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Plant Stress Physiology - A comprehensive account

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▪ Introduction:

Now-a-days, stress, depression and anxiety are the few common words that are related to almost every human being. In fact, the human body is designed to experience stress and react to it. When we experience changes or challenges (stressors), our body produces physical and mental responses. Like humans, the plants also undergo stress and react to it. For example, if a normal plant growing under favourable light conditions is subjected to low light intensity, its photosynthetic mechanism is depleted. Simply, this low light intensity can be referred as a stress factor to the aforesaid plant.

▪ What is 'Plant stress Physiology'?

The ideal growth conditions for a given plant can be defined 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 and air pollution. The study of functioning of plants under adverse environmental conditions is simply called 'Plant stress physiology'. Prof. Jacob Levitt in 1972 first used the term biological stress in relation to plants and according to him, stress is simply any change in environmental condition that might adversely change the growth and development of a plant, and also prevents the plant from achieving its full genetic potential.

▪ Types of plant stress:

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 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 the plant can demise is referred as biotic stress. The biotic stresses caused by bacteria, fungi and nematodes that are ever present in the environment are called potential biotic stresses. These are subdivided into two types, *viz*. Allelopathy and Pathogenicity.

Allelopathy refers to the biochemical inhibition of one species by another. The inhibitory chemical is released into the environment where it affects the development and growth of the neighbouring plants. These biochemicals are known as allelochemicals. For example, *Juglans nigrum* releases an allelochemical 'Juglone' which is a respiratory inhibitor. Plants (mainly Solanaceae family), when exposed to these allelochemicals, exhibit symptoms such as wilting, chlorosis and death.

Pathogenicity refers to the potential disease-causing capacity of the pathogens. For example, the bacterium *Xanthomonas citri* causes citrus canker disease in the citrus plant.

Abiotic stress such as 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 plants. These are external stress factors that can affect the plant growth for a longer duration.

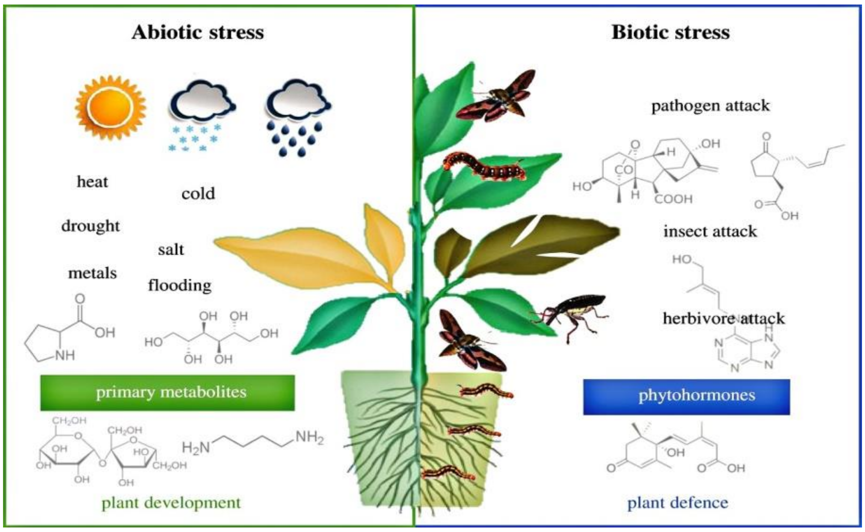

Fig: Sources of abiotic and biotic stresses
[Source: https://orbitbiotech.com/temperature-stress-plants-high-temperature-stress/responses-of-a-plant-against-abiotic-stress-orbit-biotech-training/]

Major Types of Abiotic Stress factors:

1) **Water deficit:** Water deficit is a common stress condition arising from inadequate supply of water. The affluence of water leads to a stress called flood stress and scarcity of water leads to a stress called drought stress. The temporary inundation of plants and its parts by flooding causes oxygen deficiency to the roots and soil borne microorganisms. Effects of flooding are - nitrogen turnover in the soil is reduced; abscisic acid, ethylene and ethylene precursors are formed in larger amount; stimulation of partial stomatal closure, epinasty and abscission in leaves; cellular membrane systems break down, mitochondria and microbodies disintegrate and enzymes are partially inhibited. Water deficit is a paramount abiotic stress factor that affects the plant and its development with numerous reasons, such as excessive salinity, flooding, insufficient rainfall, etc. A plant suffers from water deficit condition either when the uptake of water through roots becomes hindered or when the rate of the so-called evil

phenomena transpiration occurs relatively at a high frequency. Effects of drought are - decrease in cellular growth and synthesis of cell wall components that cause the cells to become smaller in size; increase in abscisic acid level that ultimately closes down the stomatal apparatus to the minimum; protochlorophyll formation is inhibited and photosynthetic process declines; levels of proline increases; respiration and translocation of assimilates decreases; loss of water leads to increase in the activity of hydrolytic enzymes, etc.

