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1. Abiotic Stress Alleviation by PGPR

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Abstract:

Defense against stress and active suppression of growth are two complementary strategies by which plants respond to adverse environments. Although beneficial for plant survival, active growth inhibition is often undesirable for crop productivity. Compared with the knowledge on how plants defend against stress-caused cellular impairment, much less is known about how stress signaling regulates plant growth and vice versa. Understanding this regulatory network will be critical for resetting the balance between stress resistance and growth in order to engineer stress-resistant and high-yielding crops. In agriculture, PGPR could serve as an excellent means to mitigate the damaging impacts of abiotic stressors like drought and excessive salinity, taking the place of costly inorganic fertilizers that harm the ecosystem. Further prospects for phytoremediation may arise from an increased understanding of the roles played by plants and related microbes in the matrix of interest, particularly when there is persistent degradation.

Keywords:

Stress, Abiotic, Environment, PGPR

1.1 Introduction:

Taking a look into the environmental parameters, they have a severe effect over the plant growth and development. Just like any other living cell, the plant or the plant cell also undergoes a continuous mechanism or a metabolic process for its daily regulations.

Although, there is a need of these environmental parameters for its growth, but there have been chances of to develop conditions like stress in plants. Stress in plants refers to any fundamental alteration in plant mechanism because of any foreign agent.

Considering this stress condition, it can be sometimes favorable to sustain itself in a tough environment, but persistent stressful environment leads to damage of crop and its yield. Thus, mitigating stress parameters is an important point to be considered. The stress not only affects the plant's productivity but also their survival **(Tripathi *et al.*, 2020)**.

Depending on the type of stress, plants can dry out, freeze, burn or even die. Plant stress obviously matters to the plants, but also to all of humanity because plants are the primary source of food for human consumption.

The effect of stress on plant growth can be measured as a decrease in plant growth rate or as a decrease in biomass accumulation. For example, the leaf elongation rate of cereals responds to hyperosmotic stress within seconds and is one of the most sensitive plant responses to stress **(Zhao *et al.*, 2020)**. Some plants can increase the growth of certain plant parts as a response to specific stresses; they can, for example, increase root growth in response to mild drought or increase stem growth in response to low light or flooding conditions. This type of stress-induced growth of a specific organ is usually achieved by sacrificing the growth of other parts of the plant. In these cases, whole plant biomass accumulation better reflects the overall effect of the stress.

Considering these stressful environments, plants are very sensitive to such extent and shows various alteration specially in their molecular machinery. Stress sensing and stress regulations is a part of this mechanism. Once a stress is sensed by the plant cell, the signal is relayed and amplified by second messengers such as calcium, reactive oxygen species (ROS), phospholipids, and nitric oxide (NO), along with different types of protein kinases.

Stress-induced increases in cytosolic calcium concentration (denoted $[Ca^{2+}]i$) vary in intensity, frequency, and subcellular location. Plants in the wild constantly face stresses, and ideal growth conditions for any plant may only be achieved in a controlled environment. Thus, being under stress is the "normal" state, and plant growth in the wild is usually inhibited. Contrary to the presumption that the growth-stress trade-off is due to limits in energy/carbon supply, increasing evidence indicates that the trade-off mainly results from the active suppression of growth by stress signaling pathways. The regulatory networks for stress response and growth regulation crosstalk at multiple levels **(Zhang *et al.*, 2020)**.

1.2 Types of Stress:

Since plants cannot move, they face many environmental stresses. Plants have to deal with changes in light, humidity, drought, or cold. And if that was not enough, they still have to fight against all kinds of pathogens. The stress in plants can be categorized as abiotic (originated by drought, cold, high light) and biotic (originated by the attack of bacteria, fungi, herbivores). The relationship between different stresses can be understood as the interconnection between signaling pathways which share similar members (e.g., genes and molecules). This means that a plant can use similar components (such as MAPK kinases) to develop defense responses against many different types of stresses **(Zhang *et al.*, 2021)**. However, although the plant uses similar players for different stresses, the final output or tolerance response will differ. This is known as "specificity".

