Review Article

A Review on Effects of Entomopathogenic Microbes on Insect Pests and Diseases Management

Abstract

This comprehensive review presents an in-depth analysis of the role of entomopathogenic microbes in insect pests and disease management. The study covers the taxonomy and classification of these organisms, including bacteria, fungi, viruses, and nematodes, all of which have shown efficacy in controlling various insect pests. Entomopathogenic microbes represent a valuable, sustainable, and eco-friendly alternative to synthetic pesticides, highlighting their significant role in Integrated Pest Management (IPM) strategies. The review reveals that entomopathogenic microbes affect pests at different developmental stages through various mechanisms, including disease induction, parasitism, and competition for resources. The effects are not just lethal but also ~~sub lethal~~ sub-lethal, affecting pest reproductive capacity, growth, and development. The microbes secondary metabolites often have antimicrobial properties, contributing to plant disease management by suppressing plant pathogens. Despite their promising potential, challenges exist in the widespread application of these microbes. Factors such as formulation, delivery, and environmental conditions can influence their effectiveness. The paper also discusses the importance of genomics, proteomics, and metabolomics in understanding the complex interactions between microbes, insects, and plants, which could lead to the development of more targeted and efficient bio-control agents. The review outlines future directions for this field, emphasizing the necessity for more extensive research to enhance our understanding of entomopathogenic microbes, optimize their use, overcome the current challenges, and harness their potential for sustainable pest and disease management. The need for regulatory frameworks to ensure safe and effective utilization is also underscored. This paper underscores the untapped potential of entomopathogenic microbes as a ~~key~~ critical component of sustainable agriculture.

Keywords: Bio-control, Entomopathogenic microbes, Integrated Pest Management, Microbial Metabolomics, Sustainability

Introduction

Entomopathogenic microbes (EM), derived from the Greek words "entomon" (insect), "pathos" (disease), and "genes" (born of, produced by), represent a group of microorganisms (including fungi, bacteria, viruses, and nematodes) that cause disease in insects and other arthropods [1]. These microorganisms have a longstanding relationship with their host insects, in which the host acts as a vector and ~~an incubator for them~~ the incubator. The microbes can be deadly to the host, impacting their growth, development, reproduction, and survival, thus making them of considerable interest in pest management [2]. Agricultural pests encompass a wide variety of organisms including insects, mites, nematodes, weeds, fungi, bacteria, viruses, and other microorganisms. These pests pose a significant threat to crop production, impacting both the quantity and quality of agricultural yields. Pests are omnipresent and have adapted to different climates and environments, thereby leading to a persistent threat to global food security [3]. They are responsible for pre-harvest losses by directly damaging ~~the~~ crop plants and post-harvest losses by attacking stored grains and processed foods [4]. The management of these pests is not just a matter of economic concern but also one of ecological significance. Pest management, from an economic perspective, is crucial as it influences the profitability of farming operations. Pests cause an estimated crop yield loss of 20-40% globally, which translates to an annual financial loss of about $470 billion [5]. From an ecological perspective, pest management plays a significant role in maintaining the balance of the ecosystem. An unchecked pest population can disrupt this balance, leading to a cascade of changes affecting other organisms in the ecosystem [6]. Current pest management practices rely heavily on the use of synthetic chemical pesticides. These chemicals, designed to kill or deter pests, have helped reduce crop losses significantly since their widespread adoption in the 20th century. They come with a host of problems. Insects develop resistance to these chemicals over time, leading to a decrease in their efficacy [7]. The use of synthetic pesticides has been linked to environmental pollution and human health issues. The runoff from treated fields can contaminate water bodies, affecting aquatic life, and residues on treated crops can have direct and indirect impacts on human health [8]. Given these issues, it is clear that the agriculture industry is in dire need of alternative pest management methods that are not only effective but also sustainable and ecologically friendly. This is where entomopathogenic microbes show promise. These naturally occurring organisms offer an environmentally friendly alternative to chemical pesticides, providing new opportunities to manage pests effectively without the associated drawbacks of synthetic chemicals [9]. These microbes have shown potential for use in integrated pest management (IPM) strategies, offering a holistic and sustainable approach to pest control [10].

