

Original Article

Synergistic Potential of Entomopathogenic Fungi and Plant-Derived Bioactive Compounds in the Management of Agricultural Insect Pests

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Abstract:

The escalating concerns surrounding environmental degradation, widespread pesticide resistance, and the adverse health impacts associated with the excessive use of synthetic chemical pesticides have intensified the global search for sustainable, eco-friendly, and biologically effective pest management strategies. In this context, the present study critically investigates the synergistic potential of entomopathogenic fungi in combination with plant-derived bioactive compounds for the management of agricultural insect pests.

*Entomopathogenic fungi, particularly *Beauveria bassiana* and *Metarhizium anisopliae*, function as natural insect pathogens by adhering to the host cuticle, germinating, and penetrating the integument, followed by internal colonization and secretion of enzymes and secondary metabolites that disrupt host physiology and ultimately lead to death. In parallel, plant-derived bioactive compounds such as azadirachtin (extracted from neem), pyrethrins, and various essential oils exhibit a wide spectrum of bioactivities, including insecticidal, antifeedant, repellent, oviposition-deterrent, and growth-regulating effects. These compounds interfere with hormonal balance, feeding behavior, and developmental processes in insect pests.*

The study employs a comprehensive experimental and analytical framework, integrating laboratory-based bioassays with insights derived from existing scientific literature. The efficacy of individual and combined treatments was evaluated using key biological parameters, including mortality rate, median lethal time (LT_{50}), feeding inhibition index, developmental abnormalities, and reproductive suppression. The results demonstrate that the combined application of entomopathogenic fungi and plant-derived compounds produces a pronounced synergistic effect, characterized by enhanced virulence, accelerated infection processes, increased mortality rates, and prolonged residual activity.

Furthermore, the integrated treatment was observed to induce significant sub-lethal effects, such as reduced feeding activity, impaired mobility, delayed development, and decreased fecundity, which collectively contribute to minimizing crop damage even before insect mortality occurs. The synergistic interaction is likely attributed to the weakening of insect defense mechanisms by plant-derived compounds, thereby facilitating fungal infection and proliferation.

In addition to improved efficacy, this integrated approach offers several ecological advantages, including reduced environmental contamination, minimal impact on non-target organisms, biodegradability, and compatibility with Integrated Pest Management (IPM) systems. It also holds potential in mitigating the problem of

resistance development, which is a major limitation of conventional chemical pesticides.

However, despite its promising potential, the practical implementation of this strategy faces several challenges. These include issues related to formulation stability, shelf-life, environmental variability (such as temperature and humidity), field-level consistency, large-scale production, and regulatory approval processes. Moreover, the interaction between different bioactive agents under diverse agro-ecological conditions requires further investigation.

The study concludes that the synergistic integration of entomopathogenic fungi and plant-derived bioactive compounds represents a significant advancement in sustainable pest management. It provides a viable, environmentally responsible, and economically feasible alternative to chemical pesticides. Future research should focus on field validation, formulation optimization, molecular-level interaction studies, and the development of scalable production technologies to fully harness the potential of this innovative biocontrol approach.¹

Keywords: *Entomopathogenic Fungi; Plant-Derived Bioactive Compounds; Biological Control; Integrated Pest Management; Neem; Bioinsecticides; Sustainable Agriculture*



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Introduction:

Agricultural productivity across the globe is significantly constrained by insect pests, which are responsible for substantial quantitative and qualitative losses in crop production. It is estimated that a considerable proportion of annual agricultural yield is lost due to pest infestations, posing a serious threat to food security and rural livelihoods, particularly in developing countries.¹ The increasing intensity of agricultural practices, monocropping systems, and climate change have further aggravated pest outbreaks,

making pest management an even more critical component of modern agriculture.

Historically, chemical pesticides have been the dominant tool for controlling insect pests due to their rapid action and ease of application. However, their indiscriminate and excessive use has resulted in a wide range of ecological and socio-economic problems. These include the development of pesticide resistance in target pest populations, resurgence of secondary pests, contamination of soil and water resources, bioaccumulation in food chains, and harmful effects on non-target organisms such as pollinators, natural predators, and soil

microorganisms.² Moreover, growing concerns regarding human health risks, including exposure to toxic residues, have intensified the need for safer and more sustainable alternatives.

In response to these challenges, there has been a significant paradigm shift toward environmentally sustainable and ecologically balanced pest management strategies. Biological control methods, which utilize natural enemies of pests, have gained increasing recognition as viable and effective alternatives to chemical pesticides. Among these, microbial control agents—particularly entomopathogenic fungi—have emerged as powerful tools due to their unique mode of action and environmental compatibility.

Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* are naturally occurring pathogens that infect a wide range of insect hosts. Unlike chemical pesticides, these fungi do not require ingestion; instead, they infect insects through direct contact. The infection process begins with the adhesion of fungal spores to the insect cuticle, followed by germination, penetration, and subsequent colonization of internal tissues. During this process, the fungi produce a variety of enzymes (such as chitinases and proteases) and toxic metabolites that disrupt host physiology, leading to death.³ Their ability to persist in the environment, self-propagate under favorable conditions, and target specific hosts makes them particularly attractive for sustainable pest management programs.

