BIOLOGICAL CONTROL FOR PLANT PROTECTION: RECENT ADVANCES IN RESEARCH AND SUSTAINABILITY

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Biological Control for Plant Protection: Recent Advances in Research and Sustainability

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FOREWORD

I am extremely happy to know that the book 'Biological Control for Plant Protection: Recent Advances in Research and Sustainability' is being published by Bentham Science Publishers, UAE. I feel delighted to congratulate the editorial team of Dr. Sonika Sharma (DAV University, Jalandhar), Dr. Talwinder Kaur (Guru Nanak Dev University, Amritsar), Dr. Ashutosh Sharma (DAV University, Jalandhar), and Dr. Bahaderjeet Singh (Guru Kashi University, Talwandi Sabo) for the conceptualization and compilation of this important book on the eco-friendly and sustainable approaches to plant protection in field crops. A sizeable proportion of our agricultural production is reduced by competing organisms, which include insect pests, plant pathogens, and weeds. Further, some insect pests also cause significant post-harvest losses. To ensure global food security, it is important to reduce the potential damage due to weeds, insect pests, and plant pathogens. To increase productivity by reducing the competition with weeds or the damage by insect pests and pathogens is need of the hour. The conventional methods of controlling weeds and pests through chemicals have environmental and human health concerns. In recent years, a wealth of useful information has been accumulated about the biological control of these problems in an eco-friendly manner, and some of the biocontrol formulations have also been commercialized. The present book covers a range of topics from the viewpoint of biocontrol of weeds, insect pests, nematodes, and other plant pathogens. Further, the role of botanicals and specific microbes like actinobacteria and *Alternaria* spp. have also been discussed in detail. The role of bio-priming in plant disease management has been elaborately discussed in one chapter. The book is a compilation of 15 chapters written by different academicians/researchers working in the area of biocontrol of weeds and pests. It will present a holistic package of information on the recent advances in biological control of weeds, insect pests, and plant pathogens for the researchers, teachers, and students.

I convey my thanks and best wishes to the editors and the contributing authors for this significant edited work. I hope and believe that the readers will relish reading this excellent compilation on plant protection sciences.

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PREFACE

The food and nutritional security of the increasing human population is one of the biggest challenges of the present century. Various organisms, like weeds, crop pests, diseases, *etc*., are some of the major limiting factors in increasing crop productivity for increasing human population and decreasing agricultural land. Biocontrol or biological control is a method of management for any potentially noxious organisms (crop pests, pathogens, or weeds) using another organism in an ecologically sustainable manner, thereby saving our crops from such noxious organisms. These biological strategies include the use of predators, parasitosis, antagonist organisms, pathogens of noxious organisms, competitors, herbivores, *etc*., that have naturally evolved alongside the noxious organisms during the evolution as a part of the food chain or to maintain the ecological balance. The mass multiplication of these biocontrol agents and utilization of them against crop pest pathogens and weeds is a new category of human interventions for crop protection in an eco-friendly way, thereby reducing the dependence on agrochemicals that may not be ecologically safe. In recent years, due to environmental awareness as a result of mass media and discussions at several international forums, there has been a gradual shift in people's choice toward relatively safer methods of crop protection interventions. Several efforts were made to evaluate new biocontrol methods, and a lot of scientific information has emerged. Therefore, there was a need to compile the recent progress in this area in the form of a book.

In this regard, the present edited book entitled 'Biological Control for Plant Protection: Recent Advances in Research and Sustainability' is a timely attempt to incorporate all the recent advancements in the field of biological control in relation to plant protection. A total of 15 chapters have been included in this edited collection. Its chapters cover all major areas of biocontrol, like mass multiplication of bio-control agents, their genetic engineering, biopesticides, *etc*. An attempt has also been made to discuss all major classes of biocontrol agents like actinobacteria, biocontrol agents for nematodes and lepidopteran pests, *etc*. Further, the new biotechnological methods to improve the effectiveness of biocontrol agents have also been discussed. Besides this, its role in organic agriculture and ecological sustainability has also been discussed in specific chapters. The editors wish the readers an enjoyable journey while going through this book.

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CHAPTER 1

Biological Control in Organic Agriculture

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Abstract: Eco-friendly management of insect pests using sustainable measures is the need of the hour to prevent crop yield losses caused by pests. For sustainable agriculture, the use of biological methods, viz., botanicals, biological control, biopesticides, and pheromones for pest management, should be adopted and popularized on high priority. Chemical pesticides accumulate in the soil, disrupting its structure and fertility over time, causing long-term contamination and ecological imbalance. Biological control is a central component of integrated pest management (IPM), which constitutes an array of scientific methods adopted in both conventional and organic farming systems. The main objective of the study is to better understand the potential of botanicals in sustainable pest and disease management while maintaining ecological balance to assess the effectiveness of various botanical extracts or chemicals in eradicating specific pests, diseases, or weeds and to identify natural alternatives to synthetic pesticides and herbicides, thereby lowering the environmental and health dangers connected with chemical use. The study utilized search engines, research papers, online databases, and books, with data from various platforms contributing to this study. Unlike chemical pesticides, botanicals degrade quickly, hence enhancing soil health and maintaining rhizosphere microorganisms. They are cost-effective, non-toxic, and accessible for pest management. Botanicals are a sustainable alternative to agrochemicals that benefit soil health, protect microflora, and support organic farming. Plants, such as *Azadirachta indica*, *Chrysanthemum*, *Pongamia*, *Lantana*, *Calotropis*, *Shorea robusta*, *etc*., are used as botanicals. The

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development and utilization of botanicals in pest management offer an environment-friendly and cost-effective approach. The focus should be on advancing well-researched botanical solutions to promote sustainable agriculture. These botanicals can play a crucial role in integrated pest management (IPM) strategies. By integrating these natural solutions into sustainable agricultural practices, we can reduce reliance on synthetic pesticides, minimize ecological harm, and promote long-term agricultural productivity and soil health.

Keywords: Biological control, Biopesticides, Botanicals, IPM, Organic agriculture, Parasitoids.

INTRODUCTION

The plant kingdom has benefitted human civilizations in several ways since ancient times. The discovery of agriculture took place about 10,000 years ago, during the New Stone Age. Agriculture's beginnings may be traced back to the rich Crescent Valley. Civilized man developed agriculture to use plant resources primarily as food and then with further development for fiber and fodder. As the years passed, intensive agriculture and the Industrial Revolution began to fulfill the requirements of vigorously increasing the human population and increasing the yield of crops for their benefit, and adverse effects on the environment took place. Human ailments soon took a severe toll on civilizations, and the plant world once again came to the rescue, culminating in the creation of Ayurveda, homeopathic, and Unani healthcare systems. Intensive agriculture has resulted in a rise in pest population and disease propagules, as well as increased competition for food. Synthetic pesticides are heavily used, leading to soil deterioration, environmental pollution, and various human diseases. Following the signing of the World Trade Organization (WTO) general agreement on trade and tariffs in recent years, more focus has been placed on using ecologically friendly pesticides for crop production due to their low toxicity, low disease resistance, and low residual concerns.

Since there are several methods available for pest and disease management, before using any of the control methods in organic agriculture, we must look into the advantages and drawbacks of that particular method. The major types of pest control methods are biological, physical, and chemical. Tillage for weed management and open-field burning for pest control are examples of physical control. Whereas, chemical control includes using various synthetic chemicals to control the pest population. The side effects of chemical control may lead to the deterioration of soil health, water pollution, increased salinity of the soil, *etc*. They are also expensive and every farmer cannot afford them and also have some non-target effects [1].

DeBach defines biological control as the “Action of parasites, predators, or pathogens in maintaining another organism's population density at a longer average than would occur in their absence”. Cultural practices were introduced into use much before the discovery of biocontrol by chance. The historic tradition of avoiding planting identical crops in the same agricultural land every third or fourth year, or even longer, to avoid the spreading of diseases is known as crop rotation. Crop rotation results in the insect or pathogen level in the soil falling below a certain threshold value.

Nitrates and pesticides have been found in groundwater in several agricultural areas. Nitrate levels in drinking water are harmful to people's health, especially newborns, and can be fatal in some circumstances. In cereals, pulses, vegetable oils, meat, vegetables, fruits, and animal feed, traces of banned pesticides like DDT and BHC isomers have been reported. Sustainable agriculture is one of the methods to avoid the depreciation of the environment, soil health, and human health. Sustainable agriculture encompasses a variety of atypical farming methods, including organic, alternative, regenerative, ecological, and low-input farming. A sustainable farm must produce enough quality food, safeguard its resources, and should be ecologically friendly and profitable. Organic farming relies on favorable natural processes, including resources that can be regenerated from the yard itself, rather than purchasing items such as fertilizers. Organic farmers help in improving soil health by nourishing the soil's living component *i.e.*, the microbial inhabitants who release, convert, and transport plant nutrients. Organic farming starts by focusing on soil health and using locally accessible resources to add organic matter. ‘Certified organic’ label applies to agricultural goods that have been cultivated and processed according to given standards and validated by accredited state or private organizations. Organic and integrated farming provides substantial opportunities on numerous levels, contributing to thriving rural economies through long-term growth.

The increased concern about the environmental and health effects of synthetic pesticides and herbicides has fuelled the search for sustainable alternatives in agriculture. Botanicals made from plants are a promising answer for pest and disease management in organic and environmentally sound farming systems. These natural products contain bioactive components that can efficiently manage pests, diseases, and weeds while causing minimal damage to non-target creatures and the environment. Exploring the potential of various botanicals is critical for developing sustainable methods that reduce chemical dependency, maintain ecological balance, and promote long-term productivity in agriculture. This study focuses on identifying plants, their extracts, oils, and specific compounds with proven efficacy in controlling insects, nematodes, mites, rodents, *etc*. (Fig. **1**). By analyzing their potential as natural alternatives to synthetic chemicals, the study

CHAPTER 2

Utilization of Biological Agents for Sustainable Agriculture: An Ecofriendly Approach

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Abstract: The decline of pest organisms (mites, insects, pathogens) population density by utilizing beneficial organisms demonstrates biological control. This is a very crucial component of sustainable agriculture that maintains production for a longer duration without environmental degradation. The utilization of biological agents should be enhanced in agriculture. This chapter basically discusses different varieties of biological agents that are being utilized for various types of pests in the agricultural field. Various types of biological organisms have been reported for successfully managing Diamondback Moth, *Plutella Xylostella,* Thrips, Mites, and soil-borne diseases in potatoes, hot peppers, cabbages, *etc*. Several species of *Streptomyces, Trichoderma, Bacillus, Pseudomonas, etc*., enhance plant growth and reduce the disease incidence, ultimately leading to enhanced plant yield. The awareness regarding hazards induced by chemicals in the agriculture field results in a significant increase in the use of biological control agents and a decrease in pesticide utilization. Biological control majorly depends upon factors like an abundance of biological agents, mass production, and field application for controlling pests, resulting in sustainable agriculture. The extensive knowledge of soil microflora ecology and factors affecting their population is crucial for deciding management strategies. The major strategies of utilizing microbial population in soil and biological seed treatment utilizing biological antagonists might be some alternatives that move the concept of sustainability a bit closer to reality. By utilizing the above-mentioned approaches, sustainable agriculture will help in reducing the use of synthetic pesticides and their adverse impact on the environment, improving the safety of farm workers and maintaining the economic viability of crop production. The current work includes a compilation of various diseases associated with plants and the utilization of bacterial agents such as *Bacillus*, *Pseudomonas*, Actinomycetes, *etc*., for sustainable agricultural practices.

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Keywords: Bioagents, Biocontrol, Plant disease, Sustainable agriculture.

