Biological Approaches for Sustainable Pest and Disease Management in Pulse Crops

Abstract

Pulse crops, including lentils, peas, chickpeas, and beans, play a crucial role in addressing global food security and nutritional needs. However, their production is often hampered by various pests and diseases, leading to significant yield losses. Conventional pest and disease management practices, heavily reliant on synthetic chemical pesticides, have raised concerns about environmental sustainability, human health, and the development of resistance in target organisms. In recent years, biological approaches have emerged as promising alternatives for sustainable pest and disease management in pulse crops. This review provides a comprehensive overview of various biological control strategies, including the use of beneficial microorganisms, plant extracts, and other eco-friendly methods. The review discusses the mode of action, efficacy, and potential applications of these approaches in combating major pests and diseases affecting pulse crops. Additionally, it highlights the challenges and future prospects of integrating biological control methods into integrated pest and disease management programs. By adopting these sustainable practices, pulse crop production can be enhanced while minimizing the environmental footprint and promoting long-term ecological balance. The review serves as a valuable resource for researchers, extension specialists, and stakeholders in the agricultural sector, emphasizing the importance of biological approaches in achieving sustainable and resilient pulse crop production systems.

Keywords: Pulse crops, Biological control, Pest management, Disease management, Sustainable agriculture, Integrated pest management.

1. Introduction

Pulse crops, comprising various leguminous species such as lentils, peas, chickpeas, and beans, are vital components of sustainable agricultural systems and play a crucial role in addressing global food security challenges. These crops are rich sources of protein, fiber, and essential micronutrients, making them indispensable in addressing malnutrition and promoting healthy diets [1]. Additionally, pulse crops contribute to soil fertility through their ability to fix atmospheric nitrogen, reducing the reliance on synthetic fertilizers and promoting sustainable agricultural practices [2].

However, the cultivation of pulse crops is often challenged by various pests and diseases, which can significantly reduce yield and quality. Historically, the primary approach to managing these threats has been the extensive use of synthetic chemical pesticides [3]. While these products have been effective in controlling pests and diseases, their overreliance has led to several adverse consequences, including environmental pollution, toxicity to non-target organisms, and the development of resistance in target pests and pathogens [4].

In recent years, there has been a growing emphasis on developing and implementing sustainable and eco-friendly approaches to pest and disease management in pulse crop production. Biological control strategies, which involve the use of living organisms or their products to suppress pest and disease populations, have emerged as promising alternatives to conventional chemical-based methods [5]. These approaches not only minimize the environmental impact but also promote long-term ecological balance and resilience in agricultural ecosystems.

2. Biological Control Agents for Pest Management in Pulse Crops

Biological control agents encompass a diverse range of organisms, including predators, parasitoids, entomopathogens, and antagonistic microorganisms, that can effectively suppress pest populations in pulse crops. These agents act through various mechanisms, such as direct predation, parasitism, or the production of metabolites that inhibit or kill the target pests.

2.1. Predators and Parasitoids

Predators and parasitoids are natural enemies that play a crucial role in regulating pest populations in agricultural ecosystems. Several predatory insects, such as ladybird beetles (Coccinellidae), lacewings (Chrysopidae), and predatory mites (Phytoseiidae), have been effectively employed for the biological control of aphids, thrips, and spider mites, which are common pests in pulse crop fields [6], [7].

Parasitoids, which are insects that lay their eggs within or on the body of a host insect, have also been widely used in biological control programs for pulse crops. Prominent examples include various species of parasitic wasps (e.g., Trichogramma spp., Braconidae, and Ichneumonidae) that target lepidopteran pests, such as pod borers and armyworms [8], [9].

2.2. Entomopathogens

Entomopathogens, which include bacteria, fungi, viruses, and nematodes, are natural pathogens that can infect and kill insect pests. Several entomopathogenic bacteria and fungi have been extensively studied and commercialized for pest management in pulse crops.

Bacillus thuringiensis (Bt), a soil-dwelling bacterium, is widely used for the control of lepidopteran pests, such as pod borers and armyworms, in pulse crops [10]. Bt produces insecticidal proteins (Cry toxins) that specifically target and kill these pests while being relatively safe for non-target organisms.

Entomopathogenic fungi, such as Beauveria bassiana, Metarhizium anisopliae, and Isaria fumosorosea, have shown promising results in controlling various pests, including aphids, thrips, and beetles, in pulse crop fields [11], [12]. These fungi infect and kill the host insects through a combination of mechanical penetration and the production of toxic metabolites.

