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ABIOTIC STRESS *vis a vis* NON ENZYMATIC ANTIOXIDANTS IN THE PLANTS

Kamal Kant
Aspee Shakilam Biotechnology Institute, Navsari Agricultural University, Surat
E-mail: kamalkantphysio@gmail.com

Abstract: Antioxidants are the biomolecules and metal ions which protect the plants from biotic and abiotic stress and developmental stage ripening and senescence, when the production of free radicals excess in the cell. Abiotic stress is the common phenomena in the agricultural crops which drastically affect the growth and development and eventually yield of the plant. If the production and removal of free radicals in the cell balanced then severity of stress reduces and plants survive under stress. The balance between ROS (reactive oxygen species) and antioxidants become possible when the antioxidants activity and content of antioxidants sufficient in the cell under stress. The antioxidants activities reduced when severe continue for a long time. The targeted delivery of antioxidants *viz.* Ascorbic acid, Carotenoids, Tocopherol, Glutathione, Zinc, Selenium, Phenolics- Ferulic acid, Gallic acid, Coumaric acid, Ellagic acid, Flavonoids, Flavonol, Anthocynin etc. in a concentration dependent manner provide the improved stability, biocompatibility and survival of targeted cells/tissues and plants. Thus, the maintain of antioxidants in an appropriate concentration improves the antioxidants capacity of the cell and reduce the stress in the plants.
Keywords: Antioxidants, Abiotic stress, Biomolecules, Plants, ROS.

Introduction

Free radicals in the cell acts as initiator of signaling process in many cases of metabolism but in chloroplast and mitochondria affects the photosynthesis and respiration and these are considered as harmful molecule that are by product of metabolism of oxygen (Foyer et al., 2020). In controlled production these free radicals act as signaling intermediates in stomatal regulation, growth and developmental processes, drought, salinity, temperature extremes, high light, nutrient imbalance, or heavy metal toxicity, disturb redox homeostasis and other stress response (Dumanovic et al., 2021). When the production of these radicals exceeds, leds to cellular damage, affecting lipids, proteins, and nucleic acids. Excess free radical in the system causes several disorders and eventually in uncontrolled state led to permanent damage to the plants (Faustina and Alissandra, 2025). Non Enzymatic antioxidants are the essential for defense and development of the plants. They suppressed reactive oxygen or nitrogen species produced at the cellular level and minimize the damage of different cellular structures and consequently the integrity of the entire plant (Hasanuzzaman et al., 2020). The metabolites which are capable of scavenging the ROS non-specifically are most important in

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the system for minimizing the adverse effects of free radicals produced during the stress. These metabolites are known as non-enzymatic antioxidants and they have the capacity to neutralize a variety of reactive oxygen species (Ghosh et al., 2021).

These days' abiotic stresses have become more severe due to increasing industrial pollution and deforeastation leds to global warming and varying climatic conditions. Erratic rain, floods, extreme temperature, drought, salinity are external factors which became common for our agricultural land. Increasing global population needs sustainable food production for fulfilling the demand of food in future. Uncontrolled production of ROS due to the absence of redox homeostasis damage the DNA, RNA, proteins and lipids results in membrane damage, mutations, chromosomal aberrations, and eventually cell death. In aerobic organism in stress condition incomplete reduction of molecular oxygen produce ROS such as hydrogen peroxide (H_2O_2), superoxide radical (O_2•−), hydroxyl radical (OH•) and singlet oxygen (1O_2), as a by products and their excess production leds to damage of cellular membrane and bio-molecules (Mishra et al., 2023).

Regulation through antioxidants

Ascorbate is one of the important metabolite in cell synthesized mainly in mitochondira and acts as free radical scavenger mainly hydrogen peroxide. The ascorbate-glutathione (AsA-GSH) cycle operates to reduce hydrogen peroxide to water. It also scavenge free radicals of oxygen directly and regenerates tocopherol from tocopheroxyl radical. Monodehydroascorbate reductase (MDHAR) one of the enzyme in ascorbate-glutathione (AsA-GSH) cycle, its overexpression and over production enhanced the tolerance against abiotic stress particularly ozone, salt, and polyethylene glycol. Glutathione is a tripeptide biomolecule mainly present in chloroplast. It acts as reducing molecule in ascorbate-glutathione (AsA-GSH) cycle and regenerate ascorbate further to scavenge another hydrogen peroxide (Xiao et al., 2021). Carotenoids is the antioxidants quenching singlet oxygen without degradation and are known to chemically react with free radicals such as peroxyl (ROO•), hydroxyl (•OH), and superoxide radicals (O_2) due to its conjugated double-bonded structure. It also acts as photoprotector of photosynthetic apparatus in the high intensity of light and prevent photoinhibition (Foyer et al., 2020). Tocopherols protect the plants from photoinhibtion by quenching singlet oxygen. Its concentration increases in chloroplast in drought and high light intensity to save the thylakoid membrane and photosystem from photoxidative damage caused by free radicals. It is able to stop chain reaction caused by lipid peroxidation and protect the membrane from ionic leakage and support membrane stability during stress. Flavonoids molecules scavenge ROS by chelation of Fe^{2+} and Cu^{+} ions and donation of electron or hydrogen atom. The hydroxylation at3′ and 4′ positions of the B ring provide strong antioxidants potency to scavenge ROS. Phenolics is the diverse class of plant secondary metabolites neutralize reactive oxygen species by donating electrons or hydrogen atoms and terminating radical chain reactions thereby protecting plant from oxidative stress. Free radical scavenging efficiency determined by the structural features of phenolics such as conjugated double bonds, the number and position of hydroxyl groups and glycosylation (Soares et al., 2020).

Molecular approach to combat abiotic stress through antioxidants activity

The traditional approach to combat abiotic stress through physiological and biochemical mechanism of antioxidant activity in plants have not effectively reduce the production of ROS as well as enhancement of antioxidant activity. Hence these mechanism replaced by genomics, transcriptomics, proteomics, and metabolomics under high-throughput platforms (Jiang et al., 2021). The systematic identification of key regulatory genes, stress-responsive signaling networks, mechanism of ROS action and redox-homeostatis pathways enable the exploration of whole antioxidant defense system. The two molecular approaches Genomewide association studies (GWAS) and quantitative trait locus (QTL) have associated with glutathione metabolism and ascorbate cycling in foxtail millet and Arabidopsis. The construction of pan-genomes in wheat, rice and tomatoes became possible through next-generation sequencing (NGS) including both core antioxidant genes and cultivar-specific stress-responsive loci, optimizing the genomic plasticity in the antioxidant responses (Li et al., 2022). Stress responsive gene can be modified by emerging genome editing tools, particularly CRISPR/Cas9 technology that enable precise modification of cis-regulatory elements to regulate stress protective gene expression (Yu et al., 2025).

Phytohormonal and epigenetic regulation of stress responsive genes

The four phytohormones *viz.* Abscisic acid (ABA), Salicylic acid (SA), Jasmonic acid (JA) and Ethylene (ET) mainly act in stress condition through trancription factor (TF) activation and promoter binding. ABA-responsive elements (ABREs) and TFs like ABI5 mediate the expression of antioxidant genes during stress while NPR1-TGA complex regulate redox signaling which is mediated by SA. AP2/ERF1 is TFs that regulate stress responsive genes mediated by JA and ET (Li et al., 2022). Thus integration of multiple signaling network during stress have greater impacts on cope up the plant from abiotic stress.

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