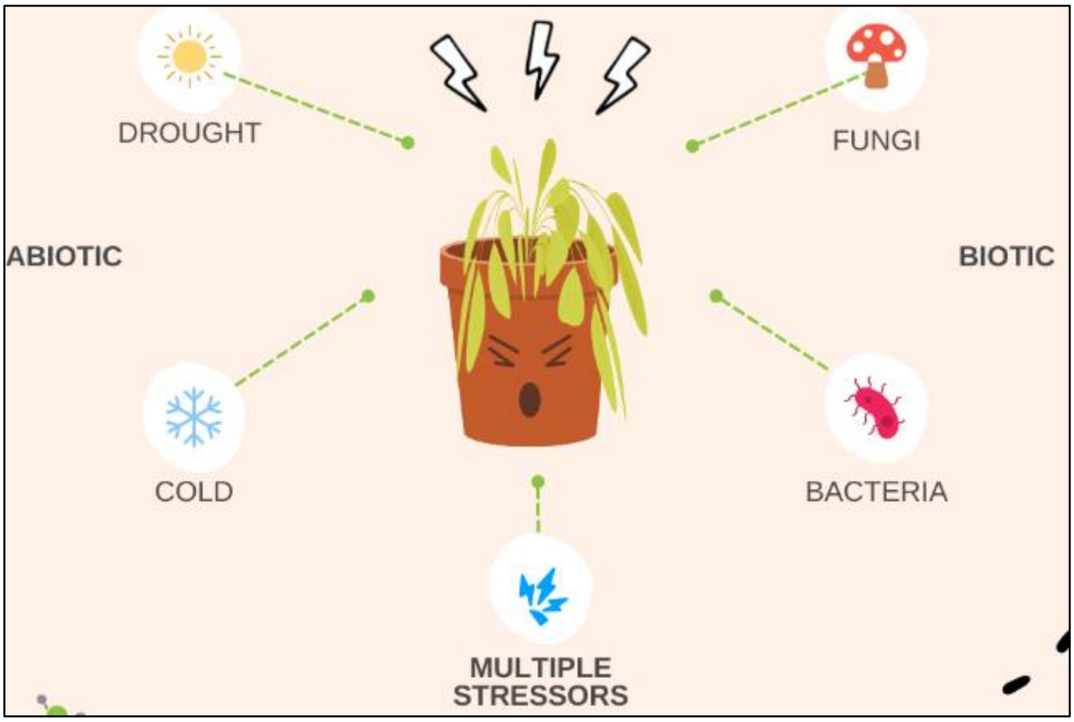

Figure 1.1: Types of Stress

1.3 Abiotic Stress and Its Impact Over Plants:

Plants are subjected to a variety of abiotic stresses, which have an impact on crop yield round the world. Majority of abiotic stress includes: drought, salt, cold, heat and toxins. Water being a crucial element for plant growth, aids in better growth and development of plant whereby if water scarcity is there, it might cause a significant mitigation to plant growth. Drought-induced crop output losses are likely to outnumber losses from all other sources because both the severity and duration of the stress are crucial **(Umar *et al*., 2021)**.

The severity of the drought depends on the occurrence and distribution of rainfall, evaporative demands, and moisture storing capacity of soils, all of which are unpredictable. Nowadays, climate has changed all around the globe by continuously increasing in temperatures and atmospheric CO_2 levels. The distribution of rainfall is unequal as a result of climate change, which functions as a major stress in the form of drought. Due to extreme drought conditions, the amount of soil water available to plants is steadily decreasing, causing plants to die prematurely. After drought is imposed on crop plants, growth will be arrested. Drought circumstances cause plants to lower their shoot growth, as well as their metabolic demands. Another limiting factor is salt or salinity. Crop productivity is also endangered due to soil salinity or excessive accumulation of salt around the agricultural area. There are several ways by which salt stress reduces the growth and yield of crops. Salt stress has two main effects on crop plants: osmotic stress and ion toxicity. These primary effects of salinity stress cause some secondary effects such as assimilate production, reduced cell expansion, and membrane function as well as decreased cytosolic metabolism.