INTRODUCTION

The extensive utilization of synthetic pesticides and the environmental as well as toxicological problems they pose have increased the interest in finding safer alternative sources for managing agricultural pests worldwide. The areas with a large population that are exposed to agrochemicals result in critical issues. With the benefit of non-phytotoxicity and rapid biodegradability, higher plant products have recently attracted interest in various parts of the world as innovative chemotherapeutics for plant protection [1]. There are many difficulties in modern agriculture, particularly in developing nations where a rapidly expanding population raises the demand for food grains; the necessity of trade and economic growth increases the demand for diverse cash crops. The rise of several phytopathogens, which pose a severe danger to productivity and the quality of the goods produced, is another difficulty modern agriculture is facing. The use of fertilizers and chemical agents like fungicides, insecticides, and other pesticides significantly reduces these issues. The excessive use of pesticides in agricultural areas always has a drawback, even though they assist farmers to prosper. To manage plant pests in an environmentally benign manner and protect crops, many plants and microorganisms have been developed for widespread usage as biopesticides.

For a healthy and productive future, environmental scientists from all around the world are looking for alternatives to chemical pesticides [2]. The synthesis of new pesticides and the production of natural pesticides both rely heavily on plants and their secondary metabolites. Many plants have been shown to have insecticidal properties. Insecticides Casida and Quistad have also been investigated using essential oils and other bioactive substances [3]. Particularly in terms of resistance to diseases and pests, it has become more apparent how significant these chemicals are. Furthermore, the purity of natural products varies greatly and depends on the plant part, age, extraction technique, geographical origin, climate, and general growth and health of the plant from which the chemical is derived [4]. The extensive use of synthetic pesticides and the environmental and toxicological problems they cause have increased the interest of scientists in finding safer chemical sources for managing agricultural pests. Due to their overuse, pesticides have contaminated every area of the environment and represent a serious risk to non-target creatures (insects, plants, fish, and birds).

To preserve the quality and abundance of food, feed, and fibre provided by farmers around the world, plant diseases must be managed. Farmers frequently rely on chemical pesticides and fertilizers in addition to better agronomic and horticulture methods. Over the past 100 years, crop yield and quality have dramatically improved due to agricultural inputs. However, fear-mongering by certain pesticide opponents and the environmental damage brought on by improper and excessive use of agrochemicals have significantly altered people's views on the use of pesticides in agriculture [5]. Today, the use of chemical pesticides is subject to rigid controls, and political pressure is mounting for the removal of the most dangerous chemicals from the market. Additionally, because of the potential scale at which such treatments would be required, the spread of plant diseases in natural environments may make it impossible to successfully apply chemicals. As a result, several researchers in pest management have concentrated their efforts on creating synthetic chemical-free alternatives to control pests and diseases [6].

Biochemicals originating from microbes and other natural sources (including plants), as well as techniques involving the genetic incorporation of DNA into agricultural products that give protection against insect damage, are all considered to be biopesticides [7]. The environment and non-targeted organisms are substantially less at risk from biological insecticides [8]. The fact that pyrethrum and neem essential oils are produced commercially for use as insecticides is evidence of the growing acceptance of their utilization [9]. Their relative cost and safety compared to their chemical competitors have been a major hurdle to their limited commercial deployment. They are made to affect only one particular pest or, in some cases, a small number of target organisms, are naturally less toxic, and have less adverse impact on the environment.

The biological control agents have the following properties: (1) They are self-perpetuating; (2) They can suppress weeds on terrain that is too rugged for ground rig spraying; (3) They spread on their own after initial establishments; and (4) One-time costs can be spread out over time and space. A sustainable weed management system for agronomic crops must satisfy the following criteria to incorporate biological control: (1) The biological control component must be compatible and complementary to the other components of the system; (2) Producers should find the biological control easy to use; (3) The biological control must be dependable, repeatable, and economical; and (4) The biological control should contribute to the sustainability.

In its broadest meaning, biological control of plant diseases refers to any method of disease management or pathogen reduction that relies on biological processes or species other than humans. The term also includes cultural actions that have an impact on pathogenic microorganisms, such as crop rotation and soil supplements. Limiting biological control to the artificial introduction of living microorganisms into the environment to control the disease is a more focused strategy. As a result,

CHAPTER 3

Biofertilizer Inputs in Agriculture for Environmental Sustainability

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Abstract: Since the global human population and the demand for food are continuously growing, the use of chemical fertilizers such as urea, ammonium sulfate, calcium nitrate, and diammonium phosphate has become more prevalent in agricultural practices. While these fertilizers initially boost production, their prolonged use can have detrimental effects on soil health and human well-being. Increased application of these agrochemicals often leads to soil degradation, environmental disruption, and pollution of groundwater. The overreliance on conventional chemical fertilizers disrupts soil ecology, decreases soil fertility, and poses risks to human health. To address these issues, biofertilizers offer a promising alternative. Biofertilizers are natural substances containing living microorganisms that enhance soil quality and plant growth. Upon their application to seeds, plant surfaces, soil, or the rhizosphere, they supply essential nutrients and suppress harmful microorganisms. Biofertilizers improve plant growth by a variety of mechanisms, which include phosphorus solubilization, biological nitrogen (N_2) fixation, and the synthesis of growth-promoting compounds. They contribute to sustainable agriculture by preserving soil health and promoting plant yields. This review will explore the different types of biofertilizers, their effects on plants, and their potential for future use in agriculture. By examining their functions and benefits, the review aims to highlight the role of biofertilizers in advancing sustainable agricultural practices.

Keywords: Biofertilizer, Chemical fertilizer, Microorganisms, Soil fertility, Sustainable agriculture.

INTRODUCTION

Understanding the role of vital phytonutrients is crucial for maximizing crop yield. There are 16 vital nutrients that plants need, including macro-nutrients such as nitrogen (N), magnesium (Mg), calcium (Ca), phosphorus (P), sulfur (S), and potassium (K), and also micro-nutrients like zinc (Zn), iron (Fe), copper (Cu),

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manganese (Mn), molybdenum (Mo), chlorine (Cl), and boron (B) [1]. Currently, the predominant focus in soil and agricultural management is the use of inorganic chemical fertilizers. Such fertilizers are industrially processed to provide highly concentrated, readily available nutrients.

The 2011 Census of India recorded a population of 121 million, with a growth rate of 17.64% over the preceding decade, and approximately 68.84% of this population resides in rural areas. This growing population, both in India and globally, is increasing the burden on the natural resources to satisfy food demands. Studies estimate that a 1% increase in crop productivity can reduce poverty in Asia by 0.48% [2, 3]. In India, about a 1% rise in agriculture per hectare can decrease poverty by 1.9% in the long run due to indirect causes such as lesser prices of foodstuffs and improved access to agricultural resources [4, 5]. Consequently, the expansion of yield declines due to frequent and enhanced usage of chemical fertilizers [6 - 8], affecting the overall well-being of humans and the environment [8, 9].

In conventional agriculture, fertilizers and pesticides are the primary inputs, with fertilizers acting as nutritional supplements and pesticides serving as protectants and treatments [10]. Despite significant advances, poverty persists in areas where productivity gains have not been reached, partly due to the enhanced usage of chemical fertilizers that have degraded soil vigor and reduced organic matter, affecting both soil fertility and overall ecosystem health while also posing risks to human and animal health [11, 12].

According to Venkataraman and Shanmugasundaram, there is an urgent need to adopt cost-effective and eco-friendly nutrient management to achieve sustainable agriculture, with biofertilizers presenting a viable alternative [13, 14]. The Indian government has made strides by promoting the use of biofertilizers alongside chemical inputs [15]. In this context, biofertilizers and biocontrol agents have become integral to integrated farming systems, offering significant potential to improve crop productivity by improving soil nutrient status [16]. This review highlights the role of biofertilizers in contemporary agriculture and their potential benefits for a more sustainable ecosystem.

BIOFERTILIZER AND THEIR TYPES

The term “biofertilizers”, also known as “micro inoculants” [17], originates from the concept of “natural toxin”, where “natural” highlights the use of living organisms. They are products that may contain microbes that colonize the rhizosphere and improve plant growth by enhancing the availability and uptake of essential minerals [18 - 20]. They achieve this by solubilizing nutrients such as phosphates and potash through natural processes, fixing atmospheric nitrogen with various growth-promoting compounds and demonstrating stability with a carbon-to-nitrogen ratio of 20:1 [21].

Recent studies have identified several effective biofertilizers, including potash mobilizing microbes such as *Frateuria aurantia*, sulfate and zinc solubilizers such as *Thiobacillus* species, and manganese solubilizing fungi such as *Penicillium citrinum* that are increasingly being used in commercial applications.

TYPES

Biofertilizers enhance soil health and plant growth by improving the availability of essential nutrients through living microbes [22]. These microbes are categorized into two main groups: those that are capable of forming symbiotic associations with plants, like *Rhizobium*, *Frankia*, and *Azolla* spp., and those that do not [23]. Key types of biofertilizers (Table **1**) include phosphate-solubilizing bacteria, mycorrhizae, organic composts, symbiotic N_2-fixers like *Rhizobium*, asymbiotic N_2-fixers such as *Azospirillum* and *Azotobacter*, and cyanobacteria in association with *Azolla* spp [24].

The employment of natural organic processes by free-living N_2-fixers will help minimize the usage of chemical nitrogen fertilizers and enhance the use of microbial fertilizers to reduce their environmental threat [25]. Rhizosphere-associated N_2-fixing *Paenibacillus* spp. have decreasingly been employed in non-leguminous crops [26]. The use of biofertilizers like *Rhizobium* strains improves rice productivity in a sustainable manner [27].

Phosphorus acquisition is significantly improved by mycorrhizal strains and phosphate-solubilizes. Many plants form symbiotic relationships with arbuscular mycorrhizal fungi (AMF), which enhance soil structure and improve rhizospheric soil characteristics, thereby promoting plant growth even under stress [28]. AMF-induced improvements in nutrient uptake also boost the production of essential phyto-hormones like gibberellins (GA) and auxins that are crucial for regulating growth. Microbes play an important role in the soil phosphorus (P) cycle, regulating the transfer of phosphorus between various soil P forms and making it available for plant uptake [29].

Microbes involved in P-solubilization are mainly *Mycorrhizal* fungi and bacterial P-solubilizers. The symbiosis AMF is also implicit in improving rhizospheric soil characteristics, thereby improving soil structure and plant growth even under stress [28]. It has been well established that AMF helps in nutrient uptake production of phyto-hormones like GA, auxins, *etc*. Microbes have been central to the soil P-cycle and have an important role in increasing the bioavailability of P to improve plant growth [29]. Phosphate solubilization occurs through a variety of

CHAPTER 4

Biorational Approaches to Pest Management Including Genetically Engineered Biopesticides

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Abstract: In the past few decades, agriculture has been revolutionized by the use of chemicals for crop protection. However, their widespread and long-term use resulted in insecticide resistance and biomagnifications of insecticides, which in turn resulted in restrictions on their export. Several environmental issues, like soil and water contamination and dramatic increase of harmful residues in many primary and derived agricultural products, have been raised, which affect human health. Therefore, there is an urgent need to promote the use of alternative methods of crop protection. Efforts are being made to develop biorational pesticides that are environment friendly. Biorational pest management involves biocontrol agents, botanicals, microbial biopesticides, insect growth regulators, and genetically engineered bio-pesticides, which have relatively higher performance and pose a lesser concern about environmental toxicity. The resistance to biopesticides in target organisms was not easily generated, unlike in many cases of their chemical counterparts. Although numerous naturally occurring biopesticides have been tested or even commercialized in a few cases, their use has not expanded as greatly as their development. Their global use has been hampered by various constraints such as slower speed of kill, narrow host range, product stability, *etc*. To address some of the above problems, biotechnological approaches like genetic engineering are being explored. This technology has led to the commercial production of genetically engineered (GE) crops on approximately 250 million acres worldwide. The present chapter highlights the recent progress in the production and utilization of biorational pesticides. Further, their types, genes/bio-active agents involved, their mode of action and environmental concerns have also been discussed to provide an up-t--date and holistic view of the recent development in the production of biorational pesticides.

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Sonika Sharma, Talwinder Kaur, Ashutosh Sharma & Bahaderjeet Singh (Eds.)

Keywords: Biopesticides, Diseases, Genetic engineering, Integrated pest management, Microbes, Pests.

