

The Mechanisms and Promise of Biological Control of Plant Diseases

Sreenath Ragiman^{1*} and Hariharan Selvam²

¹*PhD Scholar, Division of Plant Pathology, ICAR-IARI Mega University Nagpur Hub.

²PhD Scholar, Division of Entomology, ICAR-IARI Mega University Hyderabad Hub.

Corresponding Author

Sreenath Ragiman

Email: sreenathragiman79@gmail.com



OPEN ACCESS

Keywords

Biological Control, Mechanisms, Pathogens, Plant Diseases

How to cite this article:

Ragiman and Selvam, H. 2024. The Mechanisms and Promise of Biological Control of Plant Diseases. *Vigyan Varta* 5(6): 166-170.

ABSTRACT

Biological control (biocontrol) offers a sustainable solution to combat plant diseases in agriculture. By harnessing natural antagonistic relationships among microorganisms, biocontrol strategies such as hyperparasitism, antibiotic production, lytic enzyme secretion, competition, induced host resistance, and microbial diversity effectively suppress a wide range of plant pathogens. However, successful implementation requires a thorough understanding of microbial interactions with pathogens and host plants, as well as environmental factors.

INTRODUCTION

The global agriculture industry faces constant threats from plant diseases, which can devastate crops and lead to significant economic losses. Traditional chemical control methods, while effective, often result in environmental harm and the development of resistant pathogen strains. In contrast, biological control (biocontrol) presents a sustainable and eco-friendly

alternative, harnessing natural antagonistic relationships among microorganisms to manage plant diseases. This approach not only minimizes chemical inputs but also promotes soil health and plant resilience. In this article, we explore the diverse and intricate mechanisms of biocontrol, including hyperparasitism, antibiotic production, lytic enzyme secretion, competition, induced host

resistance, and the role of microbial diversity, providing insights into how these natural processes can be leveraged to enhance disease suppression in agricultural systems.

Mechanisms involved in biological control of plant diseases:

Hyperparasites and predation

Hyperparasitism involves biological control agents (BCAs) that directly target and kill pathogens or their propagules. The main types include obligate bacterial pathogens, hypoviruses, facultative parasites, and predators. For example, *Pasteuria penetrans* targets root-knot nematodes and is used as a BCA. Hypoviruses, such as the one infecting *Cryphonectria parasitica* (the fungus causing chestnut blight), reduce the fungus's pathogenicity and have controlled chestnut blight effectively under certain conditions (Milgroom and Cortesi, 2004). Several fungal parasites, like *Coniothyrium minitans* and *Pythium oligandrum*, also target plant pathogens. Unlike hyperparasitism, microbial predation is generally non-specific and less predictable. Some BCAs, like *Trichoderma* species, produce enzymes targeting fungal cell walls. For example, in decomposing bark, *Trichoderma* activates chitinase genes to parasitize *Rhizoctonia solani* (Benhamou and Chet, 1997).

Antibiotic-mediated suppression

Antibiotic-mediated suppression is a vital mechanism in biological disease control, where microbial toxins inhibit or kill other microorganisms, even at low concentrations. Many microbes naturally produce compounds with antibiotic properties, effectively suppressing plant pathogens. To achieve efficient biocontrol, these antibiotics must be produced near the pathogen. However, estimating effective quantities is challenging due to their small amounts relative to other organic compounds in the phytosphere.

Despite advancements in methods to detect antibiotic production, its significance remains evident. Manipulating genes responsible for antibiotic biosynthesis has shown reduced efficacy in suppressing soilborne root diseases. Some biocontrol strains produce multiple antibiotics, enhancing their ability to suppress diverse microbial competitors, including plant pathogens. For example, genetically engineered strains have demonstrated improved disease suppression in field-grown wheat (Glandorf *et al.*, 2001).

