Biostimulating Bacteria for Mitigating Abiotic and Biotic Stresses for Sustainable Agriculture

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ABSTRACT

Environmental stress such as abiotic and biotic threatens crop productivity and food security worldwide. Biostimulant, particularly Plant Growth Promoting Bacteria (PGPB), offer a promising and sustainable approach to enhance plant resilience and growth under adverse conditions. These beneficial microbes colonize plant roots, promoting growth by various mechanisms, including nitrogen fixation, mineral solubilization, and the production of growth hormones. Furthermore, PGPB can Induce Systemic Resistance (ISR) in plants, making them more capable of fending off pathogens and pests. The application of PGPB in agriculture can significantly reduce the use of chemical fertilizers and pesticides, thereby minimizing environmental impact and promoting sustainable farming practices.

INTRODUCTION

To achieve a sustainable agricultural vision, crops must be developed with enhanced disease resistance, salt tolerance, drought tolerance, heavy metal stress tolerance, and improved nutritional value. One approach to attaining these desirable crop traits is through the use of biological agents (bacteria, fungi, algae, etc.).

Among these, biostimulating agents as plant growth-promoting rhizobacteria (PGPR), stand out as the most promising. These beneficial microorganisms, inhabit the rhizosphere—the region of soil adjacent to plant roots. They play a crucial role in enhancing plant health and growth by improving nutrient uptake, water use efficiency, and resilience against environmental stresses (Khan et al., 2024). Unlike synthetic fertilizers and pesticides, which can lead to environmental deterioration and health risks, these biological agents offer an eco-friendly alternative that supports robust crop development. Through mechanisms such as the production of phytohormones (e.g., auxins and cytokinins), stimulation of antioxidant activity, nitrogen fixation, and mineral solubilization, these microorganisms contribute to the optimal performance of agricultural systems (Upadhayay et **al.,** 2024). By leveraging the natural symbiosis between plants and microbes, biological agents pave the way for more sustainable and productive farming practices.

Strategies to Combat Abiotic and Biotic stress by PGPB:

Enhancement of Nutrient Uptake: PGPR releases organic acids that increase acidity of the soil and dissolve minerals such as zinc, iron, and phosphorus. This activity influences rooting patterns and modifies root exudates, improving nutrient availability in the rhizosphere.

Production of Phytohormones: Bacterial production of auxins and cytokinins stimulates root and shoot growth, improves cell division, and boosts overall plant vigor. Additionally, PGPR can also modulate plant hormones like gibberellins and ethylene to enhance stress responses and promote plant growth in adverse conditions.

Induction of Systemic Resistance (ISR): Plant defense systems against pests and pathogens can be strengthened by PGPR-triggered ISR, which reduces chances of disease. Signalling chemicals like salicylic acid and jasmonic acid frequently facilitate PGPR-triggered ISR.

Antioxidant Production: Plants that are exposed to PGPRs have the potential to produce more antioxidant enzymes, such as catalase and superoxide dismutase (SOD), which can help to reduce oxidative stress brought on by environmental conditions including heavy metals, salt, and drought.

Stress Tolerance Improvement:

- **Drought Tolerance**: Water-scarcity tolerance is increased in plants by PGPRs through improved root architecture and water retention.
- **Salt Tolerance**: In order to improve development in saline soils, several PGPRs can assist plants in controlling osmotic stress and ionic equilibrium.
- **Heavy Metal Stress**: PGPRs have the potential to change the availability or immobilize heavy metals in the soil, which lowers their absorption by plants and lessens their toxicity.
- **Production of Volatile Organic Compounds (VOCs)**: Rhizospheric bacteria release various VOCs that promote plant growth, induce systemic resistance (ISR) against pathogens and help plants cope with environmental stresses.
- **Biofilm Formation:** PGPRs have the potential to develop biofilms on plant roots, which enhance microbial stability and nutrient exchange while acting as a barrier against diseases.
- **Exopolysaccharide (EPS) Production:** EPS producing bacterial strains are more drought-tolerant because they contribute

to soil aggregate stability and water retention, both of which support plant development.

Table: PGPB used as biolstimulating agent in agricultural crops for mitigation of abiotic and biotic stresses

Sl No	Plant Growth Promoting Bacteria	Characteristics	Stress Type	Crop	References
1.	*Bacillus licheniformis* K11	Auxin and ACC Deaminase production	Drought	*Capsicum annuum L.*	(Lim and Kim, 2013)
2.	*Rhizobium fabae* SR-22	EPS production	Salt and Heavy metal	*Triticum aestivum*	(Shahid et al., 2024)
3.	*Azospirillum brasilense* E MCC1454	Antioxident enzyme production	Heavy metal	*Cicer arietinum* L.	(El-Ballat et al., 2023)
4.	*Pseudomonas protegens* CP17	Zn solubilization and ACC Deaminase production	Salt	*Triticum aestivum*	(Singh et al., 2022)
5.	*Bacillus velezensis* and *Bacillus amyloliquefaciens*	Siderophore, IAA, Gibberellic acid and HCN production	Drought	*Juglans regia* L.	(Lotfi et al., 2022)

Modification in crop by PGPB:

- Alterations in the architecture of plant root systems
- Enhance nutrition absorption
- Alleviate stress
- Boost disease resistance
- Improve crop yield
- Biofortification in crop

Modification in soil by PGPB:

- Boost soil fertility
- Enhance soil microbial diversity
- Remove heavy metal stress
- Eliminate soil contamination
- Reduction in pathogen activity
- Soil structure improvement

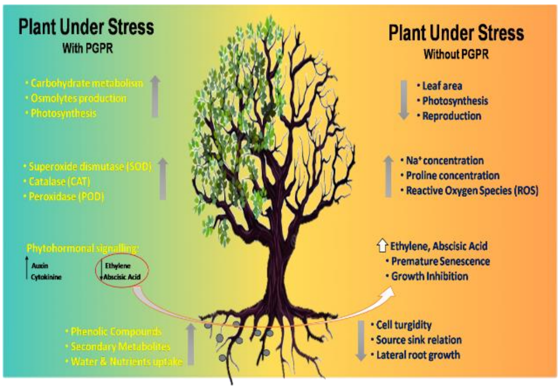

Figure: Comparison of plant responses under stress conditions with and without PGPB inoculation.

CONCLUSION:

The large-scale application of PGPB as inoculants has the potential to improve crop yields while reducing reliance on chemical fertilizers and pesticides, which can harm the environment and contaminate food. These PGPB-based biotechnologies provide a low-input, sustainable, and environmentally friendly solution for managing environmental stresses.

Futuristic approach:

Research will likely to concentrate on developing new bacterial strains that are more effective at promoting plant growth and elucidating the molecular mechanisms through which PGPB interact with plants. This strategy might aid in the development of more sustainable, effective, and less chemically dependent farming methods. Furthermore, the use of PGPB in genetic engineering and crop breeding may result in cultivars that are more resistant to abiotic as well as biotic stress.

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