INTRODUCTION

Over the years, chemical pesticides have been instrumental in controlling diseases and pests. However, due to their long-term and excessive use, export restrictions have been imposed. This prolonged use has led to issues such as soil and water contamination and increased toxic residues, posing risks to both the environment and human health. It is estimated that $8.1 billion is spent annually on mitigating these environmental and social impacts [1]. Therefore, there is a dire need to promote alternative crop protection methods. Efforts are being made to replace chemical pesticides with environmentally friendly biopesticides.

Biological pesticides, also referred to as 'biopesticides', are derived from natural sources, including plants, animals, microorganisms, and certain minerals. They are considered low-risk insecticides due to their typically unique modes of action. They fall into three primary categories, *viz*., microbial pesticides, plant-based protectants, and biochemical pesticides [2]. Biopesticides are used to manage pest populations without harming the environment or contributing to further contamination. They include organisms like worms, insects, plants (including genetically modified crops), and microbes, targeting pests specifically without affecting beneficial species or leaving harmful residues.

Currently, bacterial biopesticides dominate the market, making up over 60% of usage, followed by fungal biopesticides (27%), viral biopesticides (10%), and other types (3%) [3].

Notable examples of biopesticides include:

- **Viruses**: Nuclear polyhedrosis viruses, Granulosis viruses, *etc.*
- **Bacteria**: *Bacillus sphaericus*, *Bacillus thuringiensis*, *Paenibacillus popilliae*, *Serratia entomophila, etc.*
- **Fungi**: *Metarhizium spp.*, *Beauveria spp.*, *Entomophaga* spp*., etc.*
- **Entomopathogenic nematodes**: *Heterorhabditis* spp., *Steinernema* spp*., etc.*
- **Protozoa**: *Nosema*, *Vairimorpha*, *Thelohania, etc.*
- **Others**: Pheromones, predators, parasitoids, microbial by-products, *etc.*

Besides these biorational approaches described above, genetically engineered biopesticides have also been developed for the management of insect pests. Keeping this in mind, the present chapter was planned to highlight the recent progress in the production and utilization of various types of biorational pesticides. An attempt has also been made to highlight the genes/bioactive agents involved, their mode of action, and their impact on the environment.

MAJOR CATEGORIES OF BIOPESTICIDES

Microbial Pesticides: Such biopesticides use microorganisms like fungi, bacteria, protozoa, or viruses as their active component. Each microbial pesticide typically targets specific pests, but overall, they are useful against a broad range of insect pests. *Bacillus thuringiensis* (Bt) strains are among the commonly used microbial pesticides, specifically for insect control.

Biochemical Pesticides: Derived from naturally occurring substances or microorganisms, biochemical pesticides utilize non-toxic methods to manage pests. Unlike conventional pesticides, which rely on synthetic chemicals that directly kill or incapacitate pests, biochemical pesticides work in subtler ways. For instance, insect sex pheromones prevent mating, while certain plant extracts lure insect pests into their respective traps.

Plant-Incorporated Protectants (PIPs): These biopesticides involve introducing genetic material from other organisms into a plant's genome, enabling the plant to produce its own pest defenses. A well-known example is genetically modified (GM) crops, which express Bt toxins derived from *Bacillus thuringiensis*. While the Environmental Protection Agency (EPA) regulates the pesticidal proteins and their genetic elements, it does not regulate the modified plant itself.

GLOBAL MARKET AND USE OF BIOPESTICIDES

According to Business Communications Company (BCC), the global market for both biopesticides and synthetic pesticides was valued at $61.2 billion in 2017 and was expected to touch $79.3 billion by the year 2022 [4]. The FAO reports that between 2015 and 2018, Asia accounted for the majority (52.2%) of global pesticide use, followed by the Americas at 32.4%, Europe at 11.8%, Africa at 2%, and Oceania at 1.6% [5]. Among countries, China has the highest pesticide use per hectare, while India ranks lower, though states like Jammu and Kashmir and Andhra Pradesh lead in pesticide usage within India [6, 7]. This highlights the need to promote biopesticides as a viable alternative, especially in areas with high chemical pesticide dependence.

GENETIC ENGINEERING AND GM BIOPESTICIDES

Genetic engineering involves transferring a specific gene from one organism's DNA into another's genome. In agriculture, genetically modified (GM) microbial biopesticides are used to control pests by infecting them with disease-causing

CHAPTER 5

Actinobacteria: The Emerging Powerhouse of Biocontrol

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Abstract: Plant disease management and the use of synthetic chemicals have walked hand in hand for many decades. However, the excessive use of these agrochemicals has led to environmental pollution, ecological imbalance, and the emergence of resistant pathogens, along with harmful effects on non-target insects and human health. Therefore, scientists have diverted their attention toward finding safe and suitable alternatives for microbes. Many microbes are known to have antagonistic effects on various phytopathogens. These antagonists thrive as soil microflora or as endophytes in the rhizosphere or phyllosphere. They also inhabit harsh conditions like volcanic areas, high altitudes, marine ecosystems, *etc*. Out of the above-mentioned habitats, antagonistic microflora is majorly found in soil and plant rhizospheres. These antagonists are known as 'biological control agents' (BCAs) as they have an inexplicable capacity to control various plant pathogens. Among these biocontrol agents, actinobacteria hold considerable importance and are known to produce a diverse array of secondary metabolites and still are an inexhaustible natural source of antibiotics. They also produce various antifungal enzymes like chitinases and glucanases, which contribute to their antifungal properties. Additionally, they also act as PGPRs and help in nutrient uptakes for better growth of the host plants, thereby increasing crop yields. Thus, these bacteria exert both direct and indirect effects on the host plants and play crucial roles in plant growth promotion. Out of all actinobacteria, "*Streptomycetes*" are the most commercially harvested bacteria, contributing toward at least 60% of the available compounds of agricultural interest. In addition, actinobacteria are also associated with enhancing the plant immune response prior to infection, which provides resistance against subsequent challenges by a pathogen, known as induced systemic resistance. Accordingly, actinomycetes should be used to enhance the defensive capacity of plants and can, therefore, be an alternative to synthetic chemicals and establish a sustainable strategy to control phytopathogens. Several commercial products obtained from actinobacteria are available in the market but they are just the tip of an iceberg. Therefore, 'actinomycetes' constitute a promising

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future and a vast scope for scientific and commercial exploration for the development of new biocontrol agents. Thus, this chapter attempts to provide an overview of the present understanding of actinobacteria and their potential as a biocontrol agent, their mechanism, application, and an alternative for sustainable crop protection.

Keywords: Actinobacteria, Actinomycetes, Biological control agents, Phytopathogens.

INTRODUCTION

The application of synthetic chemicals for plant disease management is an important practice in agriculture for ages, which has led to serious complications concerning living organisms and environmental health. The continuous use of agrochemicals often results in the development of resistance in plant pathogens and negatively affects non-target organisms [1]. Thus, there is a need for some alternative eco-friendly approaches that do not impose any hazardous effect on the environment and living organisms [2]. Several microbes present in the soil or as endophytes have antagonistic properties against the phytopathogens [3]. Rhizospheric microbes play a key role in protecting plants against the various pathogens that cause several diseases in plants. Several soil bacteria that thrive in the rhizosphere have antagonistic properties, which is an effective management strategy for plant disease control and these antagonists are known as 'the biological control agents (BCAs) [4, 5]. One such microbial group is 'Actinobacteria', which are considered potential destroyers of bacterial and fungal pathogens responsible for several harmful diseases in plants [6]. Actinobacteria are famous for their potential to produce various secondary metabolites [7]. The antagonistic effect of actinobacteria is enforced by the production of a wide range of antibacterial and antifungal compounds capable of inhibiting plant pathogens [8, 9]. Taking all this into consideration, this chapter, therefore, summarizes what exactly Actinobacteria are and, most importantly, elucidates their role as biocontrol agents.

ACTINOBACTERIA

Actinobacteria, also known as actinomycetes, are one of the largest phylum within the domain of bacteria [10]. This phylum includes six major classes, *viz*., Actinobacteria, Thermoleophilia, Acidimicrobiia, Nitriliruptoria, Coriobacteriiaand, and Rubrobacteria [11]. These gram-positive, free-living bacteria are widely distributed in terrestrial as well as aquatic ecosystems [12] and can be isolated both from the rhizosphere as well as the phyllosphere [13]. Actinobacteria are one of the paramount sources of antibiotics wherein either the metabolites derived from them or the whole organism itself is used for the management of several phytopathogens [14 - 18]. In addition, actinobacteria also play the role of plant growth promoters and produce a huge collection of chemical modulators that help stimulate the growth of the plant [19]. Within the phylum Actinobacteria, *Streptomyces* are the most studied genus [20], and the members of this genus constitute a potential source for the exploration as suitable biocontrol and plant growth-promoting agents [21].

Role of Actinobacteria as Biocontrol Agents

The key component responsible for the antimicrobial activity of actinobacteria includes the production of different secondary metabolites [8, 9]. Secondary metabolites are defined as organic compounds produced by an organism, which are not particularly linked with the growth, propagation, and development of the organism, and these metabolites are usually produced in the later stages of growth, known as idiophase [22]. Actinomycetes are considered the most useful prokaryotes that are known to produce several bioactive secondary metabolites, including antibiotics, enzymes, antitumor agents, and immune-suppressive agents. These secondary metabolites are well known for the several properties that they possess, which include anti-fungal, anti-bacterial, anti-algal, neurogenic, anti-malarial, and anti-inflammatory activities. Table **1** represents the biocontrol potential of actinobacterial strains against various phytopathogens.

Table 1. Effective Actinobacteria and their strains with biocontrol activity against various phytopathogens.

Actinobacteria	Target Pathogen	References
Microbispora rosea	*Plasmodophora brassicae*	[23]
Streptomyces galbus (Strain MBR-5)	*Phytopthora cinnamomi, Pestalotiopsis sydowiana*	[24]
Streptomyces padanus (Strain AOK-30)	*Pestalotiopsis* sydowiana	[24]
Streptomyces sp. (Strain MBCu-56)	*Colletotric humorbiculare*	[25]
Streptomyces virginiae (StrainY30 and E36)	*Ralstonia solanacearum*	[26, 27]
Streptomyces halstedii AJ-7	*Phytophthora capsici*	[28]
Amycolatopsis sp. 521	*Colletotrichum gloeosporioides*	[29]
Micromonospora sp. ALFpr18c, ALFb5	*Botrytis cinerea*	[30]
Streptomyces sp.CA2, AA2	*Rhizoctonia solani*	[31]

CHAPTER 6

Recent Advances in the Biological Control of Lepidopteran Pests

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Abstract: In India and tropical Asia, insect pests are one of the most significant limiting factors for vegetable production, with Lepidopteran pests causing the highest damage. Vegetables are among the most profitable crops, and farmers all over the world recognize the need to protect them from damage by insect pests. Diamond-back moth (DBM) on cabbage (*Plutella xylostella*), fruit borer on tomato (*Helicoverpa armigera*), pod borer on chili (*Spodoptera litura*), shoot and fruit borers on brinjal (*Leucinodes orbonalis*), and the fruit borer on okra (*Earias fabia*) are some of the most common insect pests on vegetables. Although a vast range of chemical pesticides have been used to control lepidopteran pests, which are very effective too, increased knowledge of the harmful effects of pesticide usage on the environment and human health has resulted in better awareness and decreasing dependence on chemical controls in recent years. Biological management of pests utilizing their natural enemies is, therefore, considered the most effective alternative to chemical control. There are over 230 species of natural enemies, which are commercially accessible and employed in augmentative biological control. It is not always easy to ensure the efficacy of these natural enemies, as their performance as biocontrol agents is influenced by a variety of abiotic and biotic factors, including unfavorable climatic conditions, the presence of chemical pesticides, potential predator attack, the presence of plant defense mechanisms, and the negative effects of unwanted breeding selection and inbreeding in mass-rearing programs.

Therefore, keeping the above points in mind, the objective of the present study is to focus on recent advances in biocontrol strategies for lepidopteran pests by utilizing genomic information. Over the last century, academia and biocontrol firms have been interested in finding new indigenous natural enemies as well as in exploring the possibility of improving the efficacy of potential biocontrol products. This chapter will cover a wide range of advanced methods and technologies like mating disruption technology, RNAi as pest control and a sterile insect technique, *etc*., using genetic and genomic knowledge to develop better biocontrol agents, a process known as 'next generation biocontrol'.

