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Biological control in mulberry pest management: Innovations for sustainable sericulture

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Abstract

Biological control agents specifically act on target pests without harming beneficial insects or degrading soil and water quality, thereby helping maintain ecological balance. In sericulture, various insect, and non-insect pests, as well as parasites such as fungi, mites, and other insects, are encountered. This approach aligns with the principles of sustainable agriculture, as it does not disrupt environmental sustainability during pest management. Bio-control agents are also safe for humans, pollinators, and wildlife, offering an advantage over chemical pesticides, which can negatively impact human health and biodiversity. Although the initial development and procurement of bio-control organisms may be more costly than chemical methods, they can be economically favorable in the long term by providing continuous pest suppression with minimal recurring expenses. Moreover, their use can reduce dependency on conventional pesticides, lower the risk of pest resistance, and decrease pesticide residues on mulberry foliage, thereby safeguarding both product quality and environmental health. In mulberry cultivation, bio-control agents form a vital part of integrated pest management and have proven to be an effective and sustainable alternative to chemical control methods.

Keywords: Bio-control, bio-control agents, challenges, mulberry, pest management, strategies

1. Introduction

Biological control of pests and diseases has emerged as a highly effective practice in modern agriculture. Advances in scientific pest management technologies have opened new opportunities for developing alternatives to synthetic pesticides in sericulture. This progress has created the right conditions to explore innovative growth-promoting methods and biological control strategies, including the use of commercial products, for the effective management of harmful insects in mulberry cultivation.

In sericulture, a diverse range of pests threaten mulberry crops, including both insect and non-insect species, as well as parasites such as fungi, mites, and other insects. Since mulberry (*Morus* spp.) is the sole host plant for silkworms (*Bombyx mori* L.), any damage to its foliage directly impacts silk production. The main pests affecting mulberry include aphids, scales, borers, mosquitoes, mealybugs, dipterous larvae, and certain lepidopteran species. Infestations reduce both the quality and quantity of leaf yield, lowering productivity in sericulture.

Chemical pesticides have traditionally been the primary control measure against these pests. While their application can temporarily boost crop production, repeated use often results in pesticide resistance. Broad-spectrum pesticides also have unintended consequences: they can harm beneficial fauna, disrupt soil microorganisms, and contaminate air, water, and soil. Their residues may persist in the environment, posing risks to human health and biodiversity. In addition, pesticide drift during aerial spraying can expose humans and non-target organisms to toxic chemicals.

Reducing the negative effects of prolonged pesticide use requires a shift toward alternative pest control methods. Non-chemical approaches—such as mechanical methods, botanical extracts, and biological control—are being increasingly explored worldwide. Biopesticides derived from plants, including neem (*Azadirachta indica*) oil and kernel extracts, tobacco (*Nicotiana tabacum*) preparations, Mexican marigold (*Tagetes patula*) extracts, and gliricidia extracts, have shown promise. Other options include inorganic contact poisons such as magnesium fluoride

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and potassium silicofluoride. These alternatives, along with bio-control agents, have been applied successfully against pests like the pink mealybug.

Mulberry is not only crucial for silkworm rearing but also valued for its medicinal uses, fruit production, and ornamental appeal. However, like all cultivated crops, it is vulnerable to a range of pests and diseases—fungal, bacterial, and viral—that can cause severe economic losses. Heavy dependence on chemical control for these threats has led to pollution, harm to non-target organisms, and the growing problem of pest resistance. This has fueled interest in sustainable farming methods that minimize chemical inputs and emphasize environmental conservation.

Biological control agents—living organisms or products derived from them—offer a practical and eco-friendly alternative to synthetic pesticides. They work by regulating pest populations naturally, thus maintaining ecological balance. The three primary categories of bio-control agents are predators, parasitoids, and pathogens. Predators feed directly on pests, parasitoids lay eggs in or on pest hosts so that the developing larvae consume them, and pathogens infect and kill pests, often targeting specific species or life stages.

While biological control offers many benefits, its successful application in mulberry farming requires careful consideration. Many bio-control agents are species-specific, meaning they cannot eliminate all pest problems on their own. Their effectiveness can also be influenced by environmental factors such as temperature and humidity, necessitating precise timing and environmental management. Integrating bio-control agents with other pest control strategies—such as cultural and physical methods—requires thorough planning and coordination.

Research and technological advancements continue to improve the potential of bio-control agents. Genetic improvements, advanced formulations, and detailed ecological studies of both pests and their natural enemies are expected to enhance their effectiveness. As these innovations progress, bio-control is likely to play an increasingly significant role in integrated pest management (IPM) for mulberry cultivation, contributing to sustainable and environmentally responsible sericulture.

2. Understanding bio-control agents

Biological control agents are living organisms employed to suppress pest and disease populations through natural ecological interactions. They play an important role in sustainable agriculture by reducing the need for chemical pesticides and maintaining environmental balance. In general, bio-control agents fall into three main categories: predators, parasitoids, and pathogens. These groups include a variety of organisms such as beneficial insects, spiders, nematodes, fungi, and other microorganisms that naturally regulate pest numbers.