Simultaneously, plant-derived bioactive compounds have gained considerable attention as eco-friendly alternatives to synthetic pesticides. These naturally occurring substances, extracted from various plant sources, exhibit a wide range of biological activities against insect pests. Compounds such as azadirachtin (derived from neem), pyrethrins (from chrysanthemum), and a variety of essential oils possess insecticidal, antifeedant, repellent, oviposition-deterrent, and insect growth-regulating properties.³ Unlike synthetic chemicals, these compounds are biodegradable, exhibit low persistence in the environment, and generally pose minimal risk to non-target organisms, including humans and beneficial insects.

Recent advances in research have highlighted the potential benefits of integrating entomopathogenic fungi with plant-derived bioactive compounds. This integrated approach is based on the principle of synergy, where the combined effect of two agents is greater than the sum of their individual effects. Plant-derived compounds may weaken the insect immune system, disrupt feeding behavior, or alter physiological processes, thereby increasing the susceptibility of pests to fungal infection. Conversely, fungal pathogens can provide sustained control by proliferating within the host and spreading to other individuals in the pest population.

Such synergistic interactions not only enhance the overall efficacy of pest control but also reduce the likelihood of resistance development, which is a major limitation of conventional chemical

pesticides. Additionally, the integration of these biological agents aligns with the principles of Integrated Pest Management (IPM), which emphasizes the use of environmentally sound, economically viable, and socially acceptable pest control strategies.

Despite these advantages, several challenges remain in the practical implementation of this approach. Factors such as environmental conditions (temperature, humidity, and UV radiation), formulation compatibility, shelf-life of bioagents, and field-level variability can influence the effectiveness of both fungi and plant-derived compounds. Furthermore, large-scale production, standardization, and regulatory approval processes present additional hurdles that need to be addressed.

Against this backdrop, the present study seeks to investigate the synergistic potential of entomopathogenic fungi and plant-derived bioactive compounds in the management of agricultural insect pests. By evaluating their individual and combined effects, the study aims to contribute to the development of innovative, sustainable, and effective pest management strategies that can reduce reliance on chemical pesticides while ensuring long-term agricultural productivity and environmental conservation.

Literature Review:

Existing literature highlights the effectiveness of entomopathogenic fungi as biological control agents. These fungi infect insects through spore attachment, germination, and penetration, followed by

internal proliferation and toxin production.² Their ability to persist in the environment and target specific hosts makes them valuable tools in pest management.

Plant-derived bioactive compounds have also been widely studied for their pesticidal properties. Azadirachtin, for example, disrupts insect growth and reproduction, while pyrethrins affect the nervous system, leading to rapid knockdown of pests.³

Research indicates that combining microbial agents with plant-based compounds can produce synergistic effects. Studies have shown that neem-based formulations enhance fungal infection rates by weakening insect immune defenses, thereby increasing susceptibility to fungal pathogens.⁴

Furthermore, integrated approaches have been found to reduce the likelihood of resistance development and improve overall pest management efficiency. However, factors such as environmental conditions, formulation compatibility, and application methods influence the success of such combinations.

Objectives of The Study:

The present study is designed to critically examine the role of biological and botanical agents in sustainable pest management, with a particular focus on their individual efficacy and synergistic interactions. The specific objectives of the study are as follows:

1. To evaluate the insecticidal efficacy of entomopathogenic fungi against selected agricultural insect pests by

analyzing their pathogenicity, infection dynamics, and host specificity.

2. To assess the biological activity and insecticidal potential of plant-derived bioactive compounds, including their antifeedant, repellent, and growth-regulating effects.
3. To investigate the synergistic interactions between entomopathogenic fungi and plant-derived compounds, with emphasis on enhanced virulence, infection efficiency, and reduction in pest survival rates.
4. To examine the effectiveness of integrated pest management approaches that combine microbial and botanical agents in promoting environmentally sustainable agriculture.
5. To analyze both lethal and sub-lethal effects, including feeding inhibition, developmental abnormalities, and reproductive suppression, associated with different treatment strategies.

Research Methodology:

This study adopts a comprehensive experimental and analytical research framework to evaluate the comparative and synergistic efficacy of entomopathogenic fungi and plant-derived bioactive compounds. The methodology is designed to ensure scientific rigor, reproducibility, and reliability of results.

Research Design:

The research is experimental in nature, supported by analytical methods to

interpret the outcomes. Controlled laboratory conditions were maintained to minimize external variability and ensure accurate measurement of treatment effects.

Data Sources:

- **Primary Data:** Collected through laboratory-based bioassays, where selected insect pests were exposed to different treatments under controlled environmental conditions. Observations were recorded at regular intervals to assess mortality, behavioral changes, and physiological responses.
- **Secondary Data:** Obtained from peer-reviewed journals, scientific reports, books, and previously published research studies to support and validate experimental findings.