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Keywords: Biological control, Integrated pest management, Microbial pesticides, Parasitoids, Predators.

INTRODUCTION

The two big challenges that have arisen from the development of the human population in recent decades are supplying enough food for everyone and reducing environmental degradation at the global level [1]. The vast usage and frequent issue of chemical pesticides have led to substantial environmental and human health issues as well as the emergence of insects that are resistant to these pesticides, even though chemical pest management has been crucial in producing significant improvements in crop productivity. Similar to this, the genetic engineering of crops to make them resistant to pests and herbicides has raised a number of issues, including an unintentional rise in herbicide usage, the emergence of pest resistance, and some other detrimental impacts on human health [2, 3]. Therefore, biological control through natural enemies is one of the most effective alternatives to the use of genetically engineered crops as well as chemical pesticides [4]. Invertebrate pests can be controlled by predators, parasitoids, and pathogens, weeds can be controlled by herbivores and pathogens, and plant pathogens can be controlled by antagonistic microorganisms and through the utilization of host plant resistance [5]. Countries have sovereign rights over their genetic resources under the 1992 Convention on Biological Diversity (CBD). Since the 2010 approval of the Nagoya Protocol on Access and Benefit Sharing, parties involved must agree on who has access to these resources and who will share the benefits resulting from their use [6, 7]. The collection and export of natural enemies for biocontrol research have already become challenging or almost impossible in a number of nations due to recent applications of CBD principles [6]. For all of these reasons, a recent trend in augmentative biological control is to first identify or explore the local natural enemies [7]. Currently, there are probably more than 230 species of natural enemies that can be purchased commercially and employed for supplemental biological management [7].

With about 180,000 species in 128 families and 47 super-families, the order Lepidoptera is the second biggest order in the class Insecta. Moths make up more than 160,000 of these species [8]. In most of the world, moth larvae are considered a significant detrimental stage of pests of agricultural and forestry products [9 - 11]. Insecticide spraying on a calendar-based schedule is the most popular technique for protecting crops against such insect pests. However, these substances result in a higher cost of production, residual toxicity, problems associated with pest resistance, outbreaks of secondary pests, and potential risks to human health and the environment [12]. In many agricultural systems in temperate, subtropical, and tropical regions of the world, Lepidoptera includes important insect pests that need to be controlled to prevent major crop losses [13]. Failure to regulate these species can have major effects on production economics, possibly leading to a global crop failure [14]. Numerous Lepidoptera are experiencing geographic range expansion, similar to other arthropod pests [15]. Some pests, like the *Plutella xylostella* L. (Lepidoptera: Plutellidae), also known as diamondback moth, have already spread throughout the world. Similarly, the geographic ranges of many other moth pests are still expanding. According to a recent study, 88 European species in 25 families have increased their range within Europe, and 97 non-native Lepidopteran species in 20 families have settled there so far. Out of them, 74% were established during the 20th century alone [15]. A global eradication database dubbed ‘GERDA’ [16] has recorded 28 lepidopteran species that were the target of 144 known government led incursion responses as part of a project investigating factors determining outcomes from arthropod eradication attempts.

Furthermore, the developments in molecular biology, genetics, analytical chemistry, and neurophysiology have enhanced our comprehension of insect behavior and chemical communication down to the level of individual neuronal circuits. This development has suggested that disruption of mating using artificial pheromones is an efficient strategy to fight against pests. Similarly, based on this information, various other advancements like sterile insect technique as well as RNAi are now being extensively used to protect plants from insect pests. Keeping this in mind, the present chapter was structured to provide up-to-date information on the biocontrol status of the pests belonging to the order Lepidoptera of class Insecta using various techniques employed in biological pest management.

RECENT ADVANCES IN CONTROLLING LEPIDOPTERAN PESTS

Recently, several techniques like mating disruption, sterile insect technique, and RNA interference have been effectively utilized in biological pest management, as discussed under the suitable headings below.

Mating Disruption Technology/Pheromone-Based Products

The term ‘mating disruption’ refers to the decrease in egg load or larval population caused by the field's heavy pheromone inundation, which prevents mating. The low molecular weight volatile organic molecules called pheromones are produced by insects to influence the behavior of other members of their own species [17]. According to a study [18], more than 1,600 pheromones and sex attractants have been identified. Out of them, the ‘sex pheromones’ are most commonly employed to manage the pest in an agricultural area [19]. One benefit of utilizing pheromones in pest management systems is that they do not have any

CHAPTER 7

A Comprehensive Review of Biological Control of Plant Parasitic Nematodes

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Abstract: Recent scientific interest in the biological control of plant-parasitic nematodes (PPNs) has surged due to successful control attempts and the harmful effects of chemical nematicides. Chemical-based plant protectants, while effective, pose risks to both environmental and human health. By contrast, biological control offers a natural alternative that avoids introducing artificial substances and significantly minimizes the chance of resistance development in nematodes against their biological antagonists. Biological control involves using various living organisms, such as fungi, bacteria, viruses, predatory nematodes, micro-arthropods, annelids, protozoa, and other generalist predators, as biocontrol agents to manage PPN populations. These agents work to both suppress nematode populations and prevent disease, fostering healthier plant growth and development. Biological control not only prevents the development of a disease, but it also suppresses the population of plant-parasitic nematodes and thus has a beneficial impact on plant growth. Over time, as more biological control agents are developed and their application becomes more effective, they can potentially replace chemical nematicides entirely. The present chapter explores the various biocontrol agents that target plant-parasitic nematodes, detailing their mechanisms of action, such as infection, predation, and competition. Additionally, it addresses the potential of integrating these biocontrol agents into sustainable agricultural practices, providing a holistic approach to managing PPNs in diverse cropping systems. Through these efforts, biological control can help reduce the dependency on synthetic chemicals, offering a safer and environment-friendly solution for enhancing agricultural productivity. The present chapter, therefore, besides highlighting the economic importance of nematode infestation in crop plants and their various characteristics, also highlights the importance of using biological control in the management of plant parasitic nematodes, thereby reducing the population of plant-parasitic nematodes. This novel strategy of using different groups of living organisms, including fungi, bacteria, viruses, predatory nematodes, micro-arthropods, annelids, protozoa, and generalist predators as the biocontrol agents, has been discussed in detail for the management of plant parasitic nematodes in an environmentally sustainable manner. In addition, the mechanisms of action of these biocontrol agents have also been discussed in detail.

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Keywords: Biocontrol agents, Biological control, Nematodes, Plant disease management, Predators, Predatory nematodes.

INTRODUCTION

The roundworms or nematodes, also known as soil-dwelling animals, are closely associated with plants, and their parasitism has also evolved with the evolution of crop plants. The identification of more than 4100 species of plant-parasitic nematodes has been successfully carried out by various workers to date. According to Bernard *et al.* [1], only a small proportion of the described nematodes cause a significant economic loss to crop plants. The major genera of plant-parasitic nematodes reported to cause crop losses are *Heterodera*, *Hoplolaimus*, *Meloidogyne*, *Pratylenchus*, *Rotylenchulus*, *Xiphinema, etc* [2]. Therefore, the most economically important species directly target the roots of major crop plants and affect water and nutrient uptake, resulting in reduced agronomic performance, overall quality, and yields [1]. The plant-parasitic nematodes collectively cause damage to crops estimated between US$ 80-118 billion per year [3, 4]. Singh *et al*. [5] reported that overall crop yield loss due to plant-parasitic nematodes is about US$ 157 billion worldwide. Major world crops associated to their most important nematodes include wheat (*Heterodera* spp., *Meloidogyne* spp., *Pratylenchus* spp.), maize (*Meloidogyne* spp., *Pratylenchus* spp.), rice (*Aphelenchoides* spp., *Hirschmanniella* spp., *Meloidogyne* spp., *Pratylenchus* spp.), barley (*Heterodera* spp., *Meloidogyne* spp., *Pratylenchus* spp.), soybean (*Heterodera* spp., *Meloidogyne* spp., *Rotylenchulus* spp., *Pratylenchus* spp.), pulses, including bean, pea, chickpea, cowpea, pigeon pea, lentil, and lupin (*Heterodera* spp., *Meloidogyne* spp., *Rotylenchulus* spp.), cotton (*Meloidogyne* spp., *Rotylenchulus* spp., *Pratylenchus* spp.), potato (*Globodera* spp., *Meloidogyne* spp., *Pratylenchus* spp.), sorghum (*Pratylenchus* spp.), millets (*Meloidogyne incognita*), sunflower (*Meloidogyne* spp.), rye (*Heterodera* spp., *Meloidogyne* spp.,*Pratylenchus* spp.), rapeseed/canola (*Helicotylenchus pseudorobustus*, *Meloidogyne hapla*, *M. incognita*), sugarcane (*Meloidogyne* spp., *Pratylenchus* spp., *Paratrichodorus* spp., *Xiphinema* spp.), groundnut/peanut (*Meloidogyne* spp., *Pratylenchus* spp.), cassava (*Meloidogyne* spp., *Pratylenchus* spp.), sugarbeet (*Heterodera* spp., *Meloidogyne* spp.), oil palm (*Bursaphelenchus* spp.), oat (*Heterodera* spp., *Ditylenchus*spp.), coffee (*Meloidogyne* spp., *Pratylenchus* spp.), coconut (*Radopholus* spp., *Bursaphelenchus* spp.), sweet potato (*Meloidogyne* spp., *Rotylenchulus* spp., *Pratylenchus* spp.), grape (*Meloidogyne* spp., *Pratylenchus* spp.), olive (*Meloidogyne* spp., *Pratylenchus* spp.), and banana (*Radopholus* spp.) [6 - 10].

The use of plant-protectant agrochemicals is largely practiced in nematode management, but this method has limitations due to its several negative effects on the ecosystem. They pose serious environmental hazards by leaving their residues in soil and groundwater and are costly too. However, these plant-parasitic nematodes also have a diverse range of natural enemies, but generally, farmers are not aware of the use of such bioagents or biopesticides derived thereof. Biological control is an excellent method for sustainable agriculture as a bioagent will reduce nematode damage without negative effects on other beneficial organisms. According to Lewandowski *et al*. [11], the management and utilization of the agricultural ecosystem should be in such a way that maintains its biological diversity, productivity, regeneration capacity, vitality, and ability to function so that it can fulfill significant ecological, economic and social functions today and in the future at the local, national and global level and does not harm other ecosystems too.

Among nematode antagonists, several fungi have been reported to control the populations of plant-parasitic nematodes. According to Stirling and Gray [10, 12], nematode-trapping fungi are relatively easy to detect in soil. A small quantity of soil (approximately 1 g) is sprinkled on a water agar plate, a suspension of nematodes is added as bait, and within 1-2 weeks, trapped nematodes, trapping organs, and conidia can be seen at low magnification under a compound microscope [10]. These nematode-trapping fungi are commonly found in agricultural, forest, and garden soils, and they are especially abundant in soils rich in organic matter. Most nematophagous fungi can utilize some alternative food sources also, as most of them are saprophytes, some are mycoparasites, and some are parasitic on other soil animals too. However, it is often assumed that nematodes are the primary food source for nematophagous fungi. In addition, the protists, which are not specifically discussed in this chapter, also play an important role in nematode biocontrol. They are ubiquitous in soil, where they are the key contributors to nutrient cycling and energy transfer. However, protists have received far less attention than other components of the soil microbiome [13], but they are still important microbial determinants of crop yield [14].

Keeping the above in mind, the present chapter is an attempt to describe the economic importance, overall biology, and nature of damage of nematodes in crop plants, along with a detailed description of the recent advances in the biological management of plant parasitic nematodes using a variety of bioagents, which include fungi, bacteria, viruses, protists, predatory nematodes, mites, insects, and various other types that are useful in the biocontrol of nematodes in an eco-friendly and environmentally sustainable manner.