2.3. Antagonistic Microorganisms

Antagonistic microorganisms, including bacteria and fungi, have the ability to suppress pest populations through various mechanisms, such as antibiosis, competition, and induced systemic resistance in plants. Several bacterial and fungal species have been investigated for their potential in biological control of pests in pulse crops.

Plant growth-promoting rhizobacteria (PGPR), such as Bacillus spp., Pseudomonas spp., and Trichoderma spp., have been shown to enhance plant growth and induce systemic resistance against pests and diseases in pulse crops [13], [14]. These beneficial microorganisms can be applied as seed treatments, soil amendments, or foliar sprays to promote plant health and suppress pest populations.

3. Biological Control Agents for Disease Management in Pulse Crops

Pulse crops are susceptible to various fungal, bacterial, and viral diseases, which can significantly impact yield and quality. Biological control agents offer sustainable and eco-friendly alternatives to synthetic fungicides and bactericides for managing these diseases.

3.1. Antagonistic Microorganisms

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Antagonistic microorganisms, such as bacteria and fungi, have been extensively studied for their potential in suppressing plant diseases in pulse crops through various mechanisms, including antibiosis, competition, and induction of systemic resistance.

Pseudomonas spp., Bacillus spp., and Trichoderma spp. have been found to be effective against various fungal diseases, such as Fusarium wilt, Ascochyta blight, and Botrytis gray mold, in pulse crops [15], [16]. These beneficial microorganisms can be applied as seed treatments, soil amendments, or foliar sprays to protect plants from pathogen attack and promote plant growth and development.

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3.2. Plant Extracts and Biofumigants

Plant extracts and biofumigants derived from plant materials have gained increasing attention for their potential in managing diseases in pulse crops. These natural compounds can exhibit antifungal, antibacterial, and antiviral properties, making them effective alternatives to synthetic fungicides and bactericides.

Essential oils extracted from various plants, such as thyme, clove, and cinnamon, have shown promising results in controlling fungal diseases like Ascochyta blight, Botrytis gray mold, and Fusarium wilt in pulse crops [17], [18]. These essential oils can be applied as foliar sprays or incorporated into soil amendments to suppress pathogen growth and disease development.

Biofumigants, such as mustard, radish, and buckwheat, contain glucosinolates that release volatile compounds with antimicrobial properties when incorporated into the soil [19]. These biofumigants can effectively suppress soil-borne pathogens, including fungi, bacteria, and nematodes, in pulse crop production systems.

4. Integrated Pest and Disease Management (IPDM) Strategies

While biological control agents offer promising alternatives to synthetic chemical pesticides and fungicides, their efficacy can be enhanced when integrated with other sustainable management practices within an Integrated Pest and Disease Management (IPDM) framework.

4.1. Cultural Practices

Cultural practices, such as crop rotation, intercropping, and the use of resistant or tolerant cultivars, can complement biological control strategies by reducing pest and disease pressure and promoting the establishment and efficacy of beneficial organisms.

Crop rotation with non-host plants can disrupt the life cycles of pests and pathogens, reducing their populations and minimizing carry-over effects to subsequent crops [20]. Intercropping pulse crops with other compatible crops can increase biodiversity, provide physical barriers, and enhance the abundance and diversity of natural enemies [21].

The use of resistant or tolerant cultivars can reduce the susceptibility of pulse crops to pests and diseases, minimizing the need for extensive control measures and promoting the conservation of beneficial organisms [22].

4.2. Habitat Management

Habitat management practices, such as the establishment of insectary strips, hedgerows, and conservation of natural enemy refuges, can enhance the abundance and diversity of natural enemies, including predators, parasitoids, and entomopathogens [23].

Insectary strips, consisting of flowering plants, provide food resources (e.g., nectar and pollen) and shelter for natural enemies, promoting their population growth and persistence in agricultural landscapes [24]. Hedgerows and other semi-natural habitats can serve as overwintering sites and refuges for beneficial organisms, ensuring their presence throughout the growing season [25].

4.3. Monitoring and Decision Support Systems

Effective implementation of IPDM strategies requires robust monitoring and decision support systems to accurately assess pest and disease levels, predict potential outbreaks, and make informed decisions regarding control measures.

Pheromone traps, sticky traps, and field scouting can be employed to monitor pest populations and determine the need for control interventions [26]. Similarly, disease forecasting models, based on environmental conditions and pathogen life cycles, can aid in predicting disease development and guide timely application of control measures [27].

Decision support systems that integrate pest and disease monitoring data, weather information, and crop growth models can provide valuable insights for optimizing the timing and application of biological control agents and other management practices [28].

5. Challenges and Future Prospects

While biological approaches offer promising solutions for sustainable pest and disease management in pulse crops, several challenges need to be addressed to facilitate their widespread adoption and integration into IPDM programs.

