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Review Article

Rhizobacterial - Plant Interaction Approaches that Enhance Plant Growth Under Abiotic Stress

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Abstract

The global concern is population growth and rising food demands. It is unavoidable to implement new agricultural productivity-enhancing practices. Plant growth promoting rhizobacteria (PGPR) has showed promise as a sustainable agriculture approach. They have a critical function in increasing soil fertility, promoting plant growth, and suppressing phytopathogens in the development of environmentally friendly, long-term agriculture. Beneficial plant growth-promoting (PGPR) microorganisms can be used as effective biotechnological instruments to boost plant development in a variety of situations, including stressful ones. A rise in the occurrence of abiotic stresses, which have a negative impact on plant growth and productivity in major crops, has been seen all over the world. As a result of such stress elements, plant development will be reduced under stress conditions compared to non-stress ones. There is a growing global desire for effective, ecologically friendly methods to decrease the negative consequences of plant stress. The importance of plant-beneficial microbe interactions under such harsh conditions cannot be overstated. Plant growth promoting rhizobacteria (PGPRs) are a good option for reducing these stressors and are now routinely used. Plants inoculated with PGPRs undergo morphological and biochemical changes that lead to greater tolerance to abiotic stressors. In this review article we focus on PGPRs, abiotic stress effects on plant growth and PGPRs mechanism in alleviating salinity, drought and heavy metal stress condition for plant growth.

Keywords: Plant Growth Promoting Rhizobacteria (PGPR); Abiotic Stress; Drought Stress; Salinity; Heavy Metals

Introduction

Since the birth of civilization, agriculture has been the most important source of income [16]. Food security has been one of society's primary issues for a long time, and any element that threatens it has been one of society's challenges. With an increasing population rate and an unsustainable traditional agricultural system, farmers and politicians are struggling with how to produce enough food to fulfill global demand [23]. Around 7.41 billion people live on the planet, occupying 6.38 billion hectares of land, with 1.3 billion of them directly reliant on agriculture. Dynamic nature is critical for sustainable agriculture soil preservation. The Food Balance Sheet (FAO) 2004 of the United Nations' Agriculture Organization demonstrates that the terrestrial environment alone provides 99.7% of food for the world's population. Every year, 79 million people are added to the world's population, resulting in an ever-increasing demand for food and a corresponding lack of supply. Half of India's population uses 60.6% of the country's land for agriculture, growing a variety of cereals, vegetables, and pulses [29]. According to the FAO, agricultural land covers 38.47% of the world's land area, and while 28.43% of that land is arable,

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only 3.13% is permanently used for crop production. The issue has deteriorated as 20-25% of land worldwide is degraded each year, with another 5-10 million hectares destroyed each year. The movement of nutrients, energy, and carbon between soil organic matter, the soil environment, the aquatic ecosystem, and the atmosphere has a significant impact on agricultural productivity, water quality, and climate change [16]. Apart from climate change, the ever-increasing population, extensive agricultural practices, and consequently soil health degradation for crop production are all elements that affect agricultural sustainability. Furthermore, excessive use of chemical fertilizers, pesticides, and weedicides in agriculture results in a significant reduction in the diversity of beneficial soil bacteria. Abiotic and biotic stresses have a persistent impact on our agro-ecosystem, affecting soil health and fertility, as well as crop output [9].

The utilization of beneficial microorganisms as an integral part of agricultural practice is a technique that should be promoted in order to increase crop output in a sustainable and ecologically acceptable manner under stressful conditions [35]. Plant growth-promoting rhizobacteria (PGPR), also known as rhizobacteria, are bacteria that live in the rhizosphere and help plant growth through direct mechanisms such as phytohormone production and increased nutrient availability, or indirect mechanisms such as pathogen suppression through antibiosis, lytic enzyme synthesis, and induced systemic resistance (ISR) [20,32]. This review focused on the various PGPR effects on plants under stressful conditions, as well as the various ways that beneficial microbes help plants to cope with stress, and finally, the plant's requirements to use these beneficial rhizobacteria approaches to survive under abiotic stresses, making it clear that these microbes (PGPR) are an important part of sustainable agriculture [22,38].