Role of Pests in Agriculture

Agricultural pests are organisms that pose significant threats to agricultural productivity and sustainability. The term "pest" is often used to describe any organism that harms crop plants, including fungi, bacteria, viruses, and nematodes (Table 1). Each of these organisms contributes uniquely to the complex web of biotic factors that can cause severe losses in the agricultural industry. Fungi are among the most devastating pests of crops, causing diseases that can lead to significant yield losses. A notable example is the fungus *Fusarium graminearum*, the causative agent of Fusarium head blight, a devastating disease of wheat and barley [11]. Oomycetes, although similar to fungi in appearance and ecological function, belong to a different kingdom and include infamous pathogens like *Phytophthora infestans*, the cause of the Irish potato famine in the 19th century [12]. Bacterial pathogens are also a significant concern, causing diseases like bacterial wilt in tomatoes (caused by *Ralstonia solanacearum*), fire blight in apples and pears (caused by *Erwinia amylovora*), and black rot in cruciferous vegetables (caused by *Xanthomonas campestris* pv. *campestris*) [13]. Viruses can also cause significant losses in agriculture, especially in high-value crops such as tomatoes, where viruses like Tomato spotted wilt virus and Tomato yellow leaf curl virus can result in severe yield reductions [14]. Nematodes, microscopic worm-like organisms, cause significant damage to a variety of crops, especially root crops. The root-knot nematode (*Meloidogyne* spp.) is one of the most widespread and damaging nematode pests, causing severe losses in many crops worldwide [15]. Arthropods, mainly insects and mites, can cause direct damage by feeding on plant tissues or act as vectors for disease-causing pathogens. Pests such as aphids, whiteflies, and thrips are notorious for their dual role as direct pests and disease vectors [16]. Molluscs, specifically slugs, and snails, can also be destructive pests, particularly in humid, high-rainfall regions. They can cause significant damage to a wide range of crops, from cereals to leafy vegetables [17]. The impact of these pests on crop yield and quality is vast. Direct damage can result in yield reductions, while indirect damage (like vectoring plant diseases or reducing plant vigour) can affect crop quality and quantity [18]. The pests do not only affect the yield but also the aesthetic value of the crops, which plays a significant role in the market price of the produce. This is especially true for fresh produce, where minor cosmetic damage can drastically reduce the market value of the crop [19]. The economic cost associated with pest-induced losses is substantial. As previously mentioned, pests are estimated to cause a 20-40% loss in global crop yield, equating to an annual financial loss of about $470 billion [20]. But the economic impact extends beyond just yield losses. Costs associated with pest management, including the purchase and application of pesticides; also add to the economic burden of pests. The indirect costs associated with pesticide use, such as environmental cleanup and health issues, can inflate the economic impact of pests [21].

Table 1: Entomopathogenic microorganisms in crops and their host as potential target for pest management. **Source:** Dara [22].

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Entomopathogenic Group	**Entomopathogen Species**	**Target Pest as Host**
Bacteria	*Paenibacillus popilliae*	Japanese beetle, Popillia japonica
	Bacillus sphaericus	Diptera
	Bacillus papillae	Coleoptera
	Bacillus thuringenesis kurstaki	Lepidoptera

	Bacillus thuringenesis israelenis	Diptera
	Bacillus thuringenesis tenebrionsis	Coleoptera
	Bacillus thuringenesis aizawai	Lepidoptera
Viruses	*Nucleopolyhedr ovirus* (NPV)	Lepidoptera, Hymenoptera
	Hyposidra talaca npv	
	Helicoverpa zea NPV	
	Spodoptera exigua NPV	
	Granulovirus (GV)	Lepidoptera
	Cydia pomonella Granulovirus (CpGV)	
Fungi	*Poecilomyces lilacinus*	Plant–parasitic nematodes
	Verticillium lecanii	One or more pests of Coleoptera, Hymenoptera, Acarina, Hemiptera, Lepidoptera, Orthoptera, Thysanoptera, etc
	Lecanicillium longiosporun	
	Lecanicillium lecanii	
	Metarhizium brunneum	
	Metarhizium anisopliae	
	Entomophthora muscae	
	Hirsutella thompsonii	
	Beauveria bassiana	

	Nomuraea rileyi	
	Isaria fumosorosea	
	Neozygites fresenii	
Nematodes	*Heterorhabditis heliothidis*	Several orders of soil-~~-~~borne pests
	Heterorhabditis bacteriophora	
	Steinernema feltiae	
	Steinernema carpocapsae	