Lytic enzymes and other byproducts of microbial life

Various microorganisms secrete metabolites that inhibit the growth of pathogens, including lytic enzymes capable of hydrolyzing polymeric compounds like chitin, proteins, cellulose, hemicellulose, and DNA. These enzymes, expressed and secreted by different microbes, directly suppress plant pathogen activities. For example, chitinase expression in *Serratia marcescens* contributes to the biocontrol of *Sclerotium rolfsii* (Ordentlich *et al.*, 1988), while b-1,3-glucanase enzyme aids in the biocontrol activities of *Lysobacter enzymogenes*. While these enzymes can stress and lyse living organisms, their primary role is to decompose plant residues and organic matter. The extent to which lytic enzyme activity results from microbe-microbe interactions remains uncertain, though microbes favouring plant pathogen colonization are considered biocontrol agents. Some lytic enzyme products may indirectly suppress disease, such as fungal cell wall oligosaccharides, which induce plant host defenses. The *Lysobacter enzymogenes* strain C3 can induce plant host resistance, though specific activities are unclear. The impact of these compounds on disease suppression depends on soil organic matter composition. Enhancing these activities can achieve greater disease suppression, as seen with chitosan in postharvest disease control. Chitosan, derived

from chitin, suppresses root rot in tomatoes caused by *Fusarium oxysporum* f. sp. *radicislycopersici* (Lafontaine and Benhamou, 1996), potentially by enhancing plant resistance to pathogens.

Competition

Soils and plant surfaces often lack sufficient nutrients for microbial growth, necessitating efficient competition among microbes in the phytosphere. Plants provide nutrients through exudates, leachates, decaying tissue, and even waste products like aphid honeydew. While direct evidence is scarce, indirect evidence suggests that competition for nutrients between pathogens and non-pathogens significantly reduces disease incidence and severity. Soilborne pathogens like *Fusarium* and *Pythium*, which infect through mycelial contact, are particularly susceptible to competition from other soil- and plant-associated microbes compared to pathogens that germinate directly on plant surfaces. Anderson *et al.* (1988) found that the ability of *Pseudomonas putida* to colonize root systems, linked to the production of a specific plant glycoprotein, agglutinin, correlated with *Fusarium* wilt suppression in cucumbers. Non-pathogenic plant-associated microbes likely protect plants by rapidly colonizing and depleting limited substrates, leaving none for pathogens. For example, *Enterobacter cloacae* suppresses *Pythium ultimum* through efficient nutrient metabolism in the spermosphere (Kageyama and Nelson, 2003). These beneficial microbes also produce metabolites that inhibit pathogens, colonizing areas rich in water and carbon-containing nutrients, such as secondary root exits, damaged epidermal cells, and nectaries, utilizing root mucilage for sustenance.

Induction of host resistance

Plants exhibit a dynamic response to environmental cues and chemical signals from

soil- and plant-associated microbes, which can induce or condition plant defenses through biochemical changes, enhancing resistance against future pathogen infections. The induction of host defenses can be localized or systemic, influenced by the type, origin, and concentration of stimuli. Phytopathologists are increasingly studying induced resistance triggered by biological control agents and non-pathogenic microbes. Systemic acquired resistance (SAR), mediated by salicylic acid (SA), is one of the well-characterized pathways, leading to the expression of pathogenesis-related (PR) proteins following pathogen infection. These proteins can directly lyse invading cells, reinforce cell wall boundaries, or induce localized cell death. Another defense phenotype, induced systemic resistance (ISR), is mediated by jasmonic acid (JA) and/or ethylene, produced in response to certain non-pathogenic rhizobacteria. Notably, the SA- and JA-dependent defense pathways can be mutually antagonistic, with some bacterial pathogens exploiting this antagonism to bypass SAR. For instance, pathogenic strains of *Pseudomonas syringae* produce coronatine, similar to JA, to suppress the SA-mediated pathway (He *et al.*, 2004). Plants likely process multiple stimuli, leading to fluctuations in the magnitude and duration of host defence induction over time. Host resistance can only be enhanced if the induction is controlled, potentially by overwhelming or synergistically interacting with endogenous signals.