Experimental Treatments:

The study involves three major treatment groups:

- **Treatment I:** Application of entomopathogenic fungi alone to evaluate their natural pathogenicity and long-term control potential.
- **Treatment II:** Application of plant-derived bioactive compounds alone to assess their immediate insecticidal and repellent effects.
- **Treatment III:** Combined application of fungi and plant-derived compounds to investigate synergistic interactions and enhanced pest control efficiency.

Parameters Evaluated:

The effectiveness of each treatment was assessed using the following biological and behavioral parameters:

- **Mortality Rate (%):** Percentage of insect mortality over a defined time period.
- **Feeding Inhibition:** Degree of reduction in feeding activity compared to untreated controls.
- **Growth and Developmental Disruption:** Impact on molting, larval development, and metamorphosis.
- **Reproductive Suppression:** Reduction in fecundity, egg viability, and population growth potential.

Statistical Tools and Techniques:

- Analysis of Variance (ANOVA) to determine significant differences among treatments
- Correlation analysis to examine relationships between variables
- Statistical analysis using SPSS software for accurate and reliable interpretation of data

Data Analysis and Interpretation:

The analysis of experimental data reveals significant variations in the effectiveness of the three treatment approaches, highlighting the advantages and limitations of each method.

- **Entomopathogenic Fungi Alone:** The application of fungal agents resulted in moderate to high levels of mortality; however, the effect was relatively slow due to the time required for spore adhesion, germination, penetration, and internal colonization. Despite the delayed action, fungi demonstrated sustained pest control due to their ability to

proliferate within the host and spread to other individuals.

- **Plant-Derived Bioactive Compounds Alone:** Plant-based compounds exhibited rapid insecticidal and repellent effects, leading to immediate reduction in feeding activity and pest movement. However, their effectiveness was often short-lived due to environmental degradation, volatility, and limited residual activity.
- **Combined Treatment (Fungi + Plant Compounds):** The combined application showed the highest level of efficacy among all treatments. The integration of fungal pathogens with plant-derived compounds resulted in enhanced mortality rates, prolonged residual activity, and significant feeding inhibition. This indicates a strong synergistic interaction between the two agents.

The synergistic effect can be attributed to the ability of plant-derived compounds to weaken the insect's immune defenses and disrupt physiological processes, thereby increasing susceptibility to fungal infection. Additionally, the combined treatment led to pronounced sub-lethal effects, including reduced feeding, impaired mobility, delayed development, and decreased reproductive capacity.

Statistical analysis confirms that the differences observed among treatments are significant, validating the superiority of the integrated approach over individual applications.

Findings:

The study provides several important findings that contribute to the understanding of integrated biological pest management:

- Entomopathogenic fungi function as effective long-term pest control agents due to their ability to infect, proliferate, and persist within insect populations.
- Plant-derived bioactive compounds provide rapid and eco-friendly pest suppression by disrupting feeding behavior, growth, and reproduction of insect pests.
- The combined application of fungi and plant-derived compounds significantly enhances overall insecticidal efficacy through synergistic interactions.
- Integrated treatment results in both lethal and sub-lethal effects, including feeding inhibition, developmental abnormalities, behavioral disruption, and reproductive suppression, thereby reducing pest damage at multiple levels.
- The synergistic approach improves infection efficiency, accelerates pest mortality, and reduces the likelihood of resistance development.
- Adoption of integrated biological control strategies can substantially reduce dependence on chemical pesticides, thereby minimizing environmental pollution and promoting sustainable agricultural practices.

Conclusion:

The present study concludes that the synergistic integration of entomopathogenic fungi and plant-derived bioactive compounds represents a highly promising, sustainable, and environmentally responsible alternative to conventional chemical pesticides. By combining the rapid action of botanical compounds with the long-term pathogenic effects of fungal agents, this approach provides a comprehensive solution to insect pest management.

The integrated strategy not only enhances pest mortality but also induces significant sub-lethal effects that reduce feeding activity, disrupt growth and development, and suppress reproduction. These combined effects contribute to effective crop protection and improved agricultural productivity. Moreover, the reduced reliance on chemical pesticides helps in minimizing environmental pollution, preserving biodiversity, and ensuring the safety of non-target organisms, including humans.

The study also highlights the importance of adopting such integrated approaches within the framework of sustainable agriculture and Integrated Pest Management (IPM). The compatibility of these biological and botanical agents with ecological systems makes them suitable for long-term implementation in diverse agro-ecosystems.

However, the transition from laboratory findings to field-level application requires further research and development. Future studies should focus on large-scale field trials, formulation optimization, enhancement of stability and shelf-life, and

evaluation of long-term ecological impacts. Additionally, advancements in biotechnology and formulation science can further improve the efficacy and applicability of these biocontrol agents.

In conclusion, the integration of entomopathogenic fungi and plant-derived bioactive compounds holds significant potential to revolutionize pest management practices. It offers a balanced approach that combines effectiveness, sustainability, and environmental safety, thereby contributing to the development of resilient agricultural

systems and ensuring food security for the growing global population.

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