Current Pest Management Practices

Current pest management practices ~~largely~~ primarily revolve around the use of chemical insecticides. Insecticides are compounds used to kill or inhibit the life activities of insects, and their efficacy in controlling pests has long been recognized. Since the discovery of the insecticidal properties of DDT in the 1940s, insecticides have become the mainstay of pest management in agriculture [23]. Different classes of insecticides, such as organochlorines, organophosphates, carbamates, and synthetic pyrethroids, have been developed and used extensively over the years. These insecticides target various aspects of insect physiology, such as the nervous system, growth, and development, or metabolism [24]. For example, the organophosphate insecticide chlorpyrifos inhibits the action of acetylcholinesterase, a key enzyme in the nervous system of insects, leading to paralysis and death of the insect [25]. The effectiveness of insecticides in controlling pests and increasing crop yields has been demonstrated in numerous studies. For instance, a meta-analysis by Sharma [26] showed that insecticide use increased crop yields by an average of 47%. The intensive use of insecticides has led to a multitude of problems. Chief among these is the evolution of insecticide resistance in pests. Continuous exposure to insecticides imposes strong selection pressure on pest populations, favoring individuals that possess resistance traits. This can lead to the rapid proliferation of resistant pest populations, rendering insecticides ineffective. Today, resistance to one or more classes of insecticides has been documented in hundreds of pest species [27]. ~~In fact, the~~The evolution of insecticide resistance is so rapid that it is often cited as one of the most compelling examples of microevolution in action [28]. Environmental concerns associated with insecticide use are another major issue. Insecticides can have a significant impact on non-target organisms, from beneficial insects such as pollinators and natural enemies of pests~~,~~ to aquatic organisms and birds [29]. Insecticides can persist in the environment and contaminate soil and water, posing long-term ecological risks [30]. Human safety is also a significant concern with insecticide use. Many insecticides are toxic to humans and can cause a range of health problems, from acute poisoning to chronic diseases such as cancer and neurodegenerative disorders [31]. The exposure of agricultural workers and communities living near agricultural areas to insecticides is a major public health concern, especially in developing countries where regulations on pesticide use are often lax [32]. Given these problems, there is a pressing need for more sustainable, efficient, and safe pest management solutions. These solutions should ~~aim to~~ reduce reliance on insecticides, mitigate pest resistance, minimize environmental impact, and ensure human safety. Integrated pest management (IPM), which combines various pest management strategies such as biological control, host plant resistance, and cultural practices, is one such approach that is gaining traction in recent years [33].

Entomopathogenic Microbes as a Solution

Entomopathogenic microbes (EM) offer a promising solution to the problems associated with intensive insecticide use. EM are microorganisms, including fungi, viruses, protozoa, and bacteria, that cause disease in insects and can lead to their death. They are a diverse group, with each type having its unique mode of action and host range. Entomopathogenic fungi (EPF) are perhaps the most well-studied group of EM. These fungi infect insects by penetrating their cuticle, proliferating inside the insect body, and eventually causing death. Some of the most commonly used EPF in pest management are species of the genera Beauveria and Metarhizium. These fungi have a broad host range and can infect a variety of pests, including aphids, whiteflies, and beetles [34]. Entomopathogenic viruses, also known as insect viruses, are another type of EM. These viruses are highly specific to their insect hosts and usually cause systemic infections that result in death. Baculoviruses are a well-known group of entomopathogenic viruses that have been used as biopesticides in pest management [35]. Entomopathogenic protozoa are less common but still important EM. These microorganisms can infect and kill insects through various mechanisms. Some protozoa, such as species of the genus Nosema, infect the gut cells of insects and disrupt their feeding and reproduction, leading to population decline [36]. Entomopathogenic bacteria, on the other hand, typically kill insects by producing toxins. A classic example is *Bacillus thuringiensis* (Bt), a bacterium that produces a toxin lethal to many insects but harmless to non-target organisms. Bt has been widely used in pest management and has even been engineered into crops to provide built-in pest resistance [37]. The natural occurrence of EM in the environment plays a crucial role in controlling insect populations. EM are part of the natural enemies of insects and contribute to their mortality in the wild. This natural control is often underestimated but can be significant. Entomopathogens as microorganisms that control the population of insect pests to levels that cause no economic harm to crop plants. This definition emphasizes the role of EM in integrated pest management and their potential to replace or supplement chemical insecticides. EM ~~have~~ has several advantages over traditional insecticides. First, they are usually specific to their insect hosts and have little or no impact on non-target organisms, thus minimizing environmental impact. Second, they do not leave toxic residues, ensuring food safety and environmental quality. Third, they are less likely to cause pest resistance due to their complex modes of action. Fourth, they are sustainable, as they can reproduce and persist in the environment, providing long-term pest control. Lastly, they are compatible with other pest management strategies, facilitating integrated pest management [38].

