

Lecture 12. Biological Plant Protection: Use of Microorganisms for Plant Disease and Pest Control

Introduction

Biological plant protection is an environmentally oriented approach to controlling plant diseases, insect pests, and other harmful organisms through the use of living organisms or their biologically active products. Modern agriculture traditionally relies on chemical pesticides, fungicides, and insecticides because they can provide rapid and effective control of many agricultural pests and pathogens. However, intensive and repeated chemical pesticide application can contribute to the development of resistant pest populations, pesticide residues in agricultural products, contamination of soil and water, and negative effects on non-target organisms. Biological plant protection provides an alternative or complementary strategy based on ecological relationships between microorganisms, plants, pathogens, and pests. Beneficial bacteria, fungi, viruses, and other microorganisms can suppress plant pathogens, compete for nutrients and ecological niches, produce antimicrobial substances, infect specific insect pests, or stimulate the plant's own defense mechanisms. Biological protection is therefore an important component of sustainable agriculture and integrated pest management.

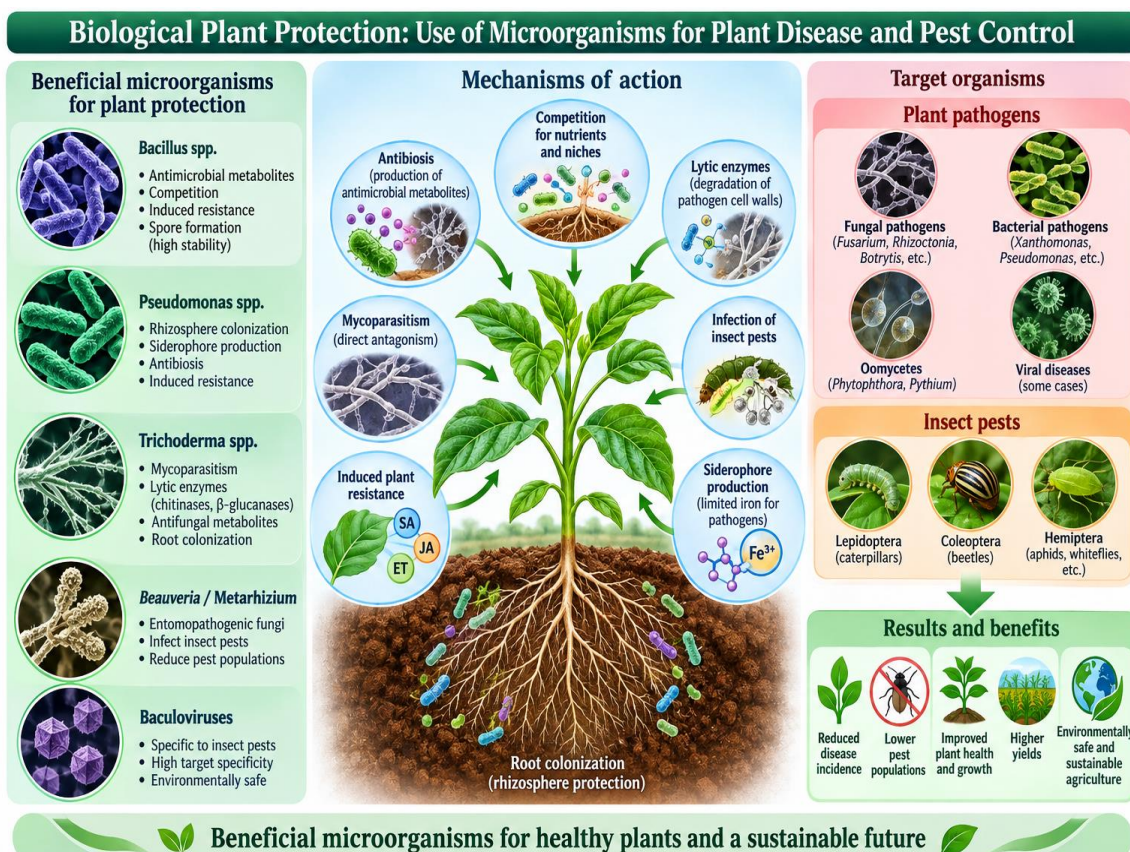


Figure 1. Biological Plant Protection: Mechanisms of Microorganism-Mediated Disease and Pest Control

Biological Control and Its Principles

Biological control is based on the use of natural biological interactions to reduce the population or activity of harmful organisms. In agricultural ecosystems, microorganisms interact continuously with plants, insects, fungi, bacteria, and other organisms. Some of these interactions can be exploited for crop protection. Beneficial microorganisms can colonize the rhizosphere, root surface, internal plant tissues, leaves, or other plant organs and create conditions unfavorable for pathogens. Biological control does not necessarily require the complete elimination of a pathogen or pest. Its primary objective is to maintain harmful organisms below levels at which they cause economically significant crop damage. The general principle can be represented as beneficial microorganism → colonization of plant or environment → interaction with pathogen or pest → suppression of harmful organism → reduced plant damage → improved crop health and productivity.

