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Unveiling Nature's Armor: Physiological Mechanisms Shielding Plants Against Abiotic Stress

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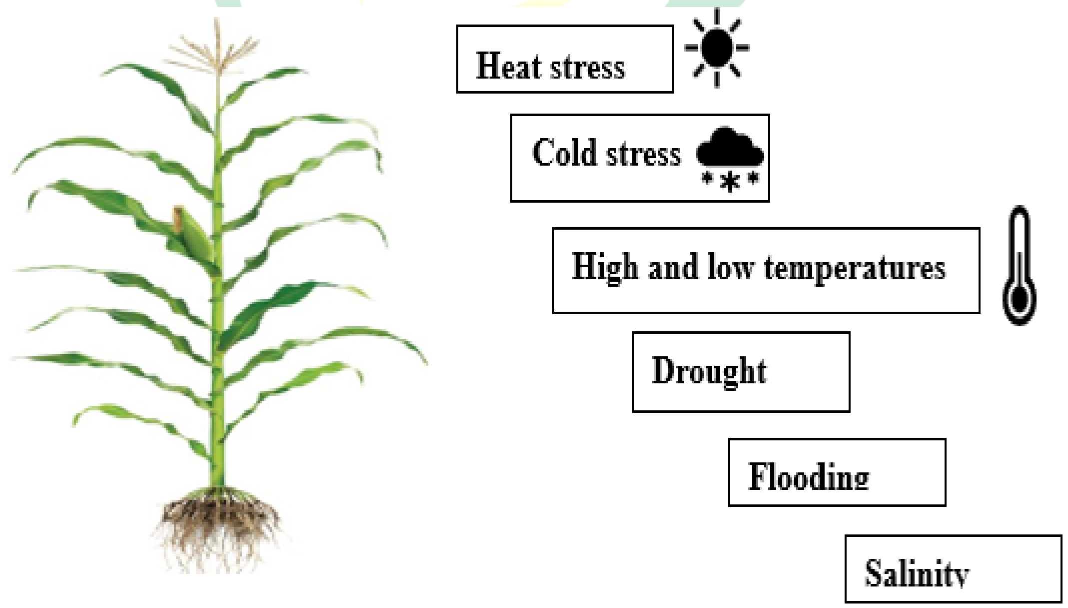
Introduction

Plants, being sessile organisms, are constantly exposed to a wide range of environmental stresses that can impede their growth and development. Stress can be defined as any environmental condition that prevents the plant from achieving its maximum genetic potential. Abiotic stress parameters include light intensity, carbon dioxide, oxygen, soil nutrient content, temperature, salinity and soil moisture availability. Deviation from typical ranges of these abiotic factors typically induces adverse biochemical and physiological outcomes in plants. However, nature has endowed plants with a variety of physiological and developmental mechanisms to confront these challenges and maintain growth and reproduction.



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Physiological mechanisms that protect plants against abiotic stress:

1. **Osmotic adjustment:**

Osmotic adjustment refers to the ability of plant cells to gather solutes and utilize them to decrease water potential in response to osmotic stress. The adjustment entails a net augmentation in solute concentration per cell, which occurs irrespective of volume alterations caused by water loss. Typically, the reduction in ψ_s is confined to approximately 0.2 to 0.8 MPa, unless in plants specialized for exceedingly arid environments. Compatible solutes are organic substances that exhibit osmotic activity within cells without causing membrane destabilization at higher concentrations, unlike ions. Plant cells can endure high levels of these compounds without adverse effects on metabolic processes. Examples of common compatible solutes encompass amino acids like proline, sugar alcohols such as sorbitol, and quaternary ammonium compounds like glycine betaine. proline also appear to serve as osmoprotectants shielding plants from harmful byproducts generated during water scarcity periods, while also serving as a reservoir of carbon and nitrogen for cells when conditions normalize

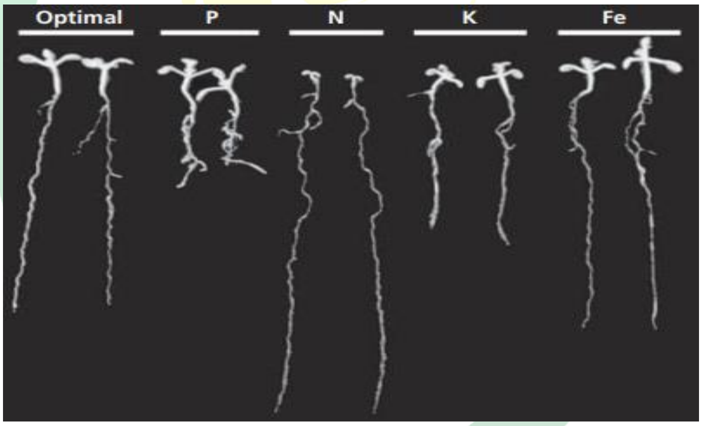

Figure 1: Effect of salt stress on the root-to-shoot ratio of tomato. (From Sánchez-Calderón *et al.* 2014.)

2. **Antifreeze proteins**

Antifreeze proteins are specialised plant proteins produced in response to cold temperatures. They restrict the growth of ice crystals by a mechanism distinct from reducing the freezing point of water. The proteins inhibit or slow down the continued expansion of ice crystals by adhering to their surfaces. Additionally, sugars, polysaccharides, osmoprotectant solutes, dehydrins, and other proteins induced by cold temperatures also have cryoprotective benefits.