5.1. Challenges

- **Consistency and Efficacy:** Ensuring consistent and reliable performance of biological control agents under diverse environmental conditions and crop production systems remains a challenge [29]. Factors such as temperature, humidity, and application methods can influence the efficacy of these agents, requiring further research and optimization.

- **Mass Production and Formulation:** The mass production and formulation of biological control agents, such as entomopathogens and antagonistic microorganisms, can be complex and costly [30]. Developing cost-effective and scalable production methods is crucial for the commercial viability and widespread adoption of these agents.

- **Regulatory Considerations:** The registration and approval processes for biological control agents can be stringent and time-consuming, hindering their commercialization and availability to growers [31]. Streamlining regulatory frameworks while ensuring safety and efficacy is essential for promoting the use of these agents.

- **Integration and Compatibility:** Integrating biological control agents with other management practices, such as cultural controls and judicious use of low-risk pesticides, requires careful consideration to avoid potential incompatibilities and ensure synergistic effects [32].

- **Knowledge Transfer and Adoption:** Effective knowledge transfer and training programs are necessary to educate growers, extension personnel, and other stakeholders about the proper implementation and benefits of biological control strategies [33]. Addressing knowledge gaps and promoting adoption through participatory approaches can facilitate the widespread implementation of these sustainable practices.

5.2. Future Prospects

Despite the challenges, the future prospects for biological approaches in pest and disease management in pulse crops are promising, driven by ongoing research, technological advancements, and increasing demand for sustainable agricultural practices.

- **Genomics and Biotechnology:** Advances in genomics and biotechnology can lead to the development of more efficient and target-specific biological control agents, such as genetically engineered entomopathogens or antagonistic microorganisms with enhanced virulence or host specificity [34].

- **Microbiome Engineering:** Manipulating the plant microbiome, including the recruitment and enhancement of beneficial microorganisms, can boost plant defense mechanisms and promote resistance against pests and diseases [35]. This area holds significant potential for developing novel biological control strategies.

- **Precision Agriculture and Decision Support Systems:** The integration of biological control strategies with precision agriculture technologies, such as remote sensing, drones, and advanced decision support systems, can improve monitoring, application, and overall management of pests and diseases in pulse crop production [36].

- **Circular Bioeconomy:** The development of sustainable and circular bioeconomy approaches, where biological control agents are produced from renewable resources and integrated into closed-loop systems, can contribute to the long-term sustainability and resilience of pulse crop production systems [37].

- **Multidisciplinary Collaborations:** Fostering multidisciplinary collaborations among researchers, extension specialists, growers, and industry partners will be crucial for accelerating the development, commercialization, and adoption of biological control solutions tailored to the specific needs and challenges of pulse crop production systems [38].

6. Conclusion

The adoption of biological approaches for sustainable pest and disease management in pulse crops is a critical step towards achieving resilient and environmentally friendly agricultural systems. This review has highlighted the diverse range of biological control agents, including predators, parasitoids, entomopathogens, antagonistic microorganisms, and plant extracts, that can effectively suppress pest and disease populations in pulse crops.

By integrating these biological control strategies with cultural practices, habitat management, and robust monitoring and decision support systems within an IPDM framework, growers can minimize the reliance on synthetic chemical pesticides and fungicides, promoting environmental sustainability and long-term ecological balance.

While challenges related to consistency, mass production, regulatory considerations, and knowledge transfer exist, ongoing research and technological advancements hold promise for addressing these challenges and unlocking the full potential of biological control approaches.

Multidisciplinary collaborations, coupled with the development of innovative technologies such as genomics, microbiome engineering, precision agriculture, and circular bioeconomy approaches, will be instrumental in driving the widespread adoption and success of biological control strategies for sustainable pulse crop production.

By embracing these eco-friendly and sustainable practices, the agricultural sector can contribute to global food security, environmental protection, and the long-term resilience of pulse crop production systems, ensuring a more sustainable future for generations to come.