Global warming and other temperature related issues have been faced recently thorught out the globe. Thus, fascinatingly the temperature rise as well as lowered temperature serves as an abiotic stress. Crop output and productivity largely depends upon the temperature of the agricultural land, thus encountering hamoered growth of crop **(Chaudhary and Sidhu 2022)**. Plants are sessile in nature; therefore, they have evolved unique ways to cope with temperature variations in their habitat. In temperate conditions, plants are encountered by chilling and freezing conditions that are very harmful to plants as stress. In order to adapt themselves, plants acquire chilling and freezing tolerance against such lethal cold stresses by a process called acclimation. However, many important crops are still incompetent to the process of cold acclimation. Similarly, Heat stress has become the most important limiting factor to crop productivity and ultimately the food security. When plants are subjected to heat stress, their seed germination rate, photosynthetic efficiency, and yield all suffer. Under heat stress, during the reproductive growth period, the function of a petal cell is lost, and the anther is dysplastic. For example, maize yields decrease sharply when the plants are exposed to temperatures greater than approximately 29–30°C **(Sabagh *et al*., 2020)**.

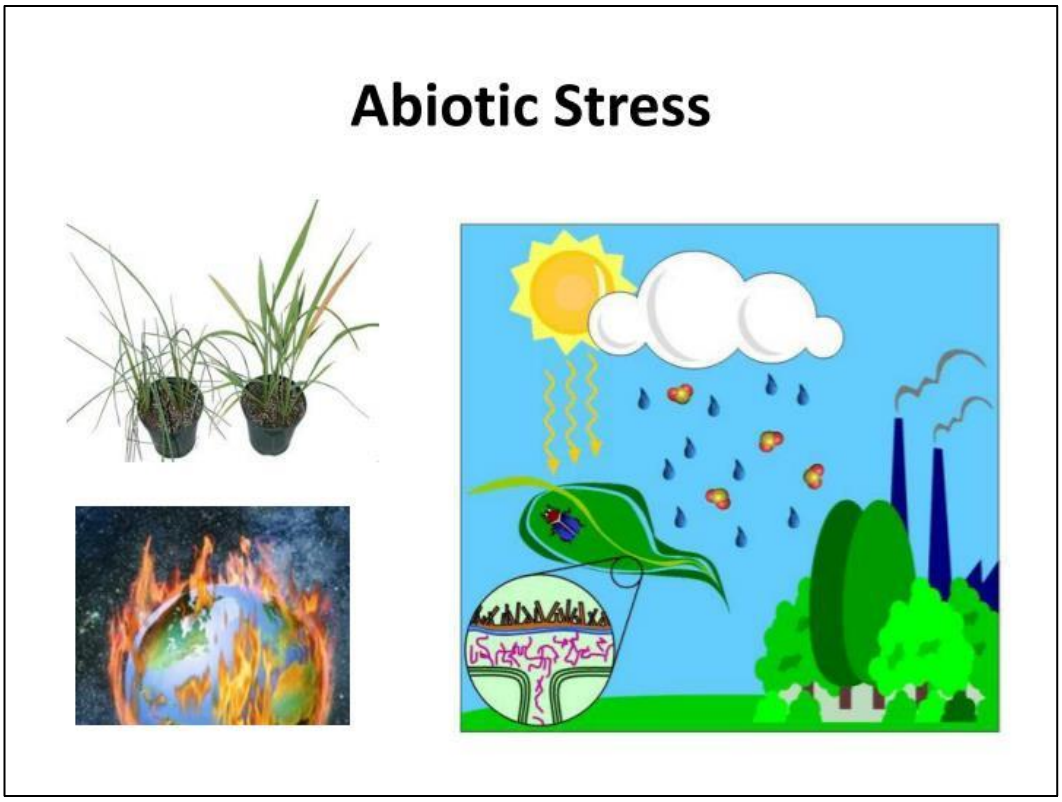

Figure 1.2: Abiotic Stress

Prolonged abiotic stress usually reduces the plant energy supply by inhibiting photosystem II activity **(Gururani *et al.*, 2015)**. For example, plants respond to water deficit by reducing stomatal opening in order to reduce water use. This leads to a series of negative effects on the photosystem. First, stomatal closure (aka. reduced stomatal conductance) and reduced mesophyll conductance of CO2 (the diffusion rate of CO2 through mesophyll cells) limit the internal CO2 concentration and thereby contribute to a decreased photosynthesis rate. Drought-induced synthesis of ABA is necessary for stomatal closure and decreased mesophyll conductance. Second, decreased CO2 availability leads to a decline in the energy consumption of the Calvin-Benson cycle and to the over-reduction of the photosynthetic electron transport chain by excess light energy. This leads to the accumulation of ROS, including singlet oxygen (1O2) and hydrogen peroxide (H2O_2) produced by the chloroplast. The oxidative stress caused by ROS mainly affects chloroplast protein synthesis and photosystem II repair **(Lima-Melo *et al.*, 2021)**.

