

Negative Effects of Biopesticides on Bees

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Abstract

Biopesticides are compounds derived from natural sources such as plants, bacteria, and minerals, serving as environmentally friendly alternatives to synthetic pesticides. They are generally preferred due to their lower toxicity and specificity towards target organisms. However, their impact on non-target species, particularly bees, which play a crucial role in ecosystem sustainability and agricultural production, must be carefully evaluated. Bees contribute significantly to biodiversity conservation and agricultural productivity through pollination. This study examines the potential risks and benefits of biopesticides on bee populations. Research indicates that although biopesticides tend to be less toxic than synthetic pesticides, their effects on bees vary depending on the active ingredient, formulation, and level of exposure. For instance, microbial biopesticides such as *Bacillus thuringiensis* (Bt) are considered to pose minimal risk to bees. In contrast, plant-based compounds such as neem oil and pyrethrins have been observed to negatively affect bee foraging behavior and reproduction. Additionally, interactions between biopesticides and other environmental stressors, such as pathogens and nutritional deficiencies, may exacerbate their adverse effects on bee health. Despite these concerns, biopesticides offer advantages, including biodegradability and lower environmental persistence, reducing unintended impacts on beneficial insects. When integrated pest management (IPM) strategies are applied effectively, the risks to pollinators can be minimized while maintaining agricultural productivity. Therefore, further research is needed to understand the long-term effects of biopesticides on bee populations and to develop safe application guidelines. A balanced approach is essential to ensure both agricultural productivity and pollinator conservation, supporting ecological and agricultural sustainability.

Key Words: *Bee health, Biopesticide, Ecological balance, Integrated pest management (IPM), Agricultural sustainability*

1. Introduction

Pollinators, particularly honeybees (*Apis mellifera*), play a vital role in maintaining biodiversity and ensuring food security through the pollination of agricultural crops and wild plants (Khalifa et al., 2021; Requier et al., 2023). However, in recent decades, significant declines in bee populations have raised global concern, prompting extensive research into the multifactorial causes of these losses (Lima et al., 2022). Among the various anthropogenic stressors, the use of pesticides in modern agriculture has been widely implicated in the deterioration of bee health (Zhao et al., 2022). While conventional synthetic pesticides are known for their acute and chronic toxicity to pollinators, biopesticides—marketed as safer, eco-friendly alternatives—have increasingly gained attention as part of integrated pest management (IPM) strategies (Cappa et al., 2022; Demirözer et al., 2022).

Biopesticides, which are derived from natural organisms such as bacteria, fungi, viruses, or plant extracts, are generally assumed to be less harmful to non-target organisms, including pollinators (Cappa et al., 2022; Guedes et al., 2024). This perception has led to their widespread acceptance and use without sufficient evaluation of their sublethal or chronic impacts on beneficial insects. Recent studies, however, have begun to challenge this assumption, highlighting that certain biopesticides may impair critical physiological and behavioral functions in bees, such as foraging efficiency, learning and memory, immune response, and colony development (Carlesso et al., 2020; Almeida et al., 2022). Moreover, the synergistic effects of biopesticides when combined with other environmental stressors, such as nutritional deficiencies, pathogens, or climate change, remain poorly understood. Given the essential ecological role of bees and the growing reliance on biopesticides in sustainable agriculture, it is crucial to reassess the environmental safety profiles of these products. This study aims to investigate the potential adverse effects of commonly used biopesticides on honeybee health, with a particular focus on sublethal behavioral and physiological impacts. By doing so, it seeks to contribute to a more nuanced understanding of how "green" plant protection strategies may still pose risks to vital pollinator species.

2. Biopesticides Effects on Bee

Biopesticides are derived from natural organisms such as bacteria, fungi, viruses, or plant extracts.



