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Oxidative Stress, Reactive oxygen species regulation and ROS scavenging pathways in plants

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Introduction:

The ideal growth condition for a plant can be regarded as the condition that allows the plant to achieve its maximum growth and reproductive potential as measured by plant weight, height, and seed number, which together comprise the total biomass of the plant. Plants are subjected to various environmental stresses, such as water deficit, drought, cold, heat, salinity, air pollution etc. Prof. *Jacob Levitt* in 1972 first expounded stress as any change in the environmental condition that might adversely change the growth and development of a plant and can prevent the plant from achieving its full genetic potential. Plant stress can be broadly classified into two main groups, *viz*., 'Biotic stress' and 'Abiotic stress'. The stress factors which occur by the communication among the plant and any other living organisms, *i.e*., viruses, bacteria, fungi, parasites, insects, weeds etc. that results in either minor injury that the plant can overcome or major injury that can cause death of the plant is referred as

biotic stress. These are again categorized into two types, *viz*., Allelopathy and Pathogenicity. Abiotic stresses like drought, excessive soil salinity, excessive watering, extreme temperatures (cold, frost and heat), salinity and mineral toxicity, too much or too little light and nutrient deficiency in the soil negatively impact growth and development of the plants. These are external stress factors that can affect the plant growth for a longer duration. Plants experience oxidative stress by the exposure to a variety of environmental factors such as salinity, drought, metal toxicity, extreme temperature conditions, air pollutants, ultraviolet-B (UV-B) radiation, pesticides, and pathogen infection etc.; in turn, consequently they lead to the generation of reactive oxygen species (ROS), which can affect a number of biological processes in the plants.

- **Reactive Oxygen Species, Types and Sites of Production:**

Reactive oxygen species (ROS) are regarded as natural by-product of plant aerobic metabolism. They are highly reactive forms of oxygen possessing at least one unpaired electron in their orbitals. The most common forms of ROS in plant cells are free radicals such as superoxide ($O_2^{\bullet-}$), hydroxyl radicals ($OH^{\bullet-}$), as well as nonradical molecules like singlet oxygen ($^1O_2$), hydrogen peroxide (H_2O_2). Due to any kind of stress, ROS are produced (Schieber and Chandel, 2014). ROS are generated in different cellular compartments, such as chloroplasts (Dietz *et al*., 2016), peroxisomes (Sandalio & Romero-Puertas, 2015), mitochondria (Huang *et al*., 2016), and endoplasmic reticulum and plasma membrane. In the case of chloroplasts, ROS are generated mainly in the electron transport chain's (ETC's) of Plastocyanin-ferredoxin oxidoreductase or PS-I and water-plastoquinone oxidoreductase or PS-II.

ROS	Abbreviation(s)	Sites of production
Superoxide	$O_2^{\bullet-}$	Chloroplasts, Mitochondria, Peroxisomes, ETC's
Hydroxyl radical	$OH^{\bullet-}$	Iron and H_2O_2

Hydrogen peroxide	H_2O_2	Peroxisomes, Chloroplasts, Mitochondria, Cytosol, Apoplast
Singlet oxygen	$^1O_2$	Chloroplasts, Nuclei, Membranes

TABLE: Types of ROS and sites of production

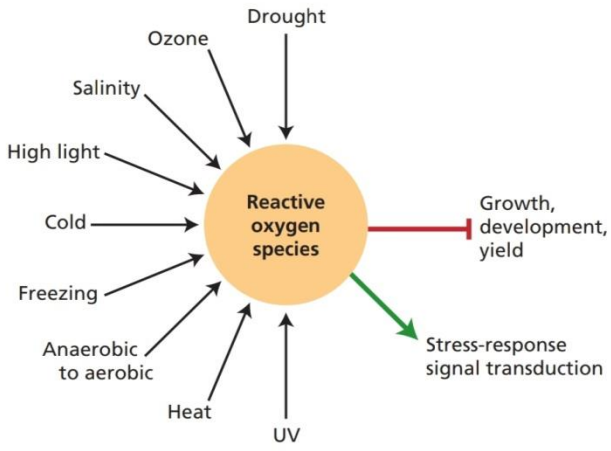


Fig: Accumulation of ROS from different abiotic sources, roles. (*Source: Taiz, L.; Zeiger, E.; Moller, I.M. and Murphy, A. (2015). Plant Physiology and Development. Sinauer associates Inc. USA. 6th edition (ISBN: 978-1-60535-255-8).)*

