Biofilm Mediated Plant Resilience for Combating Abiotic Stresses

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ABSTRACT

In the face of escalating environmental pressures that jeopardize global crop yields, enhancing crop stress tolerance becomes a paramount endeavour for restoring sufficient food production. Recently, biofilm-forming PGPR has emerged as a promising candidates for agricultural application. These biofilms are evidence of microorganism colonization on plant roots. Biofilm-mediated plant resilience represents a promising, eco-friendly approach to combat the growing challenges of abiotic stresses in agriculture. By producing extracellular polymeric substances, phytohormones, osmolytes and stress-modulating enzymes, biofilm-forming plant growth-promoting microbes enhance root colonization, improve soil water and nutrient availability and buffer plants against drought, salinity, temperature extremes and heavy metal toxicity.

INTRODUCTION

A biofilm is a structured community of microbial cells (bacteria, fungi, etc.) that are irreversibly attached to a living or inert surface such as plant roots, leaves or other surfaces embedded in a self-produced matrix of extracellular polymeric substances like polysaccharides, proteins, nucleic acids and exhibiting altered phenotypes i.e. changes in growth rate, gene expression etc. (Thakur and Yadav. 2024). The

matrix helps microbes survive in the rhizosphere, tightly colonize root surfaces and create a favourable micro-environment that buffers plants from abiotic stress (drought, salinity, heavy metals, temperature extremes). Biofilm formation is a selective survival strategy of microbes to protect themselves from unfavorable conditions. The use of plant growth regulators has been on focus in recent years for the development of agricultural products (Cam *et al*. 2023). Biofilm-mediated plant resilience is used in agriculture instead of harmful chemicals because it is eco-friendly, safe and sustainable. Unlike chemicals, they provide long-term protection and enhance crop growth without damaging the environment.

In India, ICAR-Indian Institute of Pulses Research-Microbial Consortium for Mitigation of Moisture Deficit Stress works to develop microbial consortia that help pulses withstand drought, NBAIM (National Bureau of Agriculturally Important Microorganisms) maintains banks of agriculturally useful microbes, including those that help in abiotic stress alleviation, ICAR-IISR (Indian Institute of Spices Research) - Microbial Encapsulation/Bio-capsule Technology that contributes to better performance of crops under stress since consistent and viable microbe delivery is crucial under challenging conditions. All India Network Project on Soil Biodiversity-Biofertilizers under ICAR uses microbial consortia like K/Zn solubilizing bacteria as part of the biofertilizer/soil health improvement program. Other government-led initiatives such as Paramparagat Krishi Vikas Yojana (PKVY), Soil Health Management and Integrated Nutrient Management (INM) promote the use of biofertilizers.

Biofilm mediated plant resilience for combating abiotic stresses

For immobile plants, abiotic environmental factors such as drought, salinity, heavy metals, temperature extremes are often the main detrimental factors affecting their growth and development. Abiotic stress refers to the adverse effect of any abiotic factor on a plant in a given environment and limit the survival of plants in nature.

1. Drought

Drought is a very common abiotic stress. It decreases the growth and yield of the crops. Due to drought stress, there is insufficient intake of the nutrients, the low rate of photosynthesis and limited supply of water in plants. Inoculating crops with plant growth-promoting rhizobacteria (PGPR) mitigates the deleterious effects of stress by promoting beneficial effects such as helping them in the acquisition of less available nutrients, increasing the levels of plant growth regulators and improving the physiological health of the plants (Kour *et al*. 2019).

2. Salinity

Increasing soil salinity decreases crop growth and productivity. To deal with higher salinity in the soil, the treatments of halo-tolerant PGPR may contribute to plant growth by alleviating salinity stress. Biofilm formation is a selective survival strategy of microbes to protect themselves from unfavourable conditions (Cam *et al*. 2023).

3. Temperature extremes

Biofilms formed by beneficial microbes (PGPR, mycorrhizae and other root-associated microbiota) protect plants from heat and cold by creating a micro-environment at the root/leaf surface and by triggering plant physiological and molecular defenses. They do this through physical buffering, production of protective molecules (exopolysaccharides, anti-freeze proteins, compatible solutes), modulation of stress hormones and by improving water and nutrient status, together these reduce cellular damage during both heat waves and frost.

4. Heavy metal toxicity

Biofilm-forming plant growth-promoting microorganisms (PGPR and fungi) enhance plant tolerance to heavy metal toxicity by forming an extracellular polymeric substance (EPS) matrix that binds and immobilizes toxic metals like Cd, Pb, and Cr. These biofilms reduce metal uptake by roots and secrete siderophores, organic acids, and biosurfactants that chelate or precipitate metals. They also activate plant antioxidant enzymes to minimize oxidative stress and produce phytohormones and ACC-deaminase to promote root growth. Thus, biofilm-mediated approaches offer an eco-friendly and sustainable alternative for phytoremediation and improved crop resilience in contaminated soils.

CONCLUSION

Unlike free-living inoculants, biofilm-based formulations provide greater microbial persistence, stability and consistent plant protection under fluctuating field conditions. Their application through seed coating, soil amendments or root dips improves germination, growth and yield, especially in marginal and stress-prone soils. Overall, biofilm-mediated PGPR act as a natural and sustainable strategy to strengthen plant resilience, enhance crop productivity, and maintain soil health under challenging environmental conditions. Their application through seed coating, soil amendments or root dips can improve germination, growth and yield especially in marginal and stress-prone soils.

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