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3. **Antioxidants and ROS Scavenging**

Cells accumulate reactive oxygen species (ROS) under various environmental stresses, which are then neutralized through specialized enzymes and antioxidants in a process known as ROS scavenging. Biological antioxidants can effectively counteract the negative impacts of ROS such as superoxide or hydrogen peroxide by accepting electrons from them. Common antioxidants found in plants encompass water-soluble compounds like ascorbate (vitamin C) and the reduced form of the tripeptide glutathione (GSH, oxidized form GSSG), as well as lipid-soluble antioxidants such as alpha-tocopherol (vitamin E) and beta-carotene (vitamin Certain ROS might spontaneously interact with cellular antioxidants, while others are unstable and degrade before causing any damage to the cell. Nonetheless, plants have developed various antioxidative enzymes that significantly enhance the effectiveness of these mechanisms. Eg: Catalase catalyzes the detoxification of hydrogen peroxide into water and oxygen in peroxisomes according to the reaction: $2\ H_2O_2 \rightarrow 2\ H_2O + O_2$

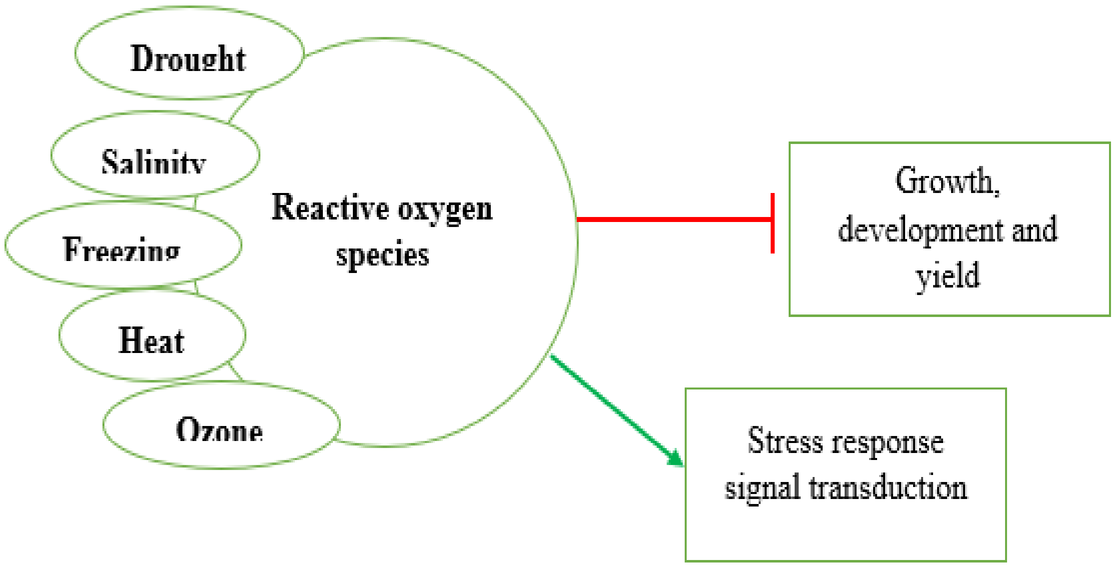

Figure 2: Dual role of Reactive oxygen species (ROS) during abiotic stress. ROS gets accumulated during abiotic stress thereby shows negative impact on plant growth and development. The ROS accumulation also has positive effect by activating the signal transduction that induces acclimation. (From Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). Plant physiology and Development.)

4. **Molecular chaperones**

Molecular chaperone proteins engage in physical interactions with other proteins to aid in protein folding, decrease misfolding, stabilize tertiary structure, and deter aggregation or disaggregation. Heat shock proteins (HSP) are one such type which are induced during a wide range of environmental conditions such as wounding, salinity, low temperature, water stress etc. So, the cells that have previously encountered one form of stress might acquire cross-protection against another type of stress. Along with this, there are other proteins also like LEA/DHN/RAB protein family which serve as molecular shields and also as cryoprotectants.

5. **ABA signalling**

Under water stress conditions, ABA level increase in leaves which triggers a signal that leads to closure of stomata. Stomatal closure is physiologically induced by reduced turgor pressure resulting from the significant efflux of K^+ and anions from guard cells. Specialized ion efflux channels on the plasma membrane facilitate this large-scale loss of K^+ and anions from guard cells. Plasma membrane K^+ efflux channels, which are voltage-gated, open solely when the plasma membrane undergoes depolarization. ABA induces membrane depolarization through two means: firstly, by instigating a temporary influx of Ca2+ ions, and secondly, by stimulating the release of Ca2+ from internal storage sites like the endoplasmic reticulum and the vacuole. Consequently, cytosolic calcium levels rise which result in efflux of K^+ ions and closure of stomata.

Conclusion

The ability of plants to manage adverse environmental conditions is referred to as stress resistance. Genetically determined plant adaptations, like CAM metabolism, contribute to this resistance. Acclimation enhances resistance by exposing the plant to stress beforehand. Plants utilize different physiological and developmental mechanisms to detect and respond to adverse environmental conditions. By employing these advanced strategies, plants can sustain growth, development, and survival even in difficult conditions. Gaining insights into these mechanisms enhances our understanding of plant resilience and can guide agricultural practices to boost crop stress resistance.

Reference:

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). Plant physiology and Development.