CHAPTER 8

Ameliorative Effect of Botanicals in Curbing the Population of Plant Parasitic Nematodes

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Abstract: Plant-parasitic nematodes (PPNs) rank among the most devastating plant pathogens, inflicting substantial economic losses in agriculture. While synthetic chemical nematicides are often employed as an effective control measure, their detrimental effects on non-target organisms and ecosystems underscore the urgent need for environmentally sustainable and eco-friendly alternatives. Plant roots naturally produce a wide array of metabolites with defensive properties, highlighting the importance of understanding root-mediated interactions between plants and nematodes as a foundation for managing these harmful pests. This book chapter delves into the potential of botanical solutions for combating PPNs. Botanical amendments, including plant metabolites and extracts, have emerged as valuable tools, serving dual roles as organic fertilizers and nematicidal agents. These amendments suppress nematode growth and development by releasing nematicidal compounds, exhibiting antagonistic effects, and enhancing plant resistance by modulating plant physiology. Furthermore, breeding programs aimed at developing resistant crop varieties through the incorporation of resistance genes present a promising avenue for nematode management. The chapter emphasizes the integration of organic agricultural practices to foster sustainable ecosystem management, enhance plant productivity, and utilize cost-effective, eco-friendly botanicals for the efficient control of phytonematodes.

Keywords: *Brassica*, Marigold, Plant-parasitic nematodes, Root metabolites, Sunn hemp.

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INTRODUCTION

Plant-parasitic nematodes (PPNs) are microscopic entities that wreak havoc on the productivity and yield of almost all vegetable crops [1, 2]. As per reports, PPNs result in annual yield losses of >$80 billion globally [3]. Furthermore, out of the 50% yield loss of crops caused by different pests, about 12.3% loss is attributed to PPNs [4]. For sustainable production of agricultural crops, the management of PPNs is necessary. Various chemical nematicides manufactured on a commercial scale are available in the market, but these chemicals not only act as major contaminants to surface and groundwater but are also found to affect the non-target organisms [5]. In order to overcome these limitations, a lot of work is being conducted by researchers worldwide for the production of environment-safe crop protection methods that are non-toxic toward non-target organisms.

Additionally, due to the hazardous potential of chemical fertilizers and pesticides toward the biosphere, the use of organic amendments (microbes, plant-based materials, manure, *etc*.) is the most feasible and eco-friendly way for the suppression of phytonematodes. Linford *et al*. [6] were the first to report that soil amendment with chopped *Ananas comosus* L. (pineapple) leaves has a negative impact on the root-knot disease caused by *Meloidogyne* sp. parasitizing *Vigna unguicualta* L. (cowpea) plants. Since then, several studies have been conducted involving soil amendments with different biocontrol agents for managing PPNs, along with enhancing the fertility of soil [7 - 11]. Basically, organic amendment enhances the number of predatory organisms in the soil [12] and helps in controlling plant pathogens. Additionally, it also decreases the level of pollution and cost of protection of agricultural crops. These organic amendments affect the behavior and biology of PPNs directly or indirectly [13, 14]. Such organic methods include the use of plants capable of producing nematicidal compounds, the use of biofumigants, the use of phytohormones, and the supplementation of rhizospheric microorganisms into the soil. Plants produce a variety of secondary metabolites, which help them in their defense against different pathogenic organisms, including nematodes. Moreover, a variety of plant species have been reported to exhibit nematicidal properties. Therefore, various properties like a target-specific approach, eco-friendly nature, and facile biodegradability make the application of botanicals an environmentally safe strategy for the management of PPNs. So, keeping into consideration all these aspects, this chapter provides an in-depth exploration of nematode behavior and the use of organic methods, including botanical amendments, to regulate nematode populations and enhance agricultural sustainability.

DISTRIBUTION AND DIVERSIFICATION OF PLANT PARASITIC NEMATODES IN SOIL

Health management in plants is a never-ending process that faces multidimensional challenges including nematode distribution and their management. However, these tiny, soil-borne creatures are obligate biotrophs that often cause nonspecific symptoms, display a variety of host-plant interactions, and also pose a major threat to worldwide food security [15]. Although nematodes have occupied all the ecosystems, tropical and subtropical climatic zones of the earth are the major focal points where PPNs are present in abundance. In tropical regions, however, the losses due to plant nematodes are more profound [16 - 18]. The diversity of PPNs in soil primarily depends upon nematode species, part of the plant where they thrive, including the roots, stem, or foliage, and the mode of feeding (*i.e.*, endoparasites or ectoparasites) [19, 20]. Table **1** summarizes phytonematodes, including the most potent species that causes massive yield loss, along with some newly discovered and lesser-known species [2, 15].

Table 1. Important plant-parasitic nematodes found in the different regions, including tropical, subtropical, and temperate zones.

Name	Common name	Symptoms	Host	References
Meloidogyne spp.	Root-knot nematode	Stunted growth, wilting, leaf discoloration, deformed roots, enhanced metabolic activity in giant cells	Wide host range, parasitizes almost every species of vascular plants	[15, 21]
Heterodera spp. and *Globodera spp.*	Cyst nematodes; golden cyst nematode	Syncytium formation, root stunting, yellowing, early senescence, discoloration, fewer nodules	Infect all major potato-growing regions of the world	[22]
Pratylenchus spp.	Root lesion nematodes	Reduced root growth, formation of lesions, necrosis, browning and cell death, root rotting, increased susceptibility to water stress, discoloration, stunting, yellowing of roots, damages epidermis, cortex and root endodermis	Sugarcane, coffee, banana, maize, legumes, potato, vegetables and fruit trees	[23, 24]
Radopholus similis	Burrowing nematode	Toppling disease, root system shows dark lesions, tissue rot, weak root system	Citrus crops, pepper, banana	[25, 26]

CHAPTER 9

Biocontrol of Weeds: An Eco-Friendly Option

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Abstract: Biocontrol of weeds makes use of instinctive living creatures, *viz*., insects, animals, disease organisms, phytophagous fishes, insects, fungi, bacteria, nematodes, and several other animals, to restrict their growth and expansion. Using biocontrol, the population of weeds can be lessened up to a fair extent, but the eradication of weeds is not attainable. The biocontrol method is generally used against serious, exotic/introduced weeds, but it also has the potential to work well against other types of non-dominating weed species. Biocontrol of weeds is environmentally safer, because it has no residual effect, is more economical, has enduring effects, is non-dangerous to untargeted species, and effectively controls the weeds in uncultivated land/areas. Except this, some aquatic and other water-loving organisms (like snails and fishes *etc*.) convert the underwater weeds into seafood resources for the food chain. Therefore, this eco-friendly technique should be encouraged and utilized to a larger extent to encounter the present and upcoming obstacles in weed control in agroecosystems. A large number of biocontrol agents may be utilized in the biocontrol methods; however, their careful evaluation and environmental impact assessment before their commercialization at a widespread level are always required. The present chapter is, therefore, an up-to-date compilation of the recent, diverse biocontrol techniques used for weed control alongside the traditional examples of weed biocontrol to present it as an environmentally safer method of weed management and an integral part of sustainable agriculture.

Keywords: Biological attributes, Eradication, Living organisms, Residual effects, Traditional methods.

INTRODUCTION

In order to fulfill the demands of a rising population, grain production must also increase proportionally to ensure food security for all. Farmers usually rely more on chemical weedicides in addition to the common agronomic and horticulture

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procedures generally adopted for weed management. However, environmental contamination caused by the excessive use of such agrochemicals, as well as scaremongering by certain pesticide opponents, has resulted in significant shifts in public perception towards the use of such agrochemicals in agriculture. Biological control should be combined with other control strategies (including chemical control) since various techniques are effective on different occasions, different places, and under varied environmental conditions [1]. The biological control refers to the use of different species of living organisms, such as some insects, herbivorous fishes, other animals, disease-causing organisms (pathogens), and other competing organisms, to limit the growth of undesirable organisms [2]. If a plant's natural enemies become inefficient or disappear, it may become a noxious weed that is difficult to manage in an agroecosystem. When a plant is brought to a new location, or when the ecological system is interrupted by any human intervention, the natural food chain may be disrupted. When these biocontrol agents are deployed deliberately, we seek the management of weeds in a novel and eco-friendly manner by making use of a natural phenomenon. In biological weed management, a complete (100%) weed eradication is generally not achievable, but the weed population can be lowered to a considerable extent [3, 4]. Out of different types of weeds, biological control is more effective against the alien weeds. The management of *Opuntia* spp. (prickly pear) in Australia and *Lantana* spp. in Hawaii are two excellent examples of quick biological control of weeds [5, 6]. Besides the reduction in crop productivity, weeds may also reduce the aesthetic value of the landscape (Fig. **1**).

Keeping in mind the extent of crop losses caused by weeds, it is imperative to look for alternative methods of weed management that are relatively safer and do not pose serious environmental concerns, as in the case of chemical weedicides. Therefore, the present chapter is an attempt to highlight the various types of biocontrol agents recently demonstrated to effectively manage the weeds in crop plants with their overall classification and mode of action with the support of the suitable examples under the appropriate sub-headings to give the readers an overview of the recent developments and insights in the biological management of weeds.

HOW DOES IT WORKS?

There are different mechanisms of weed biocontrol associated with different types of biocontrol agents (Fig. **2**). Some biological control agents get connected to the plant roots, affecting plant growth and development. Some root-surface bacteria produce certain toxins that may inhibit the root growth. Several fungi may invade the plant roots and therefore, may affect the water transport system, inhibiting leaf development also. The beneficial insects and nematodes directly feed on the roots of weeds, causing damage that permits pathogenic bacteria and fungi to invade. Plant leaves absorb solar energy and make carbohydrates, whereas the leaf-feeding insects reduce the leaf surface area available for photosynthesis. On the other hand, the pathogenic fungi and bacteria reduce the plant's ability to produce carbohydrates. In either situation, there is less available energy for the growth of weeds. However, the severe infestations of biological control agents can also kill the weeds by damaging their roots or leaves, hence minimizing their negative impacts on the desirable crop plants. Several weed species perpetuate their existence year after year by generating a large number of propagules like seeds, *etc*. Insects or fungi that feed on seeds can lower the quantity of viable weed seeds stored in the soil, hence reducing the size of upcoming weed communities. This reduces the required effort to deal with the remnant, newly growing weeds.

Fig. (1). Aesthetic improvement of different landscapes, before (left) and after (right) the biological control of weeds.

CHAPTER 10

Enhancing the Effectiveness of the Natural Enemies of Insect Pests through Biotechnological Approaches

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Abstract: The use of entomophagous organisms, including parasitoids and predators, for the biological management of insect pests presents an ecologically advantageous and economically feasible approach to achieving sustainable crop production. Traits such as tolerance to pesticides and other abiotic stresses, shortening the developmental period, increasing progeny output, changing sex ratio, and changing host or habitat preferences can be improved through genetic manipulation to increase the effectiveness of these natural enemies. The majority of genetic improvement of entomophagous and other biocontrol agents focuses mainly on pesticide tolerance or resistance, while a few attempts have been made to improve the other aspects also. When the implementation methods are adequately developed, the critical qualities limiting their effectiveness can also be discovered, and the enhanced insect strains may retain their fitness in the natural environment. Artificial selection of multiple strains under varied environmental conditions and their hybridization has been reported. Considering the advancement in insect biocontrol methods, the applications of recombinant DNA technology include introducing foreign genes into insect baculoviruses and attaining quick and efficient expression in recipient host systems. This chapter highlights the various applications of genetics in improving the fitness and usefulness of these beneficial insects, including case studies, recent advancements, and the possibilities for real-world implementation in pest management strategies. Genetic enhancement of biocontrol agents (BCAs) has the potential to be very successful, resulting in the generation of more improved strains with the desired level of effectiveness, host searching ability, broad host range, and persistence in adverse environmental conditions, thus giving a vital tool for sustainable pest management. Moreover, this chapter aims to contribute to the development of new and long-term pest management strategies by utilizing available and recent biotechnological approaches.

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Keywords: Biocontrol, Biotechnology, Entomophages, Sustainable agriculture, Zero hunger.