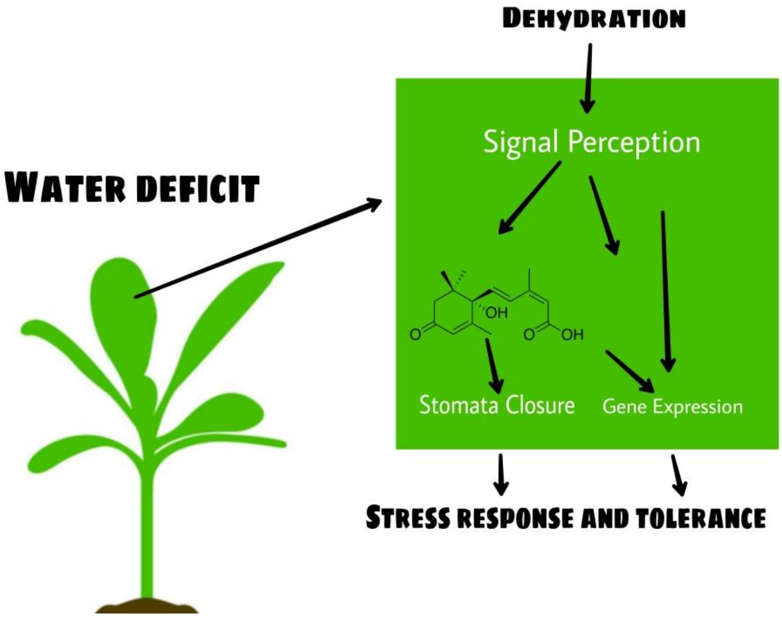

Fig: Water drought

2) **Salt Stress:** The assemblage of increased amount of salt in the soil than required causes inhibition of plant growth and sometime also leads to plant death; it is simply can be referred as salt stress. The plants which are present near the coastline area are subjected to salt stress. Na^+, Cl^-, K^+, Ca^{++} and Mg^{++} ions usually contribute to the soil salinity. Plants growing in coastline or estuaries area mainly face a number of adversities, of which absorption of water from the soil with negative water potential and interaction with high concentration of toxic sodium carbonate and chloride ions are the major problems. Based on salt tolerance, plants can be categorized into two main classes - Halophytes and Non-halophytes or glycophytes.

Salt stress on account of deficiency of minerals, such as K, P, S, Fe, Mo, Zn, Mg and Mn causes physiological disorders which lead to reduced growth and yields. Effects of salt salinity are - photosynthetic inhibition, water potential (Y) reduction, cell dehydration, ion cytotoxicity, leaf abscission, altered carbon partitioning, cytorrhysis cavitation, membrane and protein destabilization, ROS production, ion cytotoxicity and cell death, etc.

3) **Light Stress:** In a condition of low light intensity below the compensation point, the shade loving plants, i.e., ‘Sciophytes’ evolve, while in high light intensity, ‘Heliophytes’ used to get evolved. In low light intensity, stomata do not open fully; hence, there is a comparatively less diffusion of gases. As a result, the rate of photosynthesis and the chlorophyll synthesis is

also depleted. High light intensity also inhibits photosynthesis. Photoperiodic changes inhibit flowering.

4) **Temperature stress:** Temperature stress is one of the major environment factors which is classified into three types depending on the stressor. These are - Chilling, freezing and Heat Stress or High-Temperature Stress. Temperature stressed plants show water potential (Y) reduction, cell dehydration, symplastic ice crystal formation, membrane destabilization, membrane dysfunction, photosynthetic and respiratory inhibition, ROS production, cell death, low germination rates, growth retardation and often the plants die. High temperature stress causes soil and atmospheric drought. Plants are subjected to permanent wilting in soil drought and temporary wilting in atmospheric drought. Plants generally die at a temperature above 44^{o}C.

Chilling is the injury to the plant which is caused due to low but above 0^{o}C temperature where freezing injury occurs at a temperature below the freezing point of water (below 0^{o}C) and primarily the liquid phase in the cell wall freezes. Low temperature stress is also detrimental to the plants and the temperature near freezing point causes irreversible damage so that the plants fail to survive under extreme cold conditions. However, some plants growing in alpine and arctic regions can survive under low temperature, and such plants are said to be cold resistant.

5) **Heavy metal stress:** Heavy metals, such as Fe, Cu, Ni, Co, Cd, Zn and Hg are assembled in soil through industrial waste and sewage disposal. Even though some of them are essential micronutrients for the growth and development of the plants, their surplus amount, however, can affect the plant growth, metabolism, physiology and senescence.

- **Stress-Sensing Mechanisms in Plants:**

Plants rely upon a variety of mechanisms to sense abiotic stress. Environmental stress disturbs plant growth and development and alters many physiological processes in the plant by affecting protein or RNA stability, ion transport and other cellular functions. Any of these primary disruptions could signal the plant that an unusual environmental condition has occurred and that it's time to respond by altering existing pathways or by activating stress-response pathways. Plants use physical, biophysical, metabolic, biochemical and epigenetic mechanisms to detect stresses and activate response pathways.

- **Physical sensing:** Physical sensing refers to the mechanical effects of stress on the plant or cell structure. As for example, the contraction of the plasma membrane from the cell wall during drought stresses.
- **Biophysical sensing:** Biophysical sensing involves changes in protein structure or enzymatic activity, such as the inhibition of different enzymes during heat stress.
- **Metabolic sensing:** Metabolic sensing usually results from the detection of by-products that accumulate in cells due to the uncoupling of electron transfer reactions.

- **Biochemical sensing:** Biochemical sensing involves in the presence of specialized proteins that have evolved to sense a particular stress; as for example, Calcium (Ca) channels that can sense changes in temperature and alter Ca^{2+} homeostasis.
- **Epigenetic sensing:** Epigenetic sensing refers to modifications of DNA or RNA structure that do not alter genetic sequences, such as the changes in chromatin that occur during temperature stress.

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