Biofilm Mediated Plant Resilience in Changing Climate: Combating Abiotic and Biotic Stresses

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ABSTRACT

The increase in world's population is accompanied with increase in demand for food. Climate change worsens the situation by making plants more prone to abiotic and biotic stresses. To mitigate the inevitable impacts of climate change on agriculture, improving crop resilience to these stresses is crucial. Plant growth promoting rhizospheric microorganisms (PGPR) promotes plant growth through direct and indirect mechanisms. The ability to produce extracellular polymeric substances (EPS) and develop biofilm enhances the chances of survival and amplifies the various associated mechanisms involved in promoting plant growth under stress conditions as compared to planktonic counterparts. Biofilm is a structured community of microbial cells which are often embedded in an extracellular matrix composed of EPS. Inoculation with biofilm forming microbes increases the production of osmolytes, antioxidant enzymes activities, maintains ionic homeostasis, etc. However, there is a need to explore crop and soil specific biofilm forming microbes.

INTRODUCTION

The increase in demand for foodgrain is exerting a lot of pressure on our natural resources especially soil as 95 per cent of our food comes directly or indirectly from it. Over the past few years decline in land under agriculture and rise in hunger has also been reported by many organizations. The issue of ensuring food security is further aggravated by changing climatic scenarios. The global surface temperature recorded in 2024 was 1.55°C higher than the pre industrial era (1860-1900) hence, breaching the Paris agreement. The long-term shifts in temperature and the changing weather patterns makes plant more prone to a number of abiotic and biotic stresses which negatively impacts crop productivity. Hence, there is a need to understand how plants respond to various stresses in order to develop strategies to combat them and improve plant resilience.

Types of plant stress:

The word homeostasis has been taken from two Greek words. “Homeos” means similar and “stasis” means stable giving us the meaning of staying the same. Homeostasis is the characteristic of a living system to maintain a stable internal environment. Any factor that causes a disturbance in homeostasis leads to plant stress. Based on the types of stressors stress has been classified as: Abiotic and biotic stress. Abiotic stresses occur in plants when they are exposed to high or low temperature, deficit of moisture, salt etc. and biotic stress takes place due to the negative impact of fungus, bacteria, virus or any other pathogen.

Effects on plants exposed to abiotic and biotic stresses:

When plants are exposed to drought conditions they give a floppy appearance, stomata gets closed and reactive oxygen species (ROS) production takes place. Under salinity stress due to the increased osmotic pressure exosmosis takes place. Temperature stress has been classified as low and high temperature stresses. Photosynthesis process is very sensitive to exposure to high temperatures as at high temperature destabilization of enzymes takes place that plays an important role in this process. Chilling and freezing injuries takes place in cold stress conditions. Protein denaturation takes place when plants are exposed to harmful radiations which leads to photoinhibition.

There can be a number of biotic stressors like bacteria, fungi, nematodes etc. Reactive oxygen species (ROS) are produced at an exponential rate upon exposure to stress which affects stability of various biomolecules (lipids, enzymes, DNA etc.) and leads to oxidative damage, reduced photosynthetic and cell proliferation rates.

Strategies to improve crop resilience:

Due to sessile nature of plants, they cannot escape stress. Plant stress signalling acts an interconnecting link between sensing the stimulus and producing an optimum response. Plant produces a number of defense responses through signalling pathways. How quickly plants can sense the external stress stimulus and produce an appropriate defense response determines the degree of resilience. The inherent ability of plants to produce these defense responses falls short when they are exposed for longer durations to continuously changing environmental stresses. Hence, in order to mitigate the inevitable impacts of climate change on agriculture it is crucial to improve plant resilience. Some of the strategies that can be adopted are:

1. **Genetic engineering:** Traditional breeding or genetic engineering of plants with stress tolerance is an important approach. Genetic engineering involves transferring genes between species to create improved or novel organism.

2. **Agronomic practices:** Some of the agronomic practices that can be adopted include crop rotation, cover cropping, reduced tillage, integrated disease management, integrated pest management, integrated nutrient management, water management practices, diversified cropping systems, etc.

3. **Microbial inoculation:** The exploration of beneficial or plant growth promoting rhizospheric microorganisms (PGPR) is a simple and adaptable alternative due to the time consuming, laborious and expensive nature of the crop improvement methods. PGPR affects plant growth through direct and indirect mechanisms and improves resilience against various stresses.