Biological control Agents

The use of entomopathogenic microbes as Biological Control Agents (BCAs) has gained traction as a sustainable and ecologically friendly approach to pest management in agriculture. Among the most frequently employed BCAs are entomopathogenic microbes, such as fungi, bacteria, viruses, and protozoa, that infect, weaken, and eventually lead to the death of host pests [39]. BCAs, particularly entomopathogenic microbes, provide several advantages over traditional chemical pesticides. Firstly, they exhibit host specificity, meaning they target specific pests without affecting non-target organisms. This specificity is beneficial for maintaining biodiversity in agricultural ecosystems, as beneficial insects and other non-target organisms remain unharmed [40]. For instance, the bacterium *Bacillus thuringiensis* targets specific pests like caterpillars, beetles, and flies, thereby reducing the potential damage to beneficial insects [41]. Secondly, BCAs generally do not have phytotoxic effects, meaning they do not cause harm to the plants themselves. This is a significant advantage over some chemical pesticides, which can cause phytotoxicity resulting in reduced crop growth or yield [42]. This feature is especially pertinent in organic farming systems, where maintaining plant health and avoiding chemical residues are of utmost importance [43]. BCAs are safe for human health. Unlike many synthetic insecticides, entomopathogenic microbes do not produce harmful residues that can contaminate crops or enter the food chain [44]. Thus, their use is consistent with the objectives of food safety and public health. The workers who apply these BCAs are not exposed to the same level of risk as those who handle synthetic pesticides [45]. The use of BCAs aligns with sustainable pest management goals. Since BCAs are naturally occurring, their use is less likely to result in the development of pest resistance, a significant issue with the use of synthetic pesticides [46]. In addition, BCAs can be self-perpetuating in the environment, offering long-term pest control solutions [47]. ~~There have been many successful case studies demonstrating~~ Many successful case studies have demonstrated the use of BCAs in pest control. A classic example is the use of Bacillus thuringiensis (Bt) in controlling pests in various crops. Bt has been applied worldwide to manage pests such as the European corn borer and cotton bollworm, significantly reducing crop losses [48]. Another success story is the use of entomopathogenic nematodes (EPNs) in the management of the vine weevil, a significant pest of ornamental plants and strawberries in Europe. EPNs have proven to be an effective and environmentally friendly alternative to synthetic pesticides, causing significant mortality in vine weevil larvae [49]. Similarly, *Metarhizium anisopliae*, an entomopathogenic fungus, has been successfully used against the tick *Rhipicephalus microplus*, a ~~major~~ significant pest of cattle. Field trials in Brazil showed that

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the fungus effectively reduced tick populations, offering a promising biological control method for this problematic pest [50].

Challenges and Future Research Directions

Although entomopathogenic microbes have demonstrated considerable potential as biological control agents (BCAs), there remain several challenges that must be overcome for their effective and widespread application. The primary challenges can be broadly categorized into four areas: bioassay procedures, production, formulation, and application strategies. Bioassay procedures are crucial for assessing the efficacy of entomopathogenic microbes against targeted pests. Existing protocols can be complex, labor-intensive, and often lack standardization, making comparative evaluations difficult [51]. The results obtained in laboratory conditions may not always predict the performance of BCAs under field conditions due to variations in environmental factors such as temperature, humidity, and interactions with other biotic and abiotic factors [52]. As such, refining and standardizing bioassay protocols to ensure reliable and reproducible results is a critical challenge. Production of entomopathogenic microbes on a large scale also presents difficulties. Challenges include the need to maintain the virulence of the microorganisms during mass production and storage, and the necessity to develop cost-effective production techniques. The latter is particularly crucial as the cost is a significant factor in the adoption of any new technology by farmers [53]. Maintaining the viability of these microbes from production through to application in the field is essential to ensure they exert the desired effect on targeted pests [54]. ~~Formulation~~ The formulation plays a key role in the effectiveness of entomopathogenic microbes. It aids in the protection, storage, and application of these microorganisms. Developing effective formulations is challenging due to the specific requirements of different microbes. For instance, some require moisture to remain viable, while others are susceptible to ultraviolet radiation or heat [55]. Hence, formulation strategies need to take into account these specific requirements to ensure the maximum efficacy of the microbes. The final challenge lies in the application of entomopathogens in the field. For successful pest management, it's important to deliver these microorganisms to the target pests in an effective manner. Various factors, including environmental conditions, compatibility with other agricultural inputs, and specific requirements of the microorganisms, need to be considered for effective application [56]. Farmer acceptance and understanding of these new technologies also play a significant role in their successful implementation [57]. While these challenges are significant, they also present opportunities for future research. Improving the understanding of entomopathogenic microbes' biology, ecology, and interactions with their hosts could lead to the development of more effective bioassay procedures. Research into new technologies and approaches, such as genetic engineering or nanotechnology, could also enhance the production and formulation of these microbes [58]. Exploring new application methods and strategies could increase the efficacy and acceptance of these biological control agents.

Conclusion

This review underlines the significant potential of entomopathogenic microbes in the management of insect pests and diseases. It demonstrates that these microbes, ~~by virtue of~~ their unique attributes such as host-specificity, environmental safety, and ~~their~~ biotic potential, could serve as an effective and sustainable alternative to chemical pesticides. For their full potential to be harnessed, it is necessary to research ~~into~~ factors affecting their efficacy, their deployment strategies, and potential resistance mechanisms in pests. This could herald a new era in pest and disease management that is not only efficient but also environmentally responsible.

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