2.1. Entomopathogenic bacteria

The most studied entomopathogenic bacteria include species from the genera *Bacillus*, *Beauveria*, and *Metarhizium*. Among these, *Bacillus thuringiensis* (Bt) is perhaps the most widely recognized for its use in pest control. These bacteria produce toxins that can damage the insect's gut, leading to death. While these bacteria are often lethal to pests, their effects on non-target organisms like bees are not always well understood (Rousset and Gallet, 2025). Entomopathogenic bacteria, particularly strains of *B. thuringiensis*, have been shown to be toxic to bees under certain conditions. While bees are not the intended targets of these bacteria, they may encounter them when foraging on contaminated plants or surfaces. Bees can ingest or come into contact with bacterial spores or toxins, which can potentially disrupt their digestive systems, impair their health, or even result in death. However, some strains of *Bacillus* may have minimal or no direct lethal effects on bees, depending on the concentration and strain involved (Mommaerts et al., 2010; Alkassab et al., 2022). Exposure to entomopathogenic bacteria could also suppress the bee's immune system (Steinigeweg et al., 2021). Bees rely heavily on their immune response to fend off pathogens, parasites, and other environmental stressors. If bees are infected by harmful bacteria, their immune system might be compromised, leaving them more susceptible to other diseases or pathogens, such as *Nosema* or the varroa mite (Alquisira-Ramírez et al., 2017). A weakened immune system can lead to colony collapse, affecting not only individual bees but also the entire hive. Sublethal exposure to entomopathogenic bacteria might not kill bees immediately but can cause behavioral changes. Affected bees may become less efficient in foraging, decrease in grooming or nursing activities, or exhibit altered communication such as waggle dancing (Malone et al., 2001; Mommaerts et al., 2010). These behavioral shifts could affect the overall productivity of the colony, impairing pollination efforts and leading to decreased honey production. The widespread use of entomopathogenic bacteria in agriculture or horticulture may pose a risk to bees if these bacteria are applied to crops that bees frequent. Pesticide treatments containing entomopathogenic bacteria could persist in the environment, and bees could be exposed to these pathogens during their foraging activities. The long-term ecological impact of such exposure is not fully understood but could have cumulative effects on bee populations over time. While there are concerns about the harmful effects, some studies suggest that entomopathogenic bacteria may have potential benefits for bee health under certain conditions. For example, *Bacillus* species have been found to outcompete or inhibit the growth of harmful pathogens that affect bees, like *Nosema apis* (a protozoan that causes *Nosema* disease). In this sense, entomopathogenic bacteria could serve as a form of natural biological control to support colony health, though careful management would be necessary to avoid inadvertent harm.

2.2. Entomopathogenic Fungi

Entomopathogenic fungi, such as *Beauveria bassiana* and *Metarhizium anisopliae*, are increasingly utilized in integrated pest management due to their specificity and environmental safety; however, their non-target effects on pollinators warrant careful evaluation. Although adult bees generally exhibit low susceptibility to infection under field-relevant concentrations, sublethal impacts—including behavioral alterations, reduced foraging efficiency, and impaired learning—have been documented following exposure to certain fungal strains (Almeida et al., 2022; Leite et al., 2022; Bava et al., 2022). Moreover, the larval stages may be more vulnerable, especially when spores are introduced into the hive environment (Omuse et al., 2022). These effects, while often subtle at the individual level, could potentially accumulate to impair colony-level function, particularly when compounded by additional stressors such as pesticide exposure or nutritional deficiencies. Therefore, risk assessments of entomopathogenic fungi should consider strain-specific virulence, exposure routes, and the health status of bee populations to ensure pollinator safety in biological control programs.

2.3. Entomopathogenic Nematodes

Entomopathogenic nematodes (EPNs), primarily from the genera *Steinernema* and *Heterorhabditis*, are widely used as biological control agents due to their ability to parasitize and kill a broad range of insect pests. These nematodes harbor symbiotic bacteria (e.g., *Xenorhabdus spp.* and *Photorhabdus spp.*) that contribute to the host's death by releasing toxins. Although EPNs are generally considered safe for non-target organisms, including pollinators, the potential effects on bees have become an emerging area of concern (Erler et al., 2022). Bees, particularly *Apis mellifera* and other eusocial species, are not typical hosts for EPNs due to their mobility, grooming behavior, and relatively dry external cuticle, which collectively reduce the likelihood of successful infection. However, under laboratory conditions or when EPNs are applied in high concentrations and in moist environments—such as hive interiors or floral resources—there is evidence of possible adverse interactions. Some studies have shown that EPNs can cause high mortality (Dutka et al., 2015). Despite these risks, most field applications of EPNs appear to pose minimal direct threat to bee populations. Their survival and infectivity are limited on dry surfaces like flowers, and they are not typically attracted to or capable of breaching the protective defenses of adult bees. Nevertheless, comprehensive risk assessments are essential, particularly for stingless bees or solitary bee species that nest in soil or decaying wood, where EPNs are more likely to persist and interact with developing brood.



2.4. Viruses

Honey bees are known to host more than 20 distinct viruses, which typically remain latent and asymptomatic unless activated by external stressors (McMenamin and Genersch, 2015). When such stressors compromise the bees' immune function, viral replication can increase, and elevated viral loads have been associated with colony collapse (McMenamin and Genersch, 2015). Although RNA viruses from the families Dicistroviridae and Iridoviridae are frequently detected in collapsing colonies and have been proposed as potential biopesticides (Bromenshenk et al., 2010; McMenamin and Genersch, 2015), there remains a significant paucity of targeted studies investigating their direct effects on honey bees. In contrast, studies examining the impacts of nuclear polyhedrosis viruses (NPVs), granulosis viruses, and entomopoxviruses—originally isolated from other insect species—have reported no adverse effects on honey bees, thereby suggesting host specificity and indicating their relative safety in microbial pest management programs (Alves et al., 1996). With respect to the potential impacts of viral biocontrol agents on bumble bees, the body of research remains limited. Nevertheless, existing studies suggest that granuloviruses isolated from *Cydia pomonella* do not negatively affect *Bombus terrestris* worker survival, foraging behavior, or overall colony fitness (Mommaerts et al., 2009).