Tables

Table 1: Examples of Predators and Parasitoids Used for Biological Control of Pests in Pulse Crops

Organism	Target Pest	Crop
Coccinella septempunctata (Ladybird beetle)	Aphids	Lentils, Peas, Chickpeas
Chrysoperla carnea (Green lacewing)	Thrips, Aphids	Lentils, Peas, Beans
Phytoseiulus persimilis (Predatory mite)	Spider mites	Lentils, Peas, Chickpeas
Trichogramma spp. (Parasitic wasp)	Lepidopteran pests (pod borers, armyworms)	Lentils, Peas, Chickpeas, Beans
Cotesia spp. (Parasitic wasp)	Lepidopteran pests (pod borers, armyworms)	Lentils, Peas, Chickpeas, Beans
Diadegma spp. (Parasitic wasp)	Lepidopteran pests (pod borers, armyworms)	Lentils, Peas, Chickpeas, Beans

Table 2: Examples of Entomopathogens Used for Biological Control of Pests in Pulse Crops

Organism	Type	Target Pest	Crop
Bacillus thuringiensis	Bacterium	Lepidopteran pests (pod borers, armyworms)	Lentils, Peas, Chickpeas, Beans
Beauveria bassiana	Fungus	Aphids, Thrips, Beetles	Lentils, Peas, Chickpeas, Beans
Metarhizium anisopliae	Fungus	Aphids, Thrips, Beetles	Lentils, Peas, Chickpeas, Beans

Organism	Type	Target Pest	Crop
Isaria fumosorosea	Fungus	Whiteflies, Thrips	Lentils, Peas, Chickpeas, Beans
Spodoptera litura Nucleopolyhedrovirus (SpliNPV)	Virus	Armyworms	Lentils, Peas, Chickpeas, Beans
Steinernema spp.	Nematode	Soil-dwelling insect pests	Lentils, Peas, Chickpeas, Beans

Table 3: Examples of Antagonistic Microorganisms Used for Biological Control of Diseases in Pulse Crops

Organism	Mode of Action	Target Disease	Crop
Bacillus subtilis	Antibiosis, Induced Systemic Resistance	Fusarium wilt, Ascochyta blight	Lentils, Chickpeas
Pseudomonas fluorescens	Antibiosis, Competition	Rhizoctonia root rot, Ascochyta blight	Peas, Lentils
Trichoderma harzianum	Mycoparasitism, Competition	Fusarium wilt, Botrytis gray mold	Chickpeas, Lentils
Streptomyces spp.	Antibiosis	Fusarium wilt, Ascochyta blight	Lentils, Chickpeas
Ampelomyces quisqualis	Mycoparasitism	Powdery mildew	Peas, Lentils
Coniothyrium minitans	Mycoparasitism, Antibiosis	Sclerotinia stem rot	Chickpeas, Lentils

Table 4: Examples of Plant Extracts and Biofumigants Used for Disease Management in Pulse Crops

Plant Extract/Biofumigant	Active Compound(s)	Target Disease	Crop
Thyme essential oil	Thymol, Carvacrol	Ascochyta blight, Botrytis gray mold	Lentils, Chickpeas
Clove essential oil	Eugenol	Fusarium wilt, Rhizoctonia root rot	Chickpeas, Lentils
Mustard meal	Glucosinolates	Soil-borne fungal and bacterial diseases	Lentils, Peas, Chickpeas

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Plant Extract/Biofumigant	Active Compound(s)	Target Disease	Crop
Radish meal	Glucosinolates	Soil-borne fungal and bacterial diseases	Lentils, Peas, Chickpeas
Buckwheat meal	Fagopyrin	Soil-borne fungal and bacterial diseases	Lentils, Peas, Chickpeas

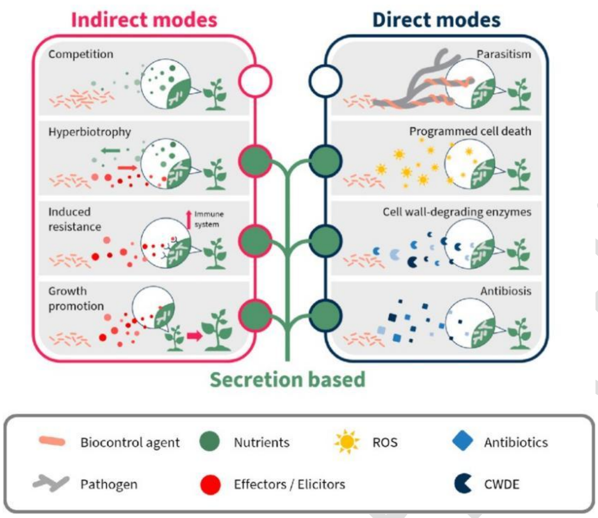

Figure 1: Modes of Action of Biological Control Agents

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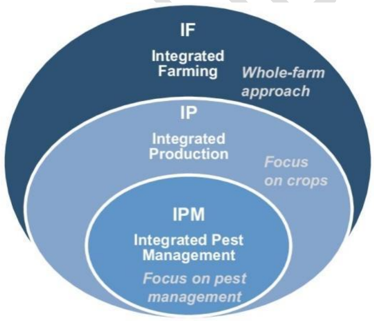

Figure 2: Integrated Pest and Disease Management (IPDM) Framework

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