Predators

Predators are organisms that feed directly on pests rather than on plants or other food sources. They actively capture and consume their prey, thereby limiting pest populations in agricultural systems. In mulberry cultivation, common predatory bio-control agents include lady beetles (Coccinellidae), lacewings (Chrysopidae), and spiders. These predators feed on soft-bodied insects such as aphids, mealybugs, and other small arthropods that damage mulberry leaves. Their presence in the field can significantly reduce pest numbers without harming the crop.

Parasitoids

Parasitoids are insects whose immature stages develop inside or

on the body of a host insect, ultimately killing it. Adult parasitoids typically lay their eggs either within or upon the pest, and the developing larvae consume the host's tissues until it dies. In mulberry pest management, tiny wasps from families such as Braconidae and Trichogrammatidae are often used. These wasps exhibit high host specificity, targeting only certain pest species while leaving beneficial insects unharmed.

Pathogens

Pathogens include microorganisms such as bacteria, fungi, viruses, and certain nematodes that infect and kill pest species. These bio-control agents can cause diseases in pests, leading to a decline in their population. Some pathogens work by invading the pest's hemolymph (insect blood) and disrupting cellular functions, in some cases inducing apoptosis in insect hemocytes. Others infect the fat body tissues, releasing spores that multiply and further suppress the pest's immune response. For example, *Bacillus thuringiensis* (Bt) produces toxic spores that, once ingested, damage the insect gut, allowing the infection to spread and eventually killing the host.

The effectiveness of pathogens lies in their ability to multiply within the pest population, providing sustained control over time. Unlike certain parasitoids that may have a narrow host range, many pathogens can infect a broader range of pest species, making them particularly useful in diverse tropical cropping systems. However, for optimal use, it is important to study their infection pathways, potential environmental constraints, and the possibility of pests developing protective immune responses.

By understanding the biology, behavior, and ecological requirements of predators, parasitoids, and pathogens, farmers and researchers can design integrated pest management strategies that maximize the benefits of biological control while minimizing risks to non-target organisms.

3. Key bio-control agents used in mulberry plantation

Biological control in mulberry cultivation relies on a range of natural enemies that target different stages of pest development. These agents are generally classified into three groups—predators, parasitoids, and pathogens—each playing a unique role in integrated pest management (IPM).

3.1 Predators

Lady Beetles (Coccinellidae)

Lady beetles are among the most efficient predators of soft-bodied arthropods such as aphids, scale insects, and mealybugs. Their aggressive feeding behavior helps maintain pest populations at low levels throughout the growing season. Both adult and larval stages of lady beetles actively consume large numbers of pests, making them highly valuable in mulberry plantations.

Lacewings (Chrysopidae)

Lacewing larvae, often referred to as “aphid lions,” are voracious feeders on aphids, whiteflies, thrips, and other small insects. They are particularly effective during pest outbreaks, as they can drastically reduce pest numbers in a short period. By targeting multiple pest species, lacewings contribute significantly to the overall health and productivity of mulberry crops.

Spiders

Various spider species, including orb-weavers and jumping spiders, are generalist predators that feed on a wide range of

insect pests. They help control pest populations by trapping or ambushing their prey, thus reducing the need for chemical interventions. Their presence in mulberry fields supports the ecological balance by suppressing multiple pest types simultaneously.

3.2 Parasitoids

Trichogramma Wasps (Trichogrammatidae)

Trichogramma species are tiny egg parasitoids that target the eggs of moths and butterflies, including species harmful to mulberry crops. By attacking pests at the egg stage, these wasps prevent the emergence of destructive larvae, offering an early and effective form of pest control. Their preventive action is particularly valuable in avoiding severe infestations.

Braconid Wasps (Braconidae)

Braconid wasps parasitize the larval stages of pests such as caterpillars and borers. They lay their eggs inside or on the pest larvae, and the developing parasitoid consumes the host from within. This targeted control is especially effective against mulberry borers, which can cause significant damage if left unmanaged.

3.3 Pathogens

Bacillus thuringiensis (Bt)

Bacillus thuringiensis is a naturally occurring soil bacterium that produces toxins lethal to caterpillars and certain insect larvae. Bt formulations are widely used in organic mulberry farming to control pests like borers. The bacteria act by disrupting the pest's digestive system, leading to death within a few days of ingestion.

Beauveria bassiana

This entomopathogenic fungus infects and kills various insect pests, including whiteflies and spider mites. It invades the host through the cuticle, proliferates inside the body, and eventually causes death. In mulberry cultivation, *B. bassiana* is applied as a biological pesticide, reducing pest populations without harming beneficial insects.

Metarhizium anisopliae

Another important entomopathogenic fungus, *Metarhizium anisopliae*, is effective against soil-dwelling pests such as beetles and other ground-feeding insects. It infects the host upon contact, penetrating the exoskeleton and multiplying inside the insect's body. This makes it particularly useful for managing pests that damage mulberry roots and lower stems.