Major Microorganisms Used in Biological Plant Protection

A wide range of microorganisms can be used as biological control agents. Important bacterial genera include *Bacillus*, *Pseudomonas*, and *Streptomyces*. Beneficial fungi include species of *Trichoderma*, *Beauveria*, and *Metarhizium*. Some microorganisms primarily suppress plant-pathogenic fungi and bacteria, whereas others act against insect pests. Certain viruses are highly specific to particular insect groups and can also be used as biological control agents. The effectiveness of a biological control microorganism depends on its ability to survive in the agricultural environment, colonize the target ecological niche, interact with the harmful organism, and remain biologically active under variable environmental conditions. Many microorganisms exhibit more than one mechanism of action, which can increase their effectiveness and reduce the probability that pathogens will easily overcome biological suppression.

Bacillus as a Biological Control Agent

Species of the genus *Bacillus* are among the most extensively investigated microorganisms for biological plant protection. They are Gram-positive bacteria capable of producing resistant endospores, which contributes to their survival under unfavorable environmental conditions and facilitates their use in commercial biological products. Various *Bacillus* strains can colonize plant roots and other plant surfaces and produce biologically active metabolites that suppress certain plant pathogens. These compounds may include lipopeptides, enzymes, and other antimicrobial metabolites. Some strains also compete with pathogens for nutrients and colonization sites. Their ability to form spores is particularly valuable for biotechnology because spores can improve product stability during production and storage. Consequently, *Bacillus*-based preparations are widely studied for the biological management of fungal and bacterial plant diseases.

Pseudomonas and Rhizosphere Protection

Species of *Pseudomonas* represent another important group of plant-associated bacteria. Beneficial strains can efficiently colonize the rhizosphere and interact with plant roots. Their protective activity may involve competition for nutrients, production of antimicrobial metabolites, synthesis of siderophores, and stimulation of plant defense mechanisms. Iron is often a limiting micronutrient in the rhizosphere, and some *Pseudomonas* strains produce siderophores with a high affinity for iron. By efficiently acquiring available

iron, beneficial bacteria can influence competition with other microorganisms, including certain pathogens. Root colonization is particularly important because biological control agents must establish sufficiently stable populations to produce a meaningful protective effect.

Trichoderma in Biological Plant Protection

Fungi belonging to the genus *Trichoderma* are among the best-known fungal biological control agents. They occur naturally in soils and are frequently associated with plant roots and organic matter. Different *Trichoderma* strains can suppress plant-pathogenic fungi through competition, production of antifungal metabolites, secretion of hydrolytic enzymes, and direct interactions with other fungi. In some cases, *Trichoderma* can recognize, grow toward, and interact directly with the hyphae of plant-pathogenic fungi. Enzymes such as chitinases and glucanases can contribute to degradation of fungal cell-wall components. In addition to direct antagonism, some *Trichoderma* strains can colonize plant roots and influence plant growth and defense responses. Thus, the interaction can be summarized as *Trichoderma* colonization → competition and antagonistic activity → suppression of phytopathogens → reduced disease development → healthier plant growth.

Competition for Nutrients and Ecological Niches

Competition represents one of the fundamental mechanisms of microbial biological control. Plant surfaces and the rhizosphere contain limited nutrients and colonization sites. Beneficial microorganisms that rapidly establish themselves in these environments can consume available nutrients and occupy ecological niches before pathogens become established. A pathogen that cannot obtain sufficient nutrients or successfully colonize plant tissues may have reduced ability to cause disease. Effective biological control agents therefore often possess high growth rates, strong rhizosphere competence, efficient nutrient acquisition systems, and the ability to adhere to plant surfaces. Competition can be especially important because it does not necessarily depend on the production of highly specific antimicrobial compounds and instead uses ecological processes to restrict pathogen development.