2.5. Plant Extracts

The use of plant-based biopesticides has emerged as a sustainable alternative to synthetic chemical pesticides, offering potential advantages such as biodegradability, target specificity, and lower toxicity to non-target organisms (Haritha et al., 2021). However, growing evidence indicates that certain plant extracts employed as biopesticides may pose unforeseen risks to pollinators, particularly bees, which are essential for ecosystem functioning and agricultural productivity. Despite being considered environmentally friendly, the phytochemical constituents in some biopesticides can exert sublethal or even lethal effects on various species of bees, including honeybees (*Apis mellifera*), bumblebees (*Bombus spp.*), and solitary bees (Morandin et al., 2015; Tome et al., 2015).

Plant-derived compounds such as essential oils, alkaloids, saponins, and phenolics are designed to deter or kill insect pests, but these bioactive substances can also affect the physiology and behavior of bees (Demirözer et al., 2022). For example, neem-based biopesticides containing azadirachtin have demonstrated antifeedant and growth-regulating effects in target pests, yet studies have shown that exposure to sublethal doses can impair bee foraging efficiency, navigation, and learning capacity (Bernardes et al., 2017; Barbosa et al., 2015; Gomes et al., 2020). Similarly, essential oils such as thymol and eugenol may disrupt neural signaling pathways in bees, potentially altering their olfactory perception and communication.

Sublethal exposure to these compounds may also compromise bees' immune responses, making them more susceptible to pathogens such as *Nosema spp.* and viruses (Chaimanee et al., 2021). Additionally, repeated exposure to plant biopesticides through contaminated nectar, pollen, or water sources can result in cumulative toxicity, especially during peak foraging seasons. Larval development may also be disrupted when brood food is contaminated, affecting colony health and productivity over the long term.

3. Conclusion

The reviewed literature underscores the complexity of biopesticide interactions with honeybee health, challenging the common assumption that these products are inherently safe for pollinators. While biopesticides—including entomopathogenic bacteria, fungi, nematodes, viruses, and plant extracts—are widely promoted as eco-friendly alternatives to synthetic pesticides, mounting evidence reveals that some of these agents can have unintended sublethal or chronic effects on bees. These effects range from impaired foraging behavior, learning deficits, and immune suppression to increased vulnerability to pathogens and potential colony-level impacts. Such outcomes are particularly concerning given the central role of honeybees in pollination services and ecosystem stability.

Among the biopesticide groups, *Bacillus thuringiensis* and other entomopathogenic bacteria can interfere with bee gut health and immunity; certain fungal strains, though generally low in direct virulence, may subtly impair behavior and larval development; entomopathogenic nematodes, while less likely to infect bees directly, pose possible risks under moist conditions or in species nesting in exposed habitats; and plant-based biopesticides, despite their natural origin, can contain bioactive compounds that disrupt key physiological and neurological functions in bees. Viral agents, although largely species-specific, remain under-studied in terms of their long-term ecological impacts, particularly in diverse bee communities.

4. Future Directions

Comprehensive Risk Assessments: Future studies must include standardized, long-term risk assessments of biopesticides under realistic field conditions. These assessments should consider species-specific sensitivities, life stages (e.g., larvae vs. adults), and exposure routes (e.g., contaminated pollen, nectar, or water).





Sublethal and Synergistic Effects: Greater emphasis should be placed on investigating sublethal effects and the potential for synergistic interactions between biopesticides and other stressors, such as poor nutrition, climate change, or existing pathogen loads.

Diversity of Bee Species: Most current research focuses on *Apis mellifera*; however, *non-Apis* pollinators such as bumblebees and solitary bees may exhibit different susceptibilities. Expanding studies to include a broader range of species is critical for biodiversity conservation.

Biopesticide Formulation Improvements: There is a need for the development of safer biopesticide formulations that minimize non-target effects on bees, including innovations in application timing, dosage, and delivery methods that reduce pollinator exposure.

Policy and Regulatory Updates: Regulatory frameworks should be updated to reflect new scientific insights into biopesticide toxicity. This includes integrating pollinator health benchmarks into the approval process for biopesticide products.

Integrated Pest and Pollinator Management (IPPM): Holistic strategies that align pest control goals with pollinator protection—such as using ecological intensification, crop diversification, and habitat conservation—should be promoted.

By pursuing these directions, researchers, regulators, and agricultural stakeholders can more effectively balance pest control needs with the imperative to protect pollinators, thereby advancing sustainable and resilient agroecosystems.

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