Environmental stress and biochemical changes in plants

Numerous stress conditions, mostly classed as abiotic and biotic, have a negative impact on plant growth and productivity. They can occur spontaneously or as a result of human induction. Drought, low/high temperature, salinity, and acidic environments, light intensity, submergence, anaerobiosis, heavy metals (HMs) pollution, and nutritional deprivation are the most common abiotic stress, which contributes to a 50% loss in annual agricultural productivity globally whereas, Biotic stress is caused by disease-causing pathogens such as bacteria, viruses, fungi, and parasites, which contribute for a 30% loss in annual agricultural productivity globally [22,39]. A plant's physiology, morphology, biochemistry, and even molecular features are all affected by stress. Soil microbial diversity, crop productivity, soil fertility, and enhanced nutrient acquisition competition are all affected by biotic stress, which is influenced by abiotic stress [23,32]. Drought (lack of water), salinity (high salt concentrations), HMs toxicity, non-optimal temperature, and nutrient shortages, as well as biotic stress such as pathogen invasion, can cause physiological and morphological alterations in plants. After recognizing the stress, the plants respond quickly and forcefully to begin complex stress-specific communication by producing plant hormones and accumulating phenolic acids and flavonoids [22,38].

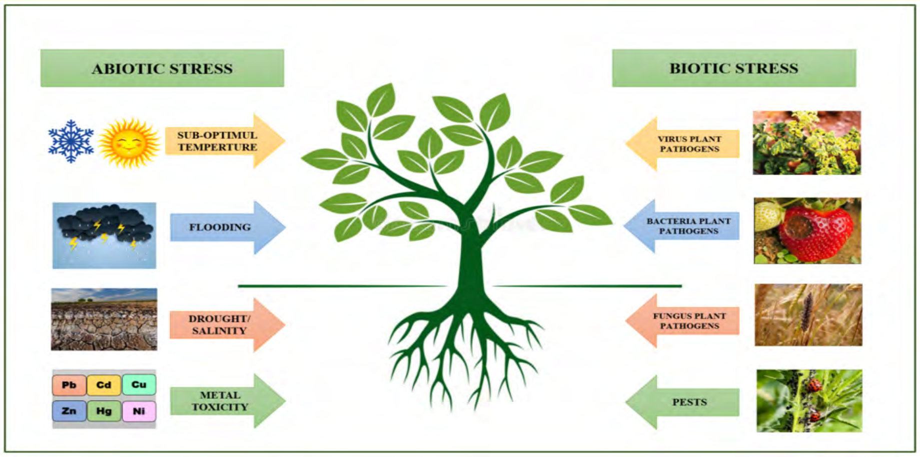

Figure 1: Different abiotic and biotic stress during plant growth (image created by PP in MS Office 365 ProPlus, PowerPoint).

Abiotic stress

Plants are harmed by a variety of unexpected events, the most common of which are abiotic stress, which is the leading cause of agricultural production limitations worldwide [23,42]. Abiotic stressors are the harmful effects of nonliving elements on living organisms in a given environment. These stresses are posing a serious threat to agriculture's long-term viability. An abiotic element's strength or quantity has an impact on plant growth and development. Abiotic stress refers to any deviation from these ideal environmental conditions, such as a chemical or physical imbalance, which has a negative influence on plant growth, development, and productivity [22,42]. Abiotic stressors are the principal limiting factors for crop yield when environmental conditions are abnormal. Heat, cold, drought, alkaline conditions and salinity, water logging, light intensity, higher concentration of heavy metal and nutritional insufficiency are all examples of abiotic stressors. Drought has harmed 64% of the world's land area, with salinity affecting 6%, anoxia affecting 13%, soil alkalinity affecting 15%, mineral depletion affecting 9%, and cold affecting 57% [23,39]. Furthermore, climate change is assisting in the development of numerous abiotic stresses, particularly high temperatures and drought, which have resulted in major yield decreases in wheat, maize, rice, barley, and other crops. The costs of abiotic stresses have the potential to be significant. Abiotic stressors resulted in a 70% reduction in crop yields, in addition to their negative consequences on agriculture, biodiversity, and the environment [9].