INTRODUCTION

The significance of natural enemies, including predatory insects, parasitic wasps, and microbial agents, is crucial for sustaining ecological balance and managing insect pests within agricultural systems. These biological control agents provide a sustainable option that minimizes the use of chemical pesticides, thereby decreasing harmful residues and supporting biodiversity. Nonetheless, obstacles like restricted effectiveness in certain environmental conditions, the emergence of resistance in pests, and the necessity for focused interventions highlight the demand for creative approaches to improve their performance. Biotechnology has surfaced as a significant instrument to tackle these challenges. Recent progress in genetic engineering, molecular biology, and microbial manipulation allows for the enhancement of natural enemies, improving their predatory, parasitic, or pathogenic capabilities. This chapter delves into the incorporation of biotechnological methods aimed at enhancing the efficacy of biological control agents. It highlights case studies, recent advancements, and the possibilities for real-world implementation in pest management strategies. Utilizing biotechnology offers the potential for enhanced, sustainable, and scalable pest management strategies, safeguarding the health and productivity of agricultural systems worldwide. As an integral part of successful integrated pest management programs, entomophagous insects play a vital role in both natural and applied biocontrol strategies. Entomophagous insects, such as parasitoids and predators of insects, can be used for biological control in the cultivation of sustainable crops. The Vedalia ladybird beetle (*Rodolia cardinalis*) in California, the parasitic wasp (*Epidinocarsis lopezi*) in West Africa, the papaya mealybug (*Paracoccus marginatus*) and the Encyrtid wasp (*Acerophagus papayae*) in Mexico, *etc*., are examples of successful biological control on the world stage. In India, some of the successful examples of insect management using bioagents include the control of sugarcane Pyrilla (*Pyrillaper pusilla*) by the utilization of an egg parasitoid (*Tetrastichus pyrillae*) and a nymphal predator (*Epipyrops melanoleuca*), as well as the management of apple woolly aphid (*Eriosoma lanigerum*) and Sanjose scale (*Quadraspidiotus perniciosus*) by *Aphelinus mali* and *Encarsia perniciosi*, respectively. Sugarcane woolly aphid (*Ceratovacuna lanigera*) was controlled by different bio-agents, *viz*., *Dipha aphidivora*, *Chrysoperla* spp., coccinellid beetles and syrphid flies, and American bollworm or gram caterpillar (*Helicoverpa armigera*) was controlled by the use of Nuclear Polyhedrosis Virus (NPV) [1, 2]. Several agricultural pests, such as sugarcane internode borer, coconut black-headed caterpillar, pupal and larval parasitoids, and green lacewings, have been successfully managed with the use of egg parasitoids, *Trichogramma* spp. Under field (natural) conditions, various insect parasitoids and predators have been observed attacking key agricultural pests of different agronomic and horticultural crops. While this may be the case, pests still cause significant crop losses and damage, necessitating the employment of other advanced management tools and techniques, such as genetic manipulation [2]. Entomophagous insects' efficacy is influenced by the following factors:

i. Specificity - Insect pests should have natural adversaries that are specific to that pest.
ii. Host searching ability- the ability to search for hosts in different field conditions.
iii. Dispersal ability - the ability to spread to a larger area.
iv. High adaptability - the ability to thrive in the most hostile of environments.
v. High reproductive rate or fecundity - the ability to reproduce in a short time
vi. Favorable sex ratio - the sex ratio should be more toward female

In view of the above points, this chapter was formulated with the following objectives:

1. To investigate the possibilities of using biotechnological methods (such as genetic engineering, RNA interference, and gene editing) to enhance the effectiveness of natural enemies.

2. To explore the application of biotechnological methods to improve the resilience or adaptability of natural predators against pesticides, environmental challenges, or other elements that could affect their performance.

3. To examine the possibilities of utilizing biotechnological methods to enhance the large-scale production, formulation, and usage of natural predators for pest management.

4. To assess the potential risks and benefits associated with employing biotechnological methods to improve the efficacy of natural predators.

BIOAGENTS IMPROVEMENT *VIA* GENETICS

Advanced techniques like genetic manipulation can be used to enhance the effectiveness of various entomophagous insects, including predators, parasitoids, and entomopathogens (microorganisms pathogenic to arthropods such as bacteria, viruses, fungi, *etc*.), which can be applied from a variety of different fields, as outlined in the following sub-headings:

CHAPTER 11

A Complete Review of the Role of Microorganisms in Biocontrol: Applications and Future Aspects

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Abstract: Seasonally, numerous invertebrate and microbial species are utilized in augmentative biological control (ABC) to combat pests across more than 30 million hectares globally. In Europe, agents of biological control in invertebrates dominate the market, although North America leads in the use of microbial agents. Latin America and Asia are also experiencing significant growth in ABC, particularly in microbiological applications. The rising popularity of ABC is due to several factors: (1) Its inherent benefits, including safety for agricultural workers and nearby residents, absence of a harvest waiting period post-agent release, long-term effectiveness because they are not resistant to their natural adversaries, arthropods, decreased amount of pesticide residues below the maximum levels (MRLs), minimal phytotoxic effects, enhanced yields, and healthier crops; (2) The professionalism within the biological control industry, characterized by cost-effective mass manufacturing, stringent quality assurance, effective packaging, shipping, and release techniques, and the availability of more than 440 pest control chemicals; (3) Recent achievements demonstrating biological control capacity to safeguard agriculture when pesticides fail or are inaccessible; (4) Demands from NGOs, customers, and merchants for pesticide residues much below the permitted maximum residual levels; and (5) New regulations in some areas that try to cut back on or switch to sustainable pest control techniques in place of synthetic pesticides. Despite its current usage, ABC has the potential for much broader application. We advocate for a pragmatic, flexible agricultural approach that integrates diverse agricultural and pest management strategies. Moving forward, we propose "Conscious agriculture", which entails everyone's active involvement in the production and consumption chains, with a commitment to environmental sustainability and future resource conservation. The adoption of "conscious agriculture" can significantly enhance the future prospects of ABC as a credible alternative to conventional farming.

Keywords: Augmentation biological control, Biological control, Conscious agriculture, Integrated pest management, Market advancements, Pest control regulations.

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INTRODUCTION

Biological control is increasingly gaining attention from politicians, policymakers, retailers, consumers, producers, and grower associations. As the authors of this chapter, we frequently receive inquiries about controlling specific pests, diseases, or weeds, sourcing biological control agents, or promoting this environmentally friendly pest management strategy. Since 2009, the European Union (EU) has encouraged the use of biological pest management through its Sustainable Use of Pesticides Directive [1]. Furthermore, China's national research initiative on cutting back on chemical fertilizers and insecticides was recently introduced by the Chinese president", with a budget exceeding 340 million dollars, underscoring the need for developing and implementing non-chemical treatment for control [2].

Biological control is the process of employing one organism to decrease another's population.

The modern use of this procedure started in the late 1800s, despite the fact that it has been used for more than 2000 years [3, 4]. The four main types of biological regulation are natural, conservation, classical, and augmentative. Natural biological regulation is an ecological service where naturally occurring beneficial organisms suppress pests without the involvement of humans, contributing significantly to agricultural economics worldwide [5, 6]. Natural biological control is an ecological service [7] in which naturally occurring beneficial organisms suppress the pest population. This is the most significant economic contribution of biological management to agriculture and happens spontaneously in all ecosystems without human interference [8]. Conservational biological control is the term for human actions that support and increase the effectiveness of naturally occurring predators. Nowadays, there is a lot of interest in this kind of biological regulation. The significance of the natural microbiome in and on plants in promoting resistance to pest and pathogen infection, as well as its function in reducing plant diseases in soil and crop wastes, is the subject of conservational biological management of plant diseases [9, 10]. In places where the pest is invasive in traditional biological control, the natural enemies are first gathered in an investigative area (usually the pest's origin) and subsequently released, frequently leading to a permanent reduction in the pest population and significant economic benefits [6]. The term 'classical' biological control refers to the first sort of biological control that was deliberately and widely used [3]. Natural enemies, such as parasitoids, predators, or microorganisms, are bred in large quantities for release in crops. This can be done to either to manage pests across several generations in crops with a longer production cycle (seasonal or inoculative biological control) or to control pests in crops with a short production cycle (inundative biological control) [2, 6, 11, 12].

This chapter highlights biological control, a technique that has been focused on effectively employing various cropping systems for over a century [6, 13]. We highlight (1) The current significance of ABC, (2) The range of commercially available biological control agents and the specific pests they target, (3) How ABC contributes to promoting more eco-friendly, sustainable, and health-conscious agricultural practices through effective policy measures and regulations, and (4) The need for an environmentally conscious agriculture strategy that optimizes the utilization of ecosystem service.

WHERE IS AUGMENTATIVE BIOLOGICAL CONTROL BEING USED TODAY?

Augmentative biological control (ABC) often operates as a commercial enterprise, as it requires large-scale, consistent emissions and large-scale manufacturing of natural predators or beneficial organisms [2]. The first recorded use of ABC dates back to around 300 AD in China [4]. The modern era of ABC began in the 1880s when Metchnikoff in Russia used the insect pathogen *Metarhizium anisopliae* to control the insect pests in different crops [14]. Today, ABC is applied across a wide range of agricultural fields, including fruit, cotton, vegetable, soybean, cereals, sugarcane, and numerous greenhouse crops (Table **1**). It is often incorporated into IPM strategies, offering a sustainable and cost-effective substitute for chemical pest control [6, 15]. Additionally, using microbial biological control agents to treat seeds is becoming a more popular ABC technique [16]. In 2015, ABC was used on more than 30 million acres globally (Table **1**). Since the 1970s, it has evolved from a small-scale industry into a professional research and manufacturing operation. This development has resulted in the discovery of numerous effective agents and improvements in areas such as quality control, large-scale production, distribution, application techniques, and training for farmers [6, 17, 18]. We will not go into detail on the compilation, estimation, improvement of mass registration, and manufacturing of biological control agents in this chapter. Cock *et al*. [6] discussed these factors for invertebrate biological control agents, whereas Parnell *et al*., Ravensberg and Kohl *et al*., [12, 18, 19] discussed similar characteristics for microbial biological control agents. It is not unusual to find dozens or even hundreds of species that target a single pest when searching for natural enemies, but unproductive species can frequently be quickly ruled out using criteria like host range, population growth rate, and crop and climate tolerance. The most promising species are next evaluated for their ability to control pests, possible effects on the environment, and the economic viability of large-scale production. Large collections of

CHAPTER 12

Biocontrol Potential of Mycotoxins

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Abstract: Fungi produce a diverse array of mycotoxins, which are secondary metabolites that exhibit varying degrees of toxicity to animal species. While many mycotoxins pose significant health risks to humans and animals, necessitating stringent global regulatory measures, others exhibit selective toxicity, making them promising candidates for biocontrol applications. Mycotoxins with narrow host ranges and minimal toxicity to humans and plants hold particular potential for use in ecologically sustainable pest management. In natural ecosystems, insects often encounter these fungal metabolites while feeding on infected plants, offering a natural avenue for their application in agriculture.

Insects not only inflict substantial economic losses by damaging crops but also act as vectors for plant viruses, exacerbating agricultural challenges. Harnessing the insecticidal properties of mycotoxins represents an innovative and environmentally friendly approach to pest control. These toxins disrupt insect physiology through specific molecular and biochemical mechanisms, which, when elucidated, could inform the development of advanced pest management strategies. For example, integrating mycotoxins into genetically engineered insect-resistant transgenic plants offers a novel solution to pest infestations with reduced reliance on chemical pesticides.

Advancing research into the modes of action and environmental interactions of mycotoxins as biocontrol agents holds the promise of sustainable, long-term pest management solutions. This approach not only addresses the pressing need for effective pest control but also aligns with global efforts to reduce the environmental impact of agricultural practices, safeguarding both crop yields and ecosystem health.

Keywords: Biological pest management, Enzymes, Insect pests, Pathogenesis, Toxins.

INTRODUCTION

Mycotoxins are a category of diverse substances generated by fungi as their secondary metabolites that may be harmful to both human and animal health.

