSH \rightarrow GSSG\text{-}ROOH$	Cytosol, nucleus
Glutathione reductase (GR)	$GSSG + NAD(P)H \rightarrow 2GSH + NAD(P)^-$	plastids, mitochondria, peroxisomes,cytoplasm membrane
Monodehydroascorbate reductase (MDAR)	$MAD + NAD(P)H \rightarrow AsA + NAD(P)^-$	chloroplast, mitochondria, peroxisomes, cytosol
Dehydroascorbate reductase (DHAR)	$DHA + 2GSH \rightarrow Asc + GSSG$	(chloro) plastids, mitochondria, peroxisomes,cytoplasm membrane

Antioxidant mechanism during drought condition

Over the last decade ROS has changed to realize their dual role: the already known adverse role of toxic metabolic by-products requiring antioxidant defense mechanisms to protect cells from their detrimental effects, and the newly emerging role of signaling molecules regulating growth, development and coordinating responses to abiotic and biotic stress. In recent years ROS have been implicated in the control and regulation of biological functions, such as growth, cell cycle, programmed cell death, hormone signaling, biotic and abiotic stress responses and development. Emerging evidence indicates that production of ROS and activation of redox-dependent signaling cascades are involved in the regulation of the antioxidant genes, which in turn affect the intracellular level of ROS and may provide a feedback control of the ROS-dependent biological processes (Photini Mylona and Alexios Polidoros 2010).

Oxidative damage in the plant tissue is alleviated by a concentraed action of both enzymatic and non-enzymatic antioxidant metabolisms (Hasegawa et al., 2000).these mechanism include ascorbic acid, α-tocopherol, β-carotenes, reduced glutathione and enzymes including SOD, peroxidise, ascorbate peroxidise, catalase, polyphenol oxidase, glutathione reductase (Prochazkova et al.,2001).There are many reports in the literature that underline the intimate relationship between enhanced constitutive antioxidant enzyme activities and increased resistance to environmental stresses (Vranova et al., Bor et al., 2003).

Catalase (CAT) and peroxidase (POD) are the most important antioxidant enzymes that scavenge H_2O_2 as well as APX (Liu *et al*., 2011). Increased activity of POD and CAT in tolerant cultivar was related to less increased MDA content under drought condition. These results are in line with those related to tolerant and sensitive cultivars of maize seedling.under water deficit (Chugh *et al*., 2011). The increased activities of anti-oxidative enzymes, induced by moderate drought stress can protect cell membranes, proteins and metabolic machinery, which would preserve sub-cellular structure from damage as a result of cell dehydration (Gill and Tuteja, 2010). A previous study showed that increased amounts of ABA induced CAT activity during drought conditions in triploid Bermuda grass have been accompanied with H_2O_2 and NO production (Lu *et al*., 2009). It has also been shown that the ABA-induced antioxidant enzyme activities in maize leaves require the participation of H_2O_2 (Jiang and Zhang, 2003). It seems that ABA-induced H_2O_2 accumulation modulated metabolic and redox control pathways in Arabidopsis by influence on many of POD. Moreover, there is an intricate relationship, at the transcriptional and possibly post-transcriptional levels, between ABA biosynthesis and scavenger system of H_2O_2 (Ghassemian *et al*., 2008).

Conclusion

Plants respond and avoidable various environmental stresses are the challenges to sustain and survivability. Due to this inevitable condition plants affect in terms of plant growth physiological biochemical and molecular metabolism. Plant growth and development involved numerous biochemical and molecular reaction which are sensitive to various physical chemical and biological stresses like temperature, light, radiations, contaminated chemicals and pathogens. However, plants alter their metabolic activity and invoking various defence mechanisms at cellular metabolic level.ABA one of the important phyotohormones which plays a pivotal role to induction of plant tolerance to this stress condition. Whilst, at the acute environmental stresses the exogenous ABA increases by the altering metabolism through triggering of ABA gene. Under stress in cellular cytoplasm the reactive oxygen species have been induced. Which are harmful to the membranous organelles such as chloroplast, mitochondria, plasma membrane and peroxisome, etc. In the same while under stress ABA induces stomatal closure to check the transpiration of water by the signalling from root to leaf.ABA enhances the various enzymatic and non-enzymatic antioxidants by the expression of genes encoding antioxidants. In this review we focused how ABA to mechanise the physical defence and cellular metabolism to upstream regulation of ABA synthesis and ABA enhances the encoding genes to in toxicicity of cellular environment at the various environmental stresses.

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