Consistent with the postulation that excess light stress is a main consequence of drought, transcriptome analyses showed that the expression of 70% of the high-light (excess-light)-induced genes is also increased under drought treatment. In response to abiotic stress, plants divert substantial resources to prevent or repair damage caused by stress to maintain cellular homeostasis, as reflected by dramatic changes in the transcriptomic, proteomic, and metabolomic profiles of stressed plants within minutes or hours.

1.4 PGP Attributes of Bacteria (PGPR & it's Applications):

Around the world, there is an increase in the frequency of abiotic factors that negatively affect plant development and productivity in principal crops. Plant development under stress conditions will therefore be lower than under non-stress settings due to these stressful reasons. Concerns are becoming more widespread, and there is a need for appropriate, eco-friendly methods that reduce the negative impacts of plant stress. The connection between beneficial microbes and plants are crucial in these kinds of stressed environments. Plant growth-promoting rhizobacteria (PGPRs) are an advantageous choice that are currently being used extensively to reduce these stressors **(Gimenez *et al.,* 2018)**. Plants exposed to PGPRs undergo morphological and biochemical changes that boost their resistance to abiotic stressors, a phenomenon known as IST (induced systemic tolerance).

Plant growth promoting rhizobacteria (PGPR) have gained worldwide importance and acceptance for agricultural benefits. This is due to the emerging demand for dependence diminishing of synthetic chemical products, to the growing necessity in the field of sustainable farming. There are several PGPR inoculants currently commercialized that seem to promote growth through at least one mechanism: suppression of plant disease (bioprotectants), improved nutrients acquisition (biofertilizers), or phytohormone production (bio stimulants) **(Vocciante *et al.,* 2022)**. Bacteria in the genera *Bacillus, Streptomyces, Pseudomonas, Burkholderia,* and *Agrobacterium* are the biological control agents predominantly studied and increasingly marketed. They suppress plant disease through at least one mechanism, production of antibiotics or siderophores and induction of systemic resistance. Identification and characterization of beneficial bacteria involves morphological, physiological and molecular characteristics based on fatty acid analysis, mol (%), DNA–DNA hybridization, and 16S rRNA sequencing. These characteristics help in defining the taxonomy and nomenclature of PGPR.

PGPR can affect plant growth by different direct and indirect mechanisms. Some examples of these mechanisms, which can probably be active simultaneously or sequentially at different stages of plant growth, are (1) increased mineral nutrient solubilization and nitrogen fixation, making nutrients available for the plant; (2) repression of soil borne pathogens (by the production of hydrogen cyanide, siderophores, antibiotics, and/or competition for nutrients); (3) improving plant stress tolerance to drought, salinity, and metal toxicity; and (4) production of phytohormones such as indole-3-acetic acid (IAA). Moreover, some PGPR have the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which hydrolyses ACC, the immediate precursor of ethylene in plants **(Nazir *et al.,* 2018)**. By producing ACC (1-aminocyclopropane-1-carboxylate) deaminase, decreasing the production of stress ethylene, altering the phytohormonal content, inducing the synthesis of plant antioxidative enzymes, enhancing the uptake of essential mineral elements, producing extracellular polymeric substances (EPS), decreasing the absorption of excess nutrients/heavy metals, and inducing abiotic stress resistance genes, PGPRs increase plant growth and resistance to abiotic stresses through a variety of mechanisms (multiple mechanisms of action). Furthermore, experimental studies point to the simultaneous activation of multiple mechanisms of action by these bacteria, which ultimately boost plant development. The action mechanisms by which PGPRs could mitigate abiotic stresses (drought, salinity, heavy metal toxicity, and nutritional imbalance) in plants were examined in this review work. It is believed that the use of PGPRs would develop into an effective approach and a growing trend in the sustainable promotion of plant development **(He *et al.*, 2018)**. As ACC deaminase and IAA-producing bacteria have numerous potentials to alleviate plant stresses such as salt, drought, nutrient imbalance, and heavy metal toxicity, they can be a promising alternative for optimal crop development and bio-fertilizer production in the future. Future research on the combined use of stress-tolerant PGPRs with numerous plant growth-promoting (PGP) properties under environmental challenges is also highlighted here.

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