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They can have a wide array of negative consequences, including cancer and immuno-suppression, as well as allergic reactions. Usually, they are not necessary for the development and reproduction of the generating organism. Several secondary metabolites produced by fungi, in turn, serve as virulence or pathogenicity factors in plants [1]. Fortunately, only a small fraction of over 300 known mycotoxins consistently contaminate food and animal feed, posing significant risks to human and animal health. Among the most studied mycotoxins are aflatoxins, ochratoxins, fumonisins, patulin, zearalenone, and trichothecenes (including deoxynivalenol and T2 toxin). The occurrence, detection, and toxic effects of these mycotoxins on humans, animals, and insects have been extensively researched.

Some of the mycotoxins are selectively toxic to insect pests, while they showed no toxicity in crop plants or domestic animals. The potential of these types of compounds can be exploited as biocontrol agents. Natural predators of insects and entomo-pathogenic fungi play a significant role in controlling insect populations [2]. The applications of entomopathogenic fungi as insecticides have gained popularity in response to the need to use fewer chemical insecticides. This interest is a result of the fact that these organisms naturally occur in the environment, they normally have a restricted host range, and there is a low possibility that the mycotoxins produced by them in insect hosts would contaminate foodstuffs [3, 4]. Beauvericin generated by *Beauveria bassiana*, cytochalasin C produced by *Metarhizium anisopliae*, and cyclosporin H produced by *Tolypocladium inflatum* are the only entomopathogenic fungal mycotoxins that are commercially available till date. There are reports on the insecticidal properties of several mycotoxins for which only meager information about their relationship with entomopathogenic fungi and the environment is available [5, 6]. Additionally, there are reports on the production of several mycotoxins by different species, as well as the production of the same mycotoxin by different species [7], making the situation more complicated. In order to manage populations of harmful insects, the present chapter provides up-to-date information on the potential of commercially available mycotoxins as bio-pesticides. It should be emphasized that numerous mycotoxins have previously been used as antibiotics, growth promoters, and other medications in clinical medicine [8]. The majority of mycotoxins are relatively stable [9, 10], which may be advantageous when employed in agricultural fields to control insect pests, but it may also increase the danger of excessive accumulation in the environment.

The mechanism of action of some mycotoxins has also been elucidated. They act on various metabolic, biochemical, and growth phases of insect pests, which leads to retardation of growth and death of the target pest. The exploration of novel mycotoxins can be an innovative strategy to develop a new range of biocontrol agents. The major objectives of the study are to evaluate the potential of commercially available mycotoxins as biopesticides and understand their mechanisms of action on insect pests, including their effects on metabolic, biochemical, and growth phases. Moreover, the focus is on the identification and characterization of novel mycotoxins with insecticidal properties, aiming to develop innovative biocontrol strategies for sustainable pest management.

INTEGRATED PEST MANAGEMENT USING MYCOTOXINS AS BIOCONTROL

In an effort to reduce the amount of reliance on agrochemicals for plant protection and increase productivity, the management of pests and diseases of cultivated plants using natural and biological methods has gained significant attention over the past few decades. The employment of predators, parasitoids, and microorganisms, including bacteria, fungi, and viruses, has been shown to be a fairly successful and long-lasting pest management strategy. Mycotoxins, produced by fungi, have been used for more than the last 150 years now, especially against insect pests. Some strains of fungal genera *Beauveria, Metarhizium, Isaria, Hirsutella,* and *Lecanicillium* are well known for mycotoxin production and are therefore effective in insect pest management too. The mycotoxins (cyclosporins B and D, cytochalasin E, gliotoxin, HC toxin, paxilline, penitrem A, stachybotrys chartarum, and verruculogen) significantly decrease Sf-9 Insect cell proliferation with minor effects on mammalian cells.

STEPS INVOLVED IN VIRULENCE

The virulence process involves four major steps in the degradation of insect pests by the fungal infection, which are as follows:

- Adhesion
- Germination
- Differentiation
- Penetration

The fundamental process involved in the development of mycosis starts with the attachment of the fungal spore to the vulnerable host's outer cuticle. Finding the host is a random occurrence, and then the passive spore attachment with the help of agencies like water or wind occurs. However, the specific mechanism behind the relationship between the cuticle and fungus spores is still to be determined in detail. The availability of nutrients, water, oxygen, pH, temperature, and harmful chemicals generated by the host on the surface all have a significant impact on the pathogen's germination, infestation, and development. In response to a variety of non-specific sources of nitrogen and carbon, fungi with a wide range of host

CHAPTER 13

Biocontrol Potential of *Alternaria* spp. Against Weeds, Pests, and Plant Pathogens: A Double-Edged Sword

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Abstract: In recent years, there has been a gradual shift in public perception about the indiscriminate use of pesticides. Therefore, there has been a search for safer plant protection interventions as a more eco-friendly alternative. The use of living agents or the formulation derived thereof is considered a safer option that is generally referred to as 'biocontrol'. *Alternaria* is a widespread and ubiquitous genus of fungi that is known to have varied roles in the ecosystem. Different isolates of *Alternaria* belonging to different species have been identified to have the properties of a good biocontrol candidate in three parallel paradigms by various researchers. Their anticipated roles, *viz*., a potential weed control agent, a pest control agent, and/or plant disease control agent, have been identified and are under further investigation. Since *Alternaria* is associated with some important plant diseases, human allergens, and toxins, we should be conscious of their harmful side also before considering them as potential biocontrol candidates. Therefore, the present chapter, besides describing them as an effective biocontrol candidate, also cautions about their other ecological impacts, which should be assessed in detail before their commercialization at a widespread level. So, authors are presenting *Alternaria* as a 'double-edged' sword in terms of their biocontrol potential.

Keywords: Antagonist, Biocontrol agent, Entomopathogen, Mycoparasitism, Pest management, Weed management.

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INTRODUCTION

Alternaria spp. is a ubiquitous fungal genus with a wide array of contrasting lifestyles, which include phytopathogenic, saprophytic, endophytic, entomopathogenic, and mycophagous nature. *Alternaria* has been associated with a wide variety of substrates, including seeds, plants, agricultural products, soil, and some living organisms like animals (both vertebrates and invertebrates), *etc*. Many species of the genus *Alternaria* are known as serious plant pathogens, causing major losses in a wide range of crops [1]. Several others are also important postharvest pathogens, leading to considerable post-harvest losses, particularly in fruits and vegetables [2, 3]. They are sometimes harmful to human health, also. They are a causative agent of phaeohyphomycosis in immuno-compromised patients [4] or a source of airborne allergens [5]. Because of the significant negative health effects of *Alternaria* spp. on humans, including the effects of their mycotoxins [6], they have bothered mycologists and plant pathologists worldwide. Besides this harmful dark side, they have a brighter side too. *Alternaria* is also considered one of the most common saprophytic fungal genera [7] that is ecologically beneficial.

Originally, the genus *Alternaria* was described to have characteristics like chains of darkly pigmented, multi-celled conidia (phaeodictyospores) with both transverse and longitudinal septa with tapering apical beaks [8]. To date, more than 250 species of *Alternaria* have been recorded [9], which are quite diverse in their morphology, lifestyles, and cultural characteristics. During the last decade, it was proposed to elevate eight well-supported, asexual *Alternaria* lineages to the taxonomic rank of 'section' for the ease of classifying the broad range of diversity within the genus [10]. However, it is still difficult to classify such diversity within a single fungal genus in terms of lifestyles, economic importance, and ecology. Some of the *Alternaria* strains have also been found to be beneficial for agriculture, besides their well-studied role as aggressive plant pathogens, reducing agricultural productivity. More than 4000 species of host plants are infected by the pathogenic strains [9]. In this regard, a previous review article published elsewhere [11] emphasized the role of *Alternaria* spp., earlier as a potential biocontrol candidate, especially against insect pests. *Alternaria* spp. has also been reported to have strong weed biocontrol capabilities in the last few decades, and its potential as a bio-control agent against some plant diseases has been shown recently. A need was felt to review the overall biocontrol capabilities of this fungal genus with diverse lifestyles. Therefore, the present chapter was structured to include the overall biocontrol potential of *Alternaria* spp. *viz*., weed management, insect pest management, and plant disease management for sustainable agriculture (Fig. **1**).

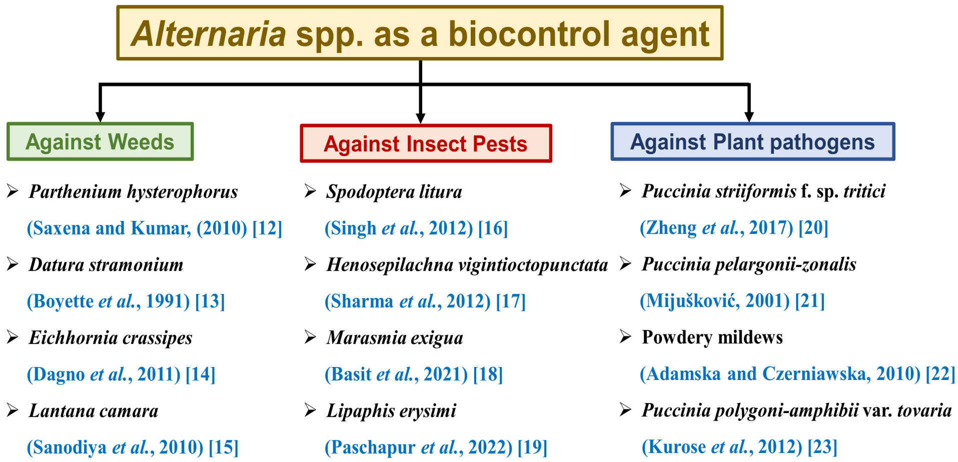

Fig. (1). A flowchart explaining the usefulness of *Alternaria* spp. as an effective biocontrol agent against weeds, insect pests, and plant pathogens.

Based on the literature available, *Alternaria* spp. seems to be a candidate of choice for the biocontrol of weeds, insect pests, and phytopathogens. However, whether there is any link between these three diverse biocontrol targets (weeds, pests, and pathogensor if any evolutional relationship exists needs to be thoroughly investigated. Moreover, the use of *Alternaria* spp. as a biocontrol agent (especially against weeds) needs a careful environmental impact assessment (especially host rage-related concerns) as they are, at the same time, also considered quite aggressive plant pathogens. After all, initially, it seems like handling a double-edged sword, which may harm its user if not used carefully.

IMPORTANT METABOLITES OF *ALTERNARIA* SPP.

The genus *Alternaria* is well known for the production of several bioactive constituents. Particularly, the endophytic strains of the fungi are known to possess some bio-active principles/metabolites, which may have some bioactive properties, like antimicrobial or anti-oxidant properties [24, 25]. Further, *Alternaria* spp. is known for the production of a wide array of mycotoxins (more than 70 types), which may play a vital role in plant pathogenesis [9]. They can either be of host-specific or non-host-specific nature. These toxins are now well recognized as the vital determinant of pathogenicity in plant hosts [26, 27]. Therefore, the evaluation of the host range of *Alternaria* spp. is essential before using them as a weed biocontrol agent. In this regard, a detached leaf assay may also serve the purpose [28] if a quick evaluation is not possible on a variety of suspected hosts *in vivo*. Further, some strains of *Alternaria* produce certain toxins that are also produced by some other plant pathogenic fungi. Brefeldin A and a,b-

CHAPTER 14

Seed Biopriming: An Eco-Friendly Method for Disease Management.