Plant growth promoting rhizospheric microorganisms (PGPR):

Plant growth promoting rhizospheric microorganisms are the microorganisms which colonize the rhizosphere and promote the plant growth. Direct mechanisms of promoting plant growth involves increase in the availability of nutrients such as nitrogen, phosphorus, potassium, iron, etc. Phytohormone such as auxins, gibberellins, cytokinins, ethylene, abscisic acid, brassinosteroids, jasmonates, and strigolactones plays a crucial role in cell division, expansion, differentiation, stem elongation, seed germination and fruit development. Increased activity of ACC deaminase enzyme reduces the ethylene levels and promotes plant growth. Indirect mechanisms involve induced systemic resistance, siderophore production, antibiosis (production of antibiotic compounds such as oomycin, mycobacillin, pyoluteorin, etc.) and enhanced tolerance to abitoic and biotic stresses.

PGPR mediated resilience against abiotic stress:

Drought stress: Mechanisms adopted by PGPR to impart resilience against drought stress include changes in morphological characters of plants through phytohormone production, physiological changes such as production of osmolytes (proline, glycine betaine, etc.), increased activity of antioxidant enzymes (catalase, superoxide dismutase, etc.), extracellular polymeric substances (EPS) production. Volatile organic compounds produced by PGPR act as signal molecules that initiate a cascade of molecular process that makes tolerant by upregulating the expression of drought responsive genes.

Salt stress: Salt stress is alleviated by increased activity of antioxidant enzymes, osmoprotectants, phytohormone production, maintenance of ionic homeostasis by compartmentalizing Na^+ ions in the vacuoles of microbial cells. EPS components chelates Na^+ hence, reducing the amount of sodium that is available for uptake by plants.

Heat stress: Mechanisms for imparting resilience against heat stress includes EPS production various components of which upregulates the expression of heat shock transcription factors and leads to increased production of heat shock proteins in plants. Production of phytohormones and increased activity of ACC deaminase enzyme promotes plant growth.

Heavy metal stress: PGPR detoxifies heavy metal through a number of processes such as biodegradation, bioaccumulation, biotransformation and biosorption. EPS production plays an important role in biosorption by increasing the amount of

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Sharma et al. (2025)

adsorbent which is available for adsorption of heavy metal to occur.

PGPR mediated resilience against biotic stress:

PGPR imparts resilience against various pathogens through antibiosis, induced systemic resistance, hydrolytic enzyme, hydrogen cyanide and siderophore production.

Role of EPS production and biofilm formation:

PGPR has many benefits but as an inoculant they fail to effectively colonize the roots and rhizosphere in field conditions. The ability of microbe to produce EPS not only improves the chances of survival, root colonization but also improves the plant growth through various PGPR associated mechanisms as discussed earlier. Production of EPS results in the formation of biofilm which acts as a protective barrier between microbes, associated plants and environment and provides protection against various stressors and enhances plant resilience. Biofilm is a structured community of microbial cells which are often embedded in an extracellular matrix composed of EPS and it is bound to a surface. 97 per cent of biofilm is formed by water followed by microbes and EPS. EPS has many components such as exopolysaccharides, proteins, lipids, enzymes, eDNA, etc. There are 5 stages in biofilm formation i.e., reversible attachment of microbes by physical forces, irreversible attachment by chemical bonds or microcolony formation, matrix formulation, formation of mature biofilm and dispersal of microbes when the number of cells has reached a certain threshold and then they again become available for attachment to a new surface. Biofilms can either single or multilayered with single or multispecies within the matrix. There are several environmental factors (pH, temperature, nutrient availability), properties of substrate (roughness, wettability, porosity) and properties of microbes (flagella, EPS production, quorum sensing) which affect the biofilm formation.

Lu *et al*. (2018) reported that exopolysaccharides produced and biofilm formed by *Bacillus amyloliquefaciens* FZB42 boosts drought tolerance in *Arabidopsis* by significantly upregulating the relative expression of ERD 1, LEA genes. The removal of ability to form biofilm compromises the ability of bacteria to protect plant under stress conditions as revealed by a significant reduction in shoot and root dry weight. El-Ghany and Attia (2020) determined the ability of exopolysaccharide producing bacteria, *Azotobacter chroococcum* to maintain ionic homeostasis and promote growth of faba bean challenged with salt stress. Inoculated treatments significantly increased K^+/ Na^+ and induced tolerance to salinity as compared to uninoculated treatments. A significant increase in defense related enzymes activities such as phenylalanine ammonia lyase and polyphenol oxidase was reported by Velmourougane *et al*. (2017). This was attributed to formation of biofilm which acts as elicitors, induces systemic resistance and imparts resilience against the pathogen.

CONCLUSIONS:

To conclude microbes, have the ability to improve plant performance under stress conditions by EPS production and biofilm formation which not only improves root colonization but also enhances the various PGPR associated mechanisms against stresses to a greater extent. However, modern transcriptomic and proteomic studies are required to elucidate the mode of action of biofilm forming microbes. Crop specific biofilm forming microbes can be explored.

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