

Microbial modulation of plant immunity: A double-edged sword.

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Introduction

Plants exist in a microbial world. From the soil to their leaves, they are constantly interacting with a diverse array of microorganisms some beneficial, others pathogenic. These interactions shape the plant's immune responses, influencing growth, development, and resilience. Microbial modulation of plant immunity is a double-edged sword: while beneficial microbes can enhance defense and promote health, pathogens exploit immune pathways to suppress resistance and facilitate infection. Understanding this complex interplay is crucial for developing sustainable strategies for crop protection and improvement [1, 2].

Plants rely on a sophisticated innate immune system to detect and respond to microbial threats. This system operates through two primary layers: Initiated when pattern recognition receptors (PRRs) detect conserved microbial signatures known as microbe-associated molecular patterns (MAMPs). Activated when intracellular receptors recognize pathogen-secreted effectors that suppress PTI [2, 3].

These immune responses involve signaling cascades, reactive oxygen species (ROS) production, hormone regulation, and transcriptional reprogramming. Beneficial microbes, such as rhizobacteria and mycorrhizal fungi, can enhance plant immunity through several mechanisms: Certain microbes prime the plant's immune system, enabling faster and stronger responses to future attacks. Beneficial microbes modulate phytohormones like jasmonic

acid and salicylic acid, balancing growth and defense. Commensal microbes outcompete pathogens for space and resources, indirectly protecting the plant [4, 5].

For example, rhizobacteria attracted by root exudates can inhibit fungal pathogens and promote colonization of Effector Proteins: Pathogens secrete effectors that interfere with immune signaling, disable PRRs, and manipulate hormone pathways. Some pathogens alter the local microbiome to favor their own colonization, releasing toxins that suppress beneficial microbes. Pathogens may mimic beneficial microbes to avoid detection or actively suppress immune responses to establish infection [5, 6].

Interestingly, microbial effectors are not exclusive to pathogens. Beneficial microbes also produce effectors that modulate plant immunity but in ways that promote mutualism. This creates a paradox: the same immune pathways can be activated or suppressed depending on the microbial context. Help beneficial microbes establish symbiosis by dampening immune responses temporarily. Exploit these mechanisms to suppress immunity and cause disease [7, 8].

The composition of the plant microbiome plays a critical role in determining immune outcomes. A diverse and balanced microbiome supports immune homeostasis, while dysbiosis an imbalance in microbial communities can lead to increased susceptibility to disease. Regulate immune receptor activity and maintain immune balance. Competition among microbes can enhance plant defense by limiting pathogen establishment. Host genotype, environmental conditions, and agricultural practices all influence microbiome composition and, consequently, immune function [9, 10].

Conclusion

Microbial modulation of plant immunity is a double-edged sword—capable of both enhancing and undermining plant health. Beneficial microbes can prime defenses and promote resilience, while pathogens exploit immune pathways to cause disease. Understanding and harnessing this complex interplay is key to developing innovative strategies for crop protection and improvement. As we move toward a future of climate-smart agriculture, the microbial world offers both challenges and solutions—waiting to be unlocked through science and collaboration.

References

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