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Abstract: Plant diseases due to seed and soil-borne pathogens are major obstacles to sustainable crop production. Therefore, plant health is crucial to ensuring food security. The use of chemicals degrades plant health and has negative environmental effects. For the establishment of healthy and superior seedlings, especially in transplanted solanaceous vegetable crops, rapid and consistent seed emergence is crucial. Among the various techniques for controlling diseases that are transmitted through seeds and soil, seed biopriming is an environmentally benign, cost-effective, and simple seed treatment method. The practice of "biopriming" is treating seeds with advantageous microbial inoculants while maintaining regulated hydration levels to prevent radicle emergence. A major obstacle to sustainable agricultural production is plant diseases brought on by soil-borne and seed-borne pathogens. Seed biopriming entails soaking seeds in liquid suspensions of bioagents for a particular period of time, which initiates the physiological and developmental processes like DNA/RNA synthesis, protein accumulation, DNA repair, *etc*., within the seeds, thereby preventing radicle emergence before the seed is sown. Stronger membrane integrity, antipathogenic effects, lipid peroxidation counteraction, cellular and enzymatic repair systems, and metabolic elimination of harmful compounds from the primed seed are all benefits of seed biopriming. Thus, seed biopriming has given farmers a new biocontrol weapon for agricultural sustainability. Seed priming is a straightforward and affordable technique that gets seeds ready for impending pathogen-related difficulties.

Keywords: Consortium, Induced systemic resistance, Mycorrhiza, *Pseudomonas*, Seed biopriming, *Trichoderma*.

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INTRODUCTION

Losses due to plant diseases account for 16 percent in the world; among them, at least 10 percent of losses have been due to seed-borne diseases. In order to ensure food security, seed health is important. Seed health is deteriorated by the use of chemicals, which have detrimental effects on the environment. Rapid and uniform seed emergence is essential for healthy and high-quality seedling production, particularly in transplanted vegetable crops. Among different seed treatments, seed biopriming is a novel green method of seed treatment that is economical, easy, and environment friendly.

The concept of seed priming was proposed by Heydecker and his co-workers in 1973 [1]. Seed priming is known as the controlled hydration process. It is used for improving the seed performance by improving the rate and uniformity of germination and thus decreasing the sensitivity of seeds to external factors. Seed priming thus refers to an approach for seed treatment in which the amount of water absorption is controlled in order to initiate metabolic and physiological activities for seed germination, but radicle emergence is prohibited. Among the different pre-sowing techniques for disease management, biopriming has emerged as a novel, simple, economical, and eco-friendly delivery system of beneficial microorganisms in the agroecosystem [2]. Biopriming is a process that involves the treatment of seeds with beneficial microbial inoculants under controlled hydration conditions without the emergence of radicles. Seed biopriming as a concept was first tested by Callan and co-workers in 1990 [3].

Fungal bioagents, bacterial bioagents, endophytes, and botanicals have been employed and tested as efficient biopriming substrates for seed biopriming. These agents can be either used alone or in combination as a consortium if compatible with each other, which enhances their applicability and effectiveness in managing diseases [4, 5]. PGPRs, commonly known as Plant Growth Promoting Rhizobacteria, have a role to play in soil health as well as in plant growth. The term was coined by Kloepper in 1978 [6]. These are involved in nutrient uptake along with crop growth and development. Seed treatment with rhizospheric microbes reduces the impact of biotic and abiotic stresses [7].

Types of Seed Priming

The seed priming concept has been categorized into different methods like biopriming, which refers to an approach where priming or conditioning of seeds is carried out with suspensions of biocontrol agents, nanopriming, which refers to an approach where priming of seeds is carried out with nanoparticles, hormopriming, which refers to an approach where priming of seeds is carried out with hormones, nutripriming, which refers to an approach where priming of seeds is carried out with nutrients, and osmopriming, which refers to an approach where priming of seeds is carried out with osmotic solutions of PEG [8 - 10]. Various types of seed priming treatments are presented in Fig. (**1**).

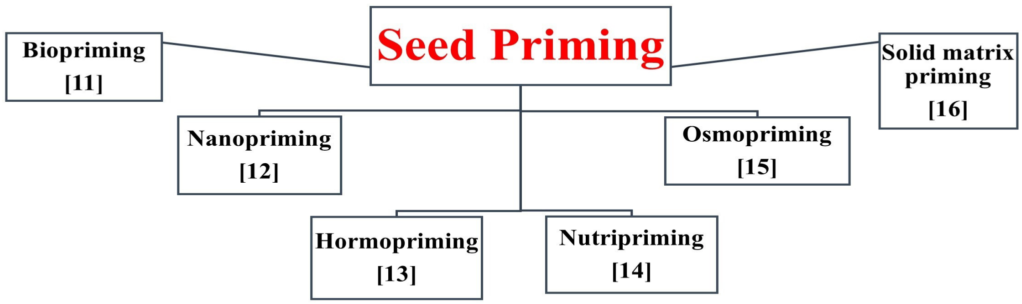

Fig. (1). Graphical representation of different types of seed priming applications.

Concept of Seed Biopriming

Among all these priming methods, biopriming is described as priming seeds with beneficial microorganisms where the physiological mechanism is integrated with the biological mechanism. In biopriming, seeds are firstly hydrated in a suspension of biological agents for a specified period of time in order to activate physiological processes inside the seeds like DNA and RNA synthesis and repair, protein synthesis, activation of enzymes, *etc*., but radicle protrusion is prevented.

The bioprimed seeds are then dried under shade or air dried to bring back their moisture content to the original. These bioprimed seeds perform better than no-primed seeds as they have the ability to induce systemic acquired resistance against soil-borne pathogens and also have better niche colonization than phytopathogens. Different crops like wheat, corn, capsicum, and pulses have shown promising impacts as a result of biopriming with bacterial strains [17, 18].

Due to the activated defense activity, including the production of antibiotics, HCN production, siderophores, *etc*., they attain the ability to reduce the effect of phytopathogens on plants. Several reports have been available mentioning the ability of biological agents like biocontrol agents, PGPRs (Plant Growth Promoting Rhizobacteria), plant extracts, endophytes, *etc*., in combating the diseases.

Seed biopriming is carried out with specified bioagents against the seed and soil-borne pathogens, which causes extensive losses and can be regarded as a substitute for the chemical method of disease management [19, 20]. There are three basic phases involved in seed hydration, which is the foremost step for seed

CHAPTER 15

Agrochemicals and Sustainable Agriculture: The Use of Bio-Agents

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Abstract: Agrochemicals play an essential role in modern agriculture by managing pests and diseases and enhancing crop productivity. However, their widespread and often indiscriminate use has led to significant environmental concerns, such as water pollution, soil degradation, and adverse impacts on unintended organisms. As the need for sustainable agriculture is being increasingly realized, stability between crop production and minimizing the environmental impact of agrochemicals by increasing the use of biocontrol agents is necessary. The current chapter seeks to explore various types of agrochemicals, their benefits, and the environmental risks associated with their usage. It also delves into the concept of sustainable agriculture, which aims to meet the current food demands while ensuring the well-being of ecosystems and the accessibility of comparable resources for future generations. The current agricultural practices and proposed alternative strategies to reduce the environmental footprint of agrochemicals are also discussed. The possible solutions include integrated pest management, precision agriculture, organic farming practices, and the adoption of environment-friendly biopesticides. The importance of the involvement of all the stakeholders, *i.e.*, farmers, policymakers, and consumers, as well as the importance of sustainable agriculture and responsible use of agrochemicals, is also emphasized. The present chapter also highlights the significance of inter-disciplinary collaboration among researchers, agronomists, ecologists, and policymakers to address the complex challenges the overuse of agrochemicals pose to our goals for sustainable agriculture. Therefore, the adoption of sustainable agricultural practices is essential to increase food production to minimize the negative impacts of agrochemicals on the environment, ensuring more secure and resilient agriculture.

Keywords: Agrochemicals, Biopesticides, Environmental impact, Sustainable agriculture.

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INTRODUCTION TO AGROCHEMICALS: THEIR ROLE IN FOOD SECURITY

Agrochemicals are materials applied to boost crop yield. This category includes a range of chemical compounds such as fungicides, fertilizers, hormones, and pesticides, all of which can be derived from both inorganic and natural sources. Over time, the production of agrochemicals through chemical synthesis for the purpose of protecting plants has grown, replacing natural products [1]. Agrochemicals are widely utilized in agriculture to close the gap between production and utilization, meeting the rising demand for food. Since the onset of the 'Green Revolution' in the 1930s, food production has seen a substantial rise. Fertilizers, especially nitrogen and phosphorus, play a crucial role by providing essential nutrients that enhance crop growth [2]. Just as they reduce the populations of pests, weeds, and diseases, the use of pesticides is justified by the fact that approximately 1/3rd of the world's future crop yield is lost to pre-harvest damage. This underscores the importance of pesticides in maintaining food security. Reports indicate that without the use of agrochemicals, pests and diseases will result in the loss of 54% of vegetable production, 78% of fruit production, and 32% of grain yield. Additionally, certain plant protection substances safeguard human health by controlling mosquito-borne infectious diseases like malaria, dengue fever, and Zika virus while also protecting plants from insect pests [3]. However, the excessive use of agrochemicals is negatively impacting both terrestrial and marine ecosystems. For species that occupy the highest levels of food chains, concerns have been raised about the effects of certain agrochemicals, *i.e.*, Organophosphates (OPs), Carbamate compounds, and Persistent Organic Pollutants (POPs), on conservation [4]. Just 1% of the agricultural chemicals applied to manage insect pests and weeds effectively make their intended targets. A significant quantity of pesticide is lost due to factors such as runoff, photo-degradation, and off-target sedimentation, among others. These processes can have detrimental effects on certain species, groups, or entire ecosystems, as well as on human populations [5]. Another important consideration is the potential for certain chemicals to cause long-term harm to organisms, leading to physiological effects that can shorten lifespans and result in genetic abnormalities. As Paracelsus stated in the 16th century, “The right dose differentiates a poison from a remedy”. It is important to note that the toxicity of a chemical is an inherent property and cannot be altered without changing the chemical structure itself. The impact of these harmful substances on people is also influenced by the level of exposure. Understanding the dosage-response relationship is essential for grasping the link between chemical exposure and illness, as it applies to all types of toxicity in individuals [6].

CATEGORIES OF AGROCHEMICALS

Agrochemicals are primarily classified into three categories: plant growth regulators, fertilizers, and plant protection compounds. Advances in technology have led to the development of nanoparticle fertilizers, which are derived from traditional fertilizers. Plant-protectant agrochemicals can be broadly categorized into insecticides, fungicides, bactericides, herbicides, and rodenticides. Further, they belong to different chemical families like triazines, carbamates, organochlorines, carbamates, phosphates, dithiocarbamates, *etc*. Neonicotinoids and pyrethrins are the latest additions to the field, marketed as relatively safer alternatives. Various types of agrochemicals based on their chemical structure are discussed in this chapter under the appropriate headings below.

Organophosphosphates

Since their development in 1937, organophosphates have been applied as insecticides and chemical warfare agents due to their phosphate component, which is a major part of their chemical structure. These compounds are, therefore, known as organophosphorus compounds (OP) [7]. They are derived from phosphoric acid and have a carbon-based structure. The presence of double-bonded sulfur or oxygen connections in their structure will influence their fundamental properties and characteristics. These can be classified into categories such as phosphates, phosphorothioates, phosphoramidites, and phosphonates. The unique metabolism and toxicity characteristics of these chemicals are attributed to their structural composition. Examples of pesticides in this category include Diazinon, Malathion, and Parathion [8]. Most OP compounds are readily absorbed by the dermis, conjunctiva, digestive system, and lungs. These substances are metabolized in the liver by cytochrome P450 isozymes, which can sometimes generate more toxic metabolites than the original compounds [9]. An example is the oxon derivative, which can engage with cholinesterase or break down to produce a dialkyl phosphate along with an organic component unique to the pesticide [10].

Carbamates

In contrast to organophosphate toxicity, carbamate insecticides generally have more reversible and less severe effects, typically leading to clinical signs and symptoms associated with cholinergic excess [7]. Carbamate poisoning involves the carbamylation of the active site of acetylcholinesterase, rendering this essential enzyme inactive within the nervous systems of animals, including humans [11]. The interaction of carbamates with acetylcholinesterase is similar to how organophosphates react with the same enzyme. Although inhibition is typically reversed within 30 minutes or less after exposure, the carbamylated

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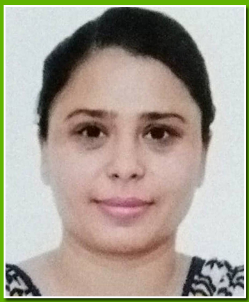

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