Antibiosis

Antibiosis occurs when one microorganism produces biologically active compounds that inhibit the growth or development of another organism. Biological control bacteria and fungi can produce a diverse range of secondary metabolites with antimicrobial activity. These compounds may inhibit spore germination, hyphal development, bacterial multiplication, or other biological processes in plant pathogens. *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Trichoderma* include strains capable of producing antimicrobial metabolites. The effectiveness of antibiosis depends on the microbial strain, concentration of active compounds, environmental conditions, sensitivity of the target organism, and ability of the biological control agent to establish itself near the pathogen.

Lytic Enzymes and Pathogen Suppression

Some biological control microorganisms produce extracellular enzymes capable of degrading structural components of other microorganisms. Fungal cell walls contain compounds such as chitin and glucans, while other microbial structures contain proteins and

additional polymers. Biological control microorganisms may produce chitinases, glucanases, proteases, and related hydrolytic enzymes. These enzymes can contribute to antagonistic interactions with plant pathogens. The mechanism can be represented as biocontrol microorganism → production of extracellular enzymes → interaction with pathogen structures → suppression of pathogen growth and development. Enzymatic activity frequently operates together with competition and antimicrobial metabolite production rather than functioning as an isolated mechanism.

Mycoparasitism

Mycoparasitism is an interaction in which one fungus directly antagonizes another fungus. Certain *Trichoderma* species provide important examples of this biological phenomenon. The biological control fungus can detect chemical signals associated with another fungus, grow toward its hyphae, establish close contact, and produce enzymes and metabolites that interfere with the target fungus. Mycoparasitism is particularly relevant to the suppression of soil-borne fungal pathogens. However, the effectiveness of this mechanism depends strongly on environmental conditions and compatibility between the biological control strain and the target pathogen.

Entomopathogenic Fungi

Some fungi naturally infect insects and are known as entomopathogenic fungi. Important examples include *Beauveria bassiana* and species of *Metarhizium*. These fungi can be used as biological control agents against selected agricultural insect pests. Their spores can interact with susceptible insects and initiate fungal infection under suitable environmental conditions. Because their effectiveness depends on the target insect species and environmental factors such as humidity and temperature, careful strain selection and field evaluation are required. Entomopathogenic fungi are particularly valuable in integrated pest management because they provide a biological mechanism for reducing pest populations and can complement other pest-management strategies.

Bacillus thuringiensis in Insect Pest Management

Bacillus thuringiensis, commonly abbreviated as Bt, is one of the most important microbial agents used in biological insect control. Different Bt strains produce specific insecticidal proteins during their life cycle. These proteins can affect susceptible insect groups when encountered under appropriate biological conditions. The specificity of individual Bt strains and proteins makes it possible to target particular groups of agricultural pests while limiting effects on many non-target organisms when products are appropriately selected and used. Bt-based products have therefore become important components of microbial pest management and represent one of the most successful applications of microorganisms in agricultural biotechnology.

Viruses as Biological Control Agents

Certain viruses naturally infect insects and can be used for biological pest control. Baculoviruses are among the most extensively investigated groups for this purpose. They generally have relatively narrow host ranges, which can provide high target specificity. Viral biological control agents can therefore be useful when a particular insect pest must be managed while minimizing effects on unrelated organisms. At the same time, narrow host

specificity means that accurate identification of the target pest is important. Viral preparations may also be influenced by environmental factors such as sunlight, temperature, and application conditions.

Induced Plant Resistance

Beneficial microorganisms do not always need to attack pathogens directly. Some microorganisms can stimulate the plant's own defense systems. When beneficial bacteria or fungi interact with plant roots, they may trigger physiological and molecular responses that prepare the plant to respond more effectively to subsequent pathogen attack. This phenomenon is often discussed in the context of induced resistance. Plant defense responses can involve changes in signaling pathways, expression of defense-related genes, production of protective proteins, strengthening of structural barriers, and synthesis of secondary metabolites. The process can be represented as beneficial microorganism → plant recognition and signaling → activation or priming of defense mechanisms → enhanced response to pathogen challenge → reduced disease development. This mechanism demonstrates that biological plant protection can operate through complex interactions involving both microorganisms and the plant immune system.

Application Methods of Biological Control Agents

Biological control microorganisms can be applied to crops using several methods. Seed treatment allows beneficial microorganisms to establish themselves around developing roots during germination. Root treatment can be used for seedlings before transplantation. Soil application is particularly useful for microorganisms targeting soil-borne pathogens or root-associated pests. Foliar application introduces microbial preparations onto leaves and other above-ground plant surfaces. Biological control agents may also be incorporated into organic substrates or other agricultural formulations. The selection of an application method depends on the microorganism, crop, target pathogen or pest, environmental conditions, and formulation characteristics. Successful application requires the microorganism to remain viable and biologically active long enough to interact with the target organism or colonize the appropriate plant tissue.