Salinity stress

Salts are a naturally occurring element in both water and soil. Salinization is the process of increased salt content in the soil, and it is significant to stress for most plants. Soil salinity stress creates a variety of issues. Excessive salt levels in plant tissues are, in fact, poisonous to it. Furthermore, when plants are exposed to salinity, they have a harder time obtaining the nutrients and water they require. As the most common abiotic stress, salinity stress impacts most agricultural fields and conventional agriculture around the world [18]. Osmosis stress occurs when the water potential in the soil is lowered, making it difficult for the plant to absorb water and nutrients. The presence of cations like Ca^{2+}, K^{+}, and Na^{+}, as well as anions like Cl^{-} and NO^{3-}, causes soil salinity. Inadequate rainfall and poor soil weathering are the primary causes of salt buildup as electrically charged ions in the soil [46]. Salt stress affects several aspects of plant life, including seed germination, nodulation, agricultural productivity, water and nutrient intake, crop production, ecological and physicochemical balance, and nitrogen fixation [46]. Plants, on the other hand, must use a variety of processes to deal with this condition. Some of the strategies used by plants to survive under salt stress conditions include osmotic tolerance, tissue tolerance, and the exclusion of Na+ from leaf blades [3]. Furthermore, plant-produced phytohormones such cytokinin, auxin, gibberellins, and ethylene, as well as siderophore and nutrient mobilization, and nitrogen fixation, are some of the direct mechanisms that lead to increased root number, length, and volume, and hence greater nutrition uptake [22,32,38].

Drought stress

Drought is another important abiotic stress that has a negative impact on the growth and production of most cultivated agricultural products, particularly in arid and semiarid areas [9]. Drought is referred to as detrimental environmental stress, and environmentalists and agricultural scientists are both concerned about it. It's a major agricultural problem all around the world, limiting plant growth, development, and output [21]. Drought stress impacts the majority of agricultural fields around the world, affecting human lives and the economy as a result [22]. Drought stress has a negative impact on plant development and metabolic processes in key field crops by affecting water relations, photosynthesis, and nutrient uptake [9]. Drought has a variety of effects on growth factors as well as stress-responsive genes in suffering. Low water content reduces cell size, turgor pressure, and membrane integrity, as well as the formation of reactive oxygen species (ROS) and leaf senescence, all of which impair crop plant yield [32,38,48]. Furthermore, a lack of water causes a variety of morphological, physiological, and molecular changes in plants, including height loss, increased ethylene production, lipid peroxidation, changes in chlorophyll content, membrane function and protein conformation due to free radical accumulation, photosynthesis apparatus damage, photosynthesis inhibition, and cell death [6,48]. It is important to note that the influence of climate change will result in more frequent and severe droughts in the near future [22].

Heavy metal stress

Pollution of Heavy metals in soils has occurred from industrialization, anthropogenic activities, and the usage of chemical fertilizers; these metals have a strong effect on plants, putting human and animal health at risk. Pollution from Heavy metals and contaminated soils are thus important global environmental issues. Metals with densities more than 5 g/cm^3 are classified as Heavy metals [22,36,43]. Heavy metals include cadmium, lead, manganese, chromium, copper, zinc, and aluminum. Metalloids, such as arsenic (As) and antimony (Sb), are chemical elements that have some of the properties of metals while also having some nonmetal qualities [27]. Some heavy metals are only required at low concentrations for various metabolic functions of organisms, but at larger concentrations than threshold levels in soils, these metals have a deleterious impact on the growth and composition of microbial communities. Heavy metals also have a negative impact on heavy metal-stressed plants' growth, biomass, and photosynthesis. Heavy metals cause depletion and imbalance of vital nutrients in plants impacted by metal stress by interfering with the uptake and distribution of essential nutrients [9,36,43]. Furthermore, heavy metals are primarily deposited in soil and transmitted to the food chain by plants that develop in that soil [9]. To protect against hazardous effects and Heavy metals pollution, these Heavy metals must be entirely removed from the environment. There are a variety of physio-chemical heavy metals remediation approaches available, but most of them have drawbacks, such as the loss of soil structures and high costs [8,13,41].

Plant growth promoting rhizobacteria

As a result, reducing environmental stress in an environmentally responsible manner is critical. The utilization of beneficial plant-associated microbial communities to promote plant growth and development in adverse environments is receiving a lot of attention. Farmers have more options with microbial solutions, and they can assist meet the demand for sustainable agricultural methods. Applying proper microbial techniques and utilizing the interactions of plant roots and soil microbes to promote crop productivity and soil health is essential in such conditions [9]. Beneficial bacteria associated with plant roots play an important role in increasing plant tolerance to both biotic and abiotic stress. Microorganism-driven physical and chemical changes in plants that result in increased plant tolerance to abiotic stimuli have been coined the name induced systemic tolerance (IST) [38,50]. Plant growth-promoting bacteria (PGPB), including plant growth-promoting rhizobacteria (PGPR), and mycorrhizal fungi would contribute to environmental stability and a transformation toward sustainable agriculture [30,32]. Plant-associated microorganisms can be classified as (a) beneficial, (b) deleterious, and (c) neuter types depending on their influence. Members of the genera *Azospirillum, Azotobacter, Pseudomonas, Bacillus, Burkholderia, Enterobacter, Klebsiella, Serratia,* and *Variovorax* are considered PGPR, which stimulates plant growth and development under both optimal and inadequate conditions. Drought, heavy metal, and salinity stress affect the majority of plant growth-promoting microorganisms (PGPM) and arbuscular mycorrhizae (AM) [23]. As a result, finding biofertilizers that are compatible with the stress environment is difficult. Nonetheless, by establishing effective processes, some of these microbes may simultaneously withstand harsh environments and establish plants. In the next chapter, a practical method for investigating the role of plant-microbe interactions in maintaining plant development and conferring disease resistance on sustainable agriculture is required [23].

