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Antioxidants: Environmental Stress Mitigating Metabolites

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Review

Environmental stresses due to cold, heat, salinity and drought adversely affect plant growth and productivity that trigger a series of morphological, physiological, biochemical and molecular changes in plants and eventually interrupt normal plant life cycle [1,2]. Most of the arable lands of the world that are exposed to abiotic stress conditions have an adverse impact on global vegetable production. These abiotic stress conditions decrease crop productivity upto 50-70% [3]. Plants have evolved several metabolic cascades for their survival under stress [4].

Plant's response to stress is a complex phenotypic and physiological phenomena which is highly influenced by adverse environmental conditions. To enhance the food production in order to cope with increasing populations, crops are often grown under stressful environments which may result in lower yields. The key factors limiting yield and quality of crops are fluctuations in climatic conditions, such as stress, water stress, salt stress, etc. During winter season, its cold stress that adversely damages the vegetables production. In response to abiotic stress, several phenotypic symptoms such as stunted seedling, poor germination, reduced leaf expansion, yellowing of leaf (Chlorosis) and wilting occur, which sometimes results into tissue damage (necrosis) [5].

Reactive oxygen species (ROS) accumulate when plants encounter abiotic stress [6] and the overproduction of ROS under environmental stress can damage plant cells irreversibly by oxidation of cellular components, such as lipids, proteins, and DNA [6,7]. Therefore, excessive ROS must be scavenged as soon as possible. It is reported that ROS ca either be harmful when produced in excess, but beneficial at lower concentrations. ROS at low concentrations play an important role in regulating plant growth and development as well as in environmental acclimation [8]. Induction of the lipid peroxidation in plants due to excessive production of ROS is one major consequence of abiotic stress [9,10]. Under abiotic stress, imbalances in metabolic processes may result in increased accumulation of ROS, such as hydrogen peroxide, hydroxyl radical, superoxide and singlet oxygen [11,12].

In order to scavenge ROS, plants have developed enzymatic and non-enzymatic antioxidant defense systems. Antioxidant enzymes viz., catalase, superoxide dismutase and ascorbate peroxidase quench ROS to protect plant cells. In addition to this, many non-enzymatic antioxidants like tocopherols, carotenoids, ascorbic acid have an important role to play in scavenging ROS. Multiple antioxidant enzymes are involved in the quenching of ROS. Superoxide dismutases (SOD) react with superoxide radical and produces hydrogen peroxide (H2O2) which is scavenged by peroxidases (POD) and catalases (CAT). CAT reacts with H2O2 to produce oxygen and water. Among peroxidases, ascorbate peroxidases (APX) and glutathione peroxidase (GPX) use ascorbate and glutathione as electron donors, respectively and lead to H2O2 detoxification in plants [13]. Exposure of plants to stress results in excessive production of ROS due to the restriction of carbon dioxide fixation in chloroplasts and mitochondrial electron transport chain [14].

The activity of antioxidant enzymes i.e., SOD, POX and CAT significantly increase in response to adverse environmental cues. Further, the maximum values of SOD, POX and CAT have been found in the plants exposed to the lowest temperature (10/3 °C), when plants encounter low temperature stress. With the decrease in the level of the temperature, the values of antioxidant enzymes increased [15]. At some stage of stress exposure, the usual consequence of nearly all stresses is that they result in an increased production of ROS, which may oxidize lipids, proteins and nucleic acids which results in deformity at the level of the cell [16]. When excessive ROS are produced, plants synthesize antioxidant enzymes (SOD, CAT and POX) and osmoprotectant (proline) that quench excess ROS. On the other hand, low temperature stress, or other environmental challenges exhibit enhanced production of ROS and malondialdehyde

(MDA), used as an indicator of lipid peroxidation [17]. APX and CAT levels increased in roots of acclimated plants, whereas their levels remained unaffected in unstressed plants. Whereas, H2O2 content in roots of acclimated plants was significantly lower than the control and non acclimated plants under low temperature stress in tomato [18].

Glycine betaine plays an important role as an compatible solute in plants experiencing in stress condition. Glycine betaine production in chloroplasts maintains the activation of Rubisco by sequestering Rubisco active near thylakoids and preventing its thermal inactivation [19]. For example, high levels of glycine betaine accumulation were reported in maize and sugarcane in response to high temperature, while in contrast, plant species such as rice, mustard and tobacco naturally do not produce glycine betaine under stress conditions [20,21].

Glutathione is a thiol which participates in redox regulation and plays a role in storage, transport, and regulation of metabolites. Furthermore, it is involved in the detoxification of reactive oxygen species. The involvement of glutathione in redox regulation plays a crucial role in withstanding environmental stresses. The application of buthionine sulfoximine, an enzyme inhibitor in the glutathione pathway, led to a 70% decrease of in vitro pollen germination in Arabidopsis [22] demonstrating the crucial role of glutathione in pollen germination. Glutathione reductase has been proclaimed to play a substantial role in the prevention of oxidative stress in plants under high and low temperature stresses. In plants, both oxidative stress and expression of antioxidant defense machinery have been observed as parallel with increasing or decreasing temperature, which was enunciated by many investigators [23,24]. The high catalase activity has the collateral effect on abiotic stress, i.e., it increases the rate of H2O2 scavenging and enhances tolerance. Highest activity of catalase was recorded for stress tolerant genotypes. However, there was a reduction in the activity of guaiacol peroxidase in temperature stress [25].

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