Microbial diversity and disease suppression

Plants benefit from a rich diversity of microfauna and microbial organisms, many of which contribute significantly to the biological control of plant diseases. Effective disease control often involves competitive saprophytes, facultative plant symbionts, and facultative hyperparasites, capable of colonizing living plant tissues and expressing biocontrol activities while thriving on dead

plant material. While some organisms like avirulent *Fusarium oxysporum* and binucleate Rhizoctonia-like fungi share similarities with plant pathogens but lack active virulence factors for many hosts, others like *Pythium oligandrum* are distinct species. Despite their phylogenetic differences, many biocontrol agents belong to the same microbial groups as pathogens, with research traditionally focusing on easily culturable genera like *Bacillus*, *Burkholderia*, and *Pseudomonas* among bacteria, and *Ampelomyces*, *Coniothyrium*, and *Trichoderma* among fungi. Yet, more challenging-to-culture organisms such as mycorrhizal fungi and hyperparasites like *Pasteuria penetrans* have also been intensively studied. In field conditions, plants often face multiple infections simultaneously, with weakly virulent pathogens sometimes suppressing more virulent ones by inducing host defenses. While specific biocontrol agents may target individual pathogens, they must contend with competition from other soil and root-associated microbes during pathogen threats. General suppression, attributed to the combined activities of multiple organisms, is crucial for reducing disease severity. High soil organic matter fosters a diverse microbial community, limiting ecological niches available to pathogens. The extent of general suppression depends on the quantity and quality of organic matter, with agricultural practices like composting and cover cropping aimed at bolstering endogenous microbial diversity and activity (Hoitink and Boehm, 1999).

CONCLUSION

In conclusion, the diverse and intricate mechanisms underlying biological control, or biocontrol, offer a compelling alternative to traditional chemical methods for managing plant diseases. By harnessing the natural antagonistic relationships between microorganisms and pathogens, biocontrol strategies such as hyperparasitism, antibiotic

production, lytic enzyme secretion, competition, induced host resistance, and microbial diversity provide effective, sustainable, and eco-friendly solutions. The specificity and efficiency of these mechanisms highlight the potential of microbial antagonists to suppress a wide range of plant pathogens. Continued research and development in this field are essential to optimize biocontrol applications and enhance their efficacy, ultimately contributing to more resilient and sustainable agricultural systems.

REFERENCES

- Anderson, A. J., Tari, P. H. and Tepper, C. S., 1988. Genetic studies on the role of an agglutinin in root colonization by *Pseudomonas putida*. *Applied Environmental Microbiology* 54: 375-380.
- Benhamou, N. and Chet, I., 1997. Cellular and molecular mechanisms involved in the intersection between *Trichoderma harzianum* and *Pythium ultimum*. *Applied Environmental Microbiology* 63: 2095–2099.
- Glandorf, D. C., Verheggen, P., Jansen, T., Jorritsma, J. W., Smit, E., Leefang, P., Wernars, K., Thomashow, L. S., Laureijs, E., Thomas-Oates, J. E., Bakker, P. A. and Van Loon, L. C., 2001. Effect of genetically modified *Pseudomonas putida* WCS358r on the fungal rhizosphere microflora of field-grown wheat. *Applied Environmental Microbiology* 67: 3371-3378.
- He, P., Chintamanani, S., Chen, Z., Zhu, L., Kunkel, B. N., Alfano, J. R., Tang, X. and Zhou, J. M., 2004. Activation of a COII-dependent pathway in *Arabidopsis* by *Pseudomonas syringae* type III effectors and coronatine. *Plant Journal* 37: 589-602.

- Hoitink, H. A. J. and Boehm, M. J., 1999. Biocontrol within the context of soil microbial communities: a substrate dependent phenomenon. Annual Review Phytopathology 37: 427-446.
- Kageyama, K. and Nelson, E.B., 2003. Differential inactivation of seed exudates stimulation of *Pythium ultimum* sporangium germination by *Enterobacter cloacae* influences biological control efficacy on different plant species. Applied Environmental Microbiology 69: 1114-1120.
- Lafontaine, P. J. and Benhamon, N., 1996. Chitosan treatment: an emerging strategy for enhancing resistance of greenhouse tomato to infection by *Fusarium oxysporum* f.sp. *radicilycopersici*. Biocontrol Science Technology 6:111-124.
- Milgroom, M. G. and Cortesi, P., 2004. Biological control of chestnut blight with hypovirulence: a critical analysis. Annual Review Phytopathology 42: 311-338.
- Ordentlich, A., Elad, Y. and Chet, I. 1988., The role of chitinase of *Serratia marcescens* in the biocontrol of *Sclerotium rolfsii*. Phytopathology 78: 84-88.