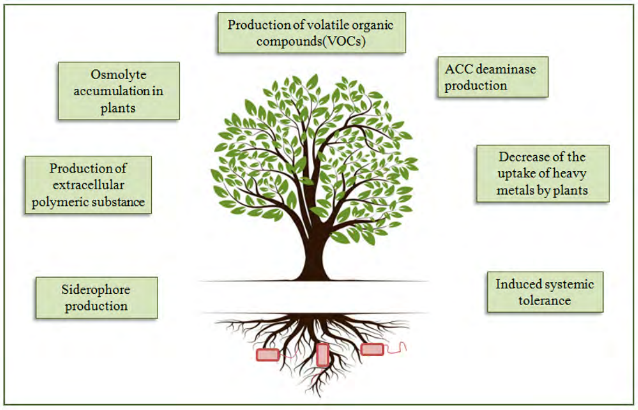

Figure 2: PGPRs action mechanism in alleviating salinity, drought and heavy metal toxicity stress in plants (image created by PP in MS Office 365 ProPlus, PowerPoint).

Action mechanism of PGPRs to support plant growth in stress condition

ACC deaminase

Plants create "stress ethylene" in response to environmental stress, and this ethylene primarily limits plant growth [1]. Stress conditions such as salinity, drought, nutritional imbalance, and heavy metals force plants to produce "stress ethylene." Ethylene is a vital hormone for plant growth and development at low concentrations. However, under stressful conditions, it is overproduced, affecting the growth and yield of all plants exposed to stress [9]. ACC (1-aminocyclopropane-1-carboxylic acid) deaminase, an important bacterial physiological characteristic, aids plant growth under stress situations [10]. PGPR with the enzyme ACC deaminase would lower the level of stress ethylene and allow the plant to flourish under abiotic stress conditions [11]. In stressed plants, PGPRs containing ACC deaminase can convert ACC, a plant ethylene precursor, to ammonia and -ketobutyrate, lowering ethylene synthesis [14].

Siderophores production

Iron is a necessary element for plants. Important physiological functions like respiration, photosynthesis, and nitrogen fixation are all mediated by enzymes, and iron serves as a cofactor for these enzymes, hence iron deprivation causes significant metabolic changes [15,40]. Furthermore, in an aerobic environment, iron occurs in an insoluble form; it exists in the trivalent state as oxyhydroxide [5]. Because iron in its trivalent state is sparingly soluble and hence unavailable to microbes and plants, it is required in the form of Fe^{+2} [35,41,44]. To circumvent this difficulty, certain bacteria synthesize ferric ion-specific chelating compounds known as siderophores [25]. Bacteria and plants create siderophores, which are low molecular weight molecules (typically less than 1 kDa) with functional groups capable of reversibly binding iron [15]. Bacterial siderophores are classified as hydroxamates, catecholates, peptide siderophores, mycobactin, and citrate hydroxymates [44]. Rhizosphere bacteria emit these compounds to raise their competitive potential since they have antibacterial properties and improve iron feeding for the plant [12]. Siderophore-producing rhizobacteria boost plant health at different levels, such as iron nutrition, and they also inhibit pathogen growth by limiting the iron available to the pathogen, because the iron-siderophore complex is not absorbed by fungus [35,45].

