AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 01 (January, 2026)
Available online at http://www.agrimagazine.in

Role of Soil and Rhizosphere Microbiomes in Enhancing Heritable Disease Resistance in Crop Plants

*Aruna Dhakad and Pokhar Rawal
Department of Plant Pathology, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India
*Corresponding Author's email: arunadhakad088@gmail.com

Plant diseases pose a longstanding threat to global food security, traditionally countered by genetic host resistance and chemical fungicides. However, plant–microbiome interactions offer sustainable alternatives to disease management. Soil and rhizosphere microbiomes play critical roles in enhancing plant immunity through direct suppression of pathogens, modulation of plant immune pathways, and beneficial feedback mechanisms. Emerging evidence also suggests that beneficial microbes can prime plants for enhanced defense and that such immune priming may be heritable across generations through epigenetic modifications. This review synthesizes current understanding of microbiome-mediated plant defense mechanisms, explores epigenetic aspects of inherited resistance, and highlights applications for reducing chemical inputs in agriculture.

Introduction

Plants coexist with diverse microbial communities in the soil, particularly in the rhizosphere-the narrow zone immediately surrounding roots influenced by root exudates. These microbial communities, including bacteria, fungi, and archaea, do not merely colonize roots; they actively contribute to plant health and disease resistance. Recent research in plant pathology and microbial ecology has revealed that these microbiome members can suppress pathogens, stimulate plant immunity, and even modulate plant metabolism to enhance resilience against disease. The concept of transgenerational immune priming (TGIP) — where exposure to beneficial microbes leads to heritable immune enhancements — presents a paradigm shift in sustainable crop protection. This involves durable changes in plant immune responsiveness that can persist into subsequent generations, offering the potential to reduce dependency on fungicides and other chemical controls.

Mechanisms of Microbiome-Mediated Immunity

Direct Antagonism and Competition

Soil and rhizosphere microbes protect plants by directly inhibiting pathogen growth. Beneficial bacteria like Bacillus and Pseudomonas produce antibiotics, siderophores, and lytic enzymes that suppress fungal and bacterial pathogens in the rhizosphere, reducing pathogen colonization and disease incidence. Microbial competition for nutrients and niche space further limits pathogen establishment, contributing to the phenomenon known as disease-suppressive soils, where the overall microbial community naturally restricts disease development even in the presence of pathogens.

Induced Systemic Resistance (ISR)

Beneficial microbes can trigger induced systemic resistance (ISR), a systemic enhancement of plant defense signaling pathways. ISR primes the plant immune system, enabling faster and stronger activation of defense genes upon pathogen attack. Key plant hormones — salicylic acid (SA), jasmonic acid (JA), and ethylene (ET) — mediate such responses. ISR differs from local defense responses by providing broad-spectrum resistance throughout the plant, making it a powerful tool against a diversity of pathogens. This mechanism is often activated by microbial metabolites or molecular patterns recognized by plant receptors.

Recruitment and Root Exudates

Plants actively shape their rhizosphere microbiomes through root exudation, secreting sugars, amino acids, and other metabolites that preferentially attract beneficial microbes. This "cry for help" strategy enables plants under stress to enrich protective microbial taxa, reinforcing their defenses. Successive generations cultivated in the same conditioned soil can exhibit enhanced resistance due to the soil-borne legacy of beneficial microbes.

Epigenetic Changes Associated with Plant Defense

Epigenetic regulation — including DNA methylation and histone modifications — allows plants to "remember" environmental cues without altering their DNA sequence. When beneficial microbes prime plant defenses, these epigenetic marks can result in enhanced responsiveness to future pathogen exposure. Recent studies reveal that microbial interactions can lead to heritable changes in defense gene expression, with DNA methylation changes in promoter regions of key immune genes observed in progeny of primed plants. This phenomenon, described as transgenerational immune priming (TGIP), supports a molecular basis for inherited resilience.

Applications for Reducing Chemical Fungicides

Harnessing soil and rhizosphere microbiomes offers promising strategies to reduce reliance on chemical fungicides:

- Bioinoculants and probiotics: Application of beneficial microbes as soil amendments can establish protective communities that suppress pathogens.
- Modifying agricultural practices: Crop rotation, intercropping, and organic amendments can foster diverse and resilient microbial communities, indirectly enhancing disease resistance.
- Microbiome-aware breeding: Selecting plant genotypes that effectively recruit beneficial microbes may improve disease resistance and reduce fungicide needs.
- These approaches align with sustainable agriculture goals, offering durable disease control while mitigating environmental impacts associated with chemical inputs.

Conclusion

Soil and rhizosphere microbiomes play an integral role in plant disease resistance by directly suppressing pathogens, priming systemic immunity, and shaping plant immune memory through epigenetic changes. The emerging evidence of transgenerational immune priming underscores a new frontier in plant pathology, offering sustainable and eco-friendly approaches to crop protection. Future research should focus on elucidating underlying mechanisms, optimizing microbiome manipulations in field conditions, and integrating microbial traits into crop breeding programs.