Factors Affecting the Effectiveness of Biological Control

The effectiveness of microbial biological control is influenced by numerous environmental and biological factors. Temperature and humidity strongly affect microbial survival, growth, spore germination, and biological activity. Soil pH, organic matter, nutrient availability, ultraviolet radiation, rainfall, and interactions with native microorganisms can also influence performance. The target pathogen or pest population, crop genotype, developmental stage of the plant, timing of application, formulation, and inoculum quality are equally important. A biological control agent that performs effectively under laboratory conditions may demonstrate different results under field conditions because agricultural ecosystems are highly complex. Therefore, development of biological control products requires laboratory screening, greenhouse experiments, field trials, formulation optimization, quality control, and evaluation across different environmental conditions.

Advantages and Limitations of Biological Plant Protection

Biological plant protection offers several important advantages. Microbial agents can reduce reliance on some conventional chemical pesticides, support integrated pest-management programs, and exploit naturally occurring ecological interactions. Many biological control agents are relatively specific to particular pathogens or pest groups, which can reduce impacts on unrelated organisms when they are correctly selected and applied. Biological control can also support soil microbial diversity and sustainable crop-management practices. However, microbial products have limitations. Their action may be slower or more variable than that of some chemical pesticides, and their effectiveness can depend strongly on environmental conditions. Some microorganisms require specific temperatures or humidity levels, while others may have limited persistence after application. Product storage, formulation, microbial viability, and compatibility with other agricultural treatments are therefore important considerations.

Biological Control and Integrated Pest Management

Biological plant protection is particularly effective when incorporated into Integrated Pest Management (IPM). IPM combines biological, cultural, physical, genetic, and, when necessary, chemical approaches to maintain pest populations below economically damaging levels. Instead of relying exclusively on one control method, IPM integrates crop rotation, resistant plant varieties, monitoring of pest populations, appropriate agricultural practices, biological control agents, and selective pesticide application when justified. The general strategy can be represented as pest monitoring + prevention + biological control + resistant varieties + optimized agricultural practices + targeted chemical control when necessary → sustainable pest and disease management. This integrated approach can reduce unnecessary pesticide applications while maintaining crop productivity.

Modern Biotechnology and Biological Plant Protection

Modern biotechnology provides new opportunities for identifying and characterizing microorganisms with biological control potential. Molecular identification, genome sequencing, metagenomics, transcriptomics, proteomics, and metabolomics can be used to investigate genes and metabolites involved in microbial antagonism, root colonization, plant defense stimulation, and adaptation to environmental conditions. Plant microbiome research has demonstrated that disease resistance is influenced not only by individual microorganisms but also by complex microbial communities. Consequently, researchers are increasingly investigating microbial consortia in which several compatible microorganisms perform complementary functions. One microorganism may compete effectively for nutrients, another may produce antimicrobial metabolites, and another may stimulate plant defenses. Understanding these interactions can contribute to the development of more reliable biological plant-protection technologies.

Future Perspectives

Future biological plant protection is expected to combine microbiology, molecular biology, plant pathology, entomology, genomics, microbiome engineering, and precision agriculture. Improved formulations can increase microbial survival during storage and after application. Genome-based selection can help identify strains with desirable combinations of biological characteristics. Microbial consortia may provide broader and more stable crop protection than individual strains in some agricultural environments. Precision agriculture technologies can help determine where and when biological products should be applied

according to environmental conditions, disease risk, and pest population dynamics. The combination of biological control agents with resistant crop varieties and integrated pest-management systems represents an important direction for reducing environmental impacts while maintaining agricultural productivity.

Conclusion

Biological plant protection uses beneficial microorganisms and their biological activities to suppress plant pathogens and agricultural pests. Important biological control agents include bacteria such as *Bacillus*, *Pseudomonas*, and *Streptomyces*; fungi such as *Trichoderma*, *Beauveria*, and *Metarhizium*; and selected insect-specific viruses. Their mechanisms include competition for nutrients and ecological niches, production of antimicrobial metabolites, secretion of extracellular enzymes, direct antagonistic interactions, biological suppression of insect pests, and stimulation of plant defense responses. The effectiveness of microbial biological control depends on the selected strain, target organism, crop, formulation, application method, and environmental conditions. Biological control is therefore most effectively considered as part of an integrated plant-protection strategy rather than as an isolated technology. Combined with modern biotechnology, microbiome research, and precision agriculture, beneficial microorganisms have considerable potential to support sustainable crop production while reducing dependence on conventional chemical plant-protection products.