Exopolysaccharide production

Exopolysaccharide, an extracellular carbohydrate polymer, is secreted by Rhizobacteria [7]. Homopolysaccharides and heteropolysaccharides are two types of exopolysaccharides. Exopolysaccharide is secreted in two forms: capsular EPS, which is attached to the cell wall, and extracellular slime layer, which is discharged into the environment [37]. Stress triggers the synthesis of EPS. It has been found that in stressed conditions, more EPS is produced than in non-stressed conditions [4]. Because exopolysaccharides are hydrated substances with 97 percent water in a polymer matrix, they stimulate plant development and ensure plant survival in draught stress circumstances [9,44]. Exopolysaccharide can protect the plant from desiccation by forming a hydrophilic biofilm on the root surface [26,33]. Some plant growth-promoting rhizobacteria produce exopolysaccharide, which has a negative charge and can bind cations such as Na^+. As a result, it will inhibit the plant from absorbing Na^+ ions, allowing it to live in saline circumstances [2]. As a result, heavy metal-tolerant exopolysaccharide-producing PGPRs will bind to potentially hazardous trace elements and create organic metal complexes. These phenomena will increase heavy metal resistance in plants grown in heavy metal-contaminated soils [26,31]. Exopolysaccharide also provides important nutrients to the plant for healthy growth and development through successful colonization of plant roots by EPS-producing microbes, which helps to hold free phosphorous from the insoluble one [17]. EPS-producing PGPRs maintain higher soil moisture content and plant growth even in extremely dried sandy soils [26,41].

Osmolyte accumulation

The build-up of suitable solutes such as proline, trehalose, glycine betaine, and others to maintain cellular swelling for proper cellular physiology is known as osmolyte adjustment. It is a significant physiological process found in plants that allows them to withstand osmotic stress caused by drought and salinity [9]. Plants cannot secure their growth and survival despite their ability to create osmolyte accumulation under salty and drought situations because it has been documented that salinity and drought can modify the osmolarity accumulation in plants [9]. Plant growth is aided by the generation of compatible osmolytes by the PGPR strain and plants in response to drought and salinity stress [28]. Some essential elements, such as substrate availability in the rhizosphere and the duration of osmotic stress, are involved in the generation of a specific osmolyte in bacteria during stressful conditions [20]. The major osmolyte produced in plants as a result of protein hydrolysis is proline, which is susceptible to osmotic stress [24]. When plants are injected with rhizobacteria, proline levels are increased during drought and salinity [49]. Tomato plants treated with *Bacillus polymyxa* produced more proline, which helped the plants deal with drought stress, according to one example [20]. Trehalose is an essential osmolyte made up of two molecules of -glucose that forms a gel phase as the cells dehydrate and protects the plant from drought and salt stress by decreasing cell damage [11].

Volatile organic compounds

Many bacteria and plants communicate with one another in the soil by synthesizing a variety of volatile organic molecules [11]. Rhizobacterial volatile organic compound production is species-specific. Lipophilic liquids with a high vapor pressure are known as volatile organic compounds [19]. Plant genes producing reactive oxygen species scavenging enzymes such as glutathione reductase, monodehydroascorbate reductase, catalase, and superoxide dismutase are activated by volatile organic molecules, which protect plants from drought and salt stress [47]. By increasing the manufacture of choline and glycine betaine, volatile organic chemicals improve the plant's tolerance to osmotic stress [20]. [34] Ryu investigated the VOCs 3-hydroxy-2-butanone and 2R, 3R-butendiol generated by *Bacillus subtilis GB03* and *Bacillus amyloliquefacience IN937a*. By influencing the expression of genes involved in cell wall formation, these two VOCs aided growth in Arabidopsis plants.

Conclusion

Abiotic stressors such as salinity, drought, and heavy metals have an impact on plant growth, quality, survivorship, and productivity. Crop losses occur all throughout the world as a result of these stresses. Salinity, drought, and heavy metals resistant proteins are overexpressed as a result of altered physiological and biological features, allowing crop plants to survive in stressful situations. Hormonal imbalance, ion toxicity vulnerability, nutrient mobilization, crop production, food quality, and security all suffer as a result of stress, in addition to limiting plant growth and development. The best way to deal with plant stress is to use microbe-mediated tools and approaches that take use of the triple interaction of plant-microbe soil.In terms of ecology, PGPR is a functional group whose ability to modulate plant physiology appears to be worthy of dealing with abiotic influences in natural and agricultural soils. Significant effects of plant tolerance to abiotic stress include increased yield and production of foods for human and livestock use. By examining the critical role of PGPR in stress mitigation, all of which have a favorable impact on crop productivity and ecosystem functioning, they demand active use in agriculture. The usage of PGPR will almost certainly become a reality, and it will be critical to processes that ensure the stability and productivity of the agroecosystems, pushing us toward a perfect agricultural system.

Conflicts of Interest

We declare that there are no conflicts of interest.

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