- **Roles of ROS metabolism in plants:**

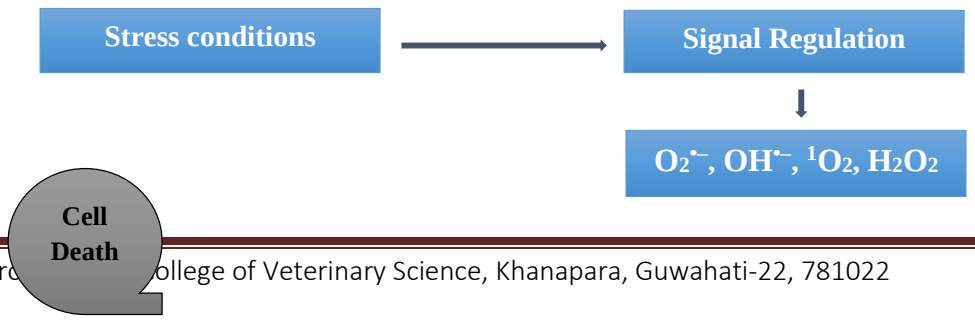
All types of ROS are severely detrimental to living organisms. They assimilate an autocatalytic process of oxidation of membrane that can lead to the degradation of organelles and the plasma membrane. The heightened production of ROS during stress condition can cause threat to the cells by causing oxidation of proteins, oxidize photosynthetic pigments, damage to the biomolecules, damage to nucleic acids and programmed cell death (PCD), ultimately leading to death of the living cells. At a moderate concentration of its generation,

it can also be beneficial by acting as a secondary messenger in intracellular signalling in plant cells. However, maintenance of a definite level of ROS regulation is quite crucial for aerobic organisms.

Reactive oxygen species are not only involved in the stress physiological mediation rather recent studies have revealed that they are also involved in numerous processes throughout the plant life cycle such as seed development and germination, shoot and flower development etc.

- **Plant Antioxidative defense management in response to stress:**

As mentioned above, salinity, drought, chilling, metal toxicity, air pollutants, UV-B radiation, and exercise of high amount of pesticides dependency as well as pathogen infection lead to intensified generation of ROS in plant cells; a broad study has suggested the regulation of intracellular antioxidant defence management systems in response to these assortment or variety of stresses. These antioxidant defence management systems include enzymatic and non-enzymatic components that regulate at different cellular compartments such as chloroplasts, peroxisomes, plasma membranes and endoplasmic reticulum. Enzymatic antioxidants comprise of enzymes such as, superoxide dismutase (SOD), catalase, guaiacol peroxidase (GPX), ascorbate peroxidase (APX), guaiacol peroxidase (GPOX), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR), glutathione reductase (GR) and glutathione Stransferases (GST), and non-enzymatic antioxidants which are ascorbic acid, glutathione, carotenoids, tocopherols, proline, glycine betaine, and favonoids *(*Xie *et al*., 2019).



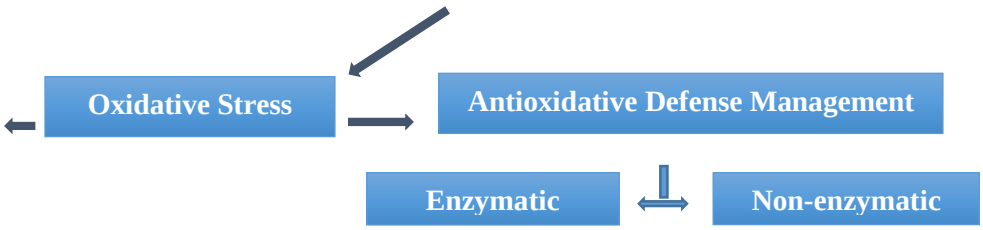


Fig: ROS generation, Antioxidative defense, and cell death in plant

- **Antioxidants, ROS scavenging pathways in plants:**

Antioxidants and ROS scavenging pathways act as safeguard to the cells from oxidative stress conditions. ROS assemble in cells during many different types of environmental stresses and are detoxified by specialized type of enzymes and antioxidants and this process is referred to as ROS scavenging. Biological antioxidants are organic compounds that can accept electrons from ROS such as superoxide or H_2O_2 and normalize them. Some of the widely known antioxidants in plants include the water-soluble ascorbate (Vit-C) and reduced tripeptide glutathione and the lipid-soluble a-tocopherol (Vit- E) and b-carotene (Vit-A).

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