4. Effective strategies for implementing bio-control agents

The use of bio-control agents is most effective when incorporated into a broader integrated pest management (IPM) framework. These agents should not be seen as standalone measures but as part of a well-coordinated pest management system. For maximum success, several strategies must be followed.

4.1 Selection of Appropriate Bio-Control Agents

The efficiency of bio-control depends largely on selecting the correct agent for the target pest and prevailing environmental conditions. The selection process should be based on accurate pest identification, knowledge of the pest's life cycle, and the mode of action of the bio-control agent. For example, Trichogramma species are ideal for controlling moth and butterfly pests because they parasitize the egg stage, preventing

larval damage. Lady beetles (Coccinellidae) are effective against aphids and scale insects, while entomopathogenic fungi such as *Beauveria bassiana* target a wide range of insect pests. Similarly, *Bacillus thuringiensis* (Bt) is particularly useful for managing caterpillar infestations.

4.2 Timing and Application Methods

The success of biological control also depends on the correct timing and method of application. "Sensitive timing"—introducing the control agent at the most vulnerable stage of the pest's life cycle—is critical. For instance, Trichogramma wasps should be released when adult moths are laying eggs to ensure the parasitoids can target them before they hatch. Application techniques must ensure thorough coverage of affected areas and promote the movement and establishment of bio-control agents throughout the crop. In some cases, this may involve localized release, slow dispersal methods, or repeated introductions to sustain pest suppression.

4.3 Monitoring and Evaluation

Continuous monitoring is essential to evaluate the effectiveness of bio-control agents. Regular surveys of pest and natural enemy populations help determine whether the agents are successfully establishing and reducing pest numbers. If results are insufficient, adjustments can be made—such as increasing release frequency or modifying application methods. Data from monitoring programs also provide valuable feedback for refining bio-control strategies over time.

4.4 Benefits of Using Bio-Control Agents

Biological pest control in mulberry cultivation offers several advantages over conventional chemical interventions. Many bio-control agents, including bacteria, fungi, viruses, protozoa, and beneficial nematodes, operate through multiple modes of action, making them versatile and sustainable pest management tools.

Residue-Free Production

Unlike chemical pesticides, bio-control agents leave minimal or no residues on crops or in the environment. Many beneficial microorganisms degrade quickly under natural environmental conditions, reducing the risk of long-term contamination.

Environmental Protection

By reducing the reliance on synthetic chemicals, bio-control minimizes pesticide residues in food, prevents water and soil pollution, and helps protect beneficial organisms.

Sustainability

Bio-control supports natural pest regulation, maintains biodiversity, and is far less likely to contribute to pest resistance compared to chemical methods.

Human and Wildlife Safety

These agents are generally biodegradable and have low toxicity to humans, pollinators, and other non-target species, making them a safer choice for pest control.

Cost-Effectiveness

Although initial setup costs may be higher, bio-control can be more economical in the long term. Once established, natural enemies can provide ongoing pest suppression, reducing the need for repeated chemical applications and associated expenses.

Resistance Management

By diversifying pest control methods and reducing the overuse of chemicals, bio-control agents lower the risk of pests developing resistance, thereby enhancing the long-term effectiveness of pest management strategies.

5. Conclusion

Biological control agents represent a cornerstone in the sustainable management of pests and diseases in mulberry cultivation. Their value lies not only in their ability to effectively suppress harmful pest populations but also in their capacity to do so while maintaining ecological balance, safeguarding farmer health, and reducing the environmental footprint of pest management practices. By harnessing the natural roles of predators, parasitoids, and microbial pathogens, farmers can protect mulberry crops without relying heavily on synthetic pesticides, which often lead to soil and water contamination, pesticide resistance, and harmful residues on foliage.

The integration of bio-control agents into a comprehensive Integrated Pest Management (IPM) framework ensures that pest control is proactive, targeted, and long-lasting. Scientific advancements are continuously improving the efficiency, specificity, and adaptability of these agents, making them even more practical for modern agriculture. In mulberry farming—particularly for sericulture—this approach ensures healthier plants, improved yields, and reduced production costs over time. As global demand for mulberry-based products rises, the importance of resilient, high-yielding crops becomes increasingly clear. Bio-control strategies, by replacing or reducing chemical interventions, not only safeguard the long-term productivity of mulberry plantations but also align with global movements toward environmentally responsible agriculture. By promoting crop health, enhancing biodiversity, and supporting farmer livelihoods, bio-control agents serve as a strategic, sustainable, and economically viable alternative that will continue to play a pivotal role in the future of mulberry cultivation.

6. Future prospects and research directions

Looking ahead, the future of biological control in mulberry cultivation lies in harnessing cutting-edge molecular biology, genetics, and biotechnology to improve the efficiency, specificity, and adaptability of bio-control agents (BCAs). The development of user-friendly technologies for isolating, mass-producing, and enhancing the performance of bio-priming agents and biopesticides will be essential for their widespread adoption.

One promising avenue is the exploration of novel microbial isolates and their bioactive metabolites from diverse environments. These could provide new tools for controlling multiple pest species that threaten mulberry fields. Such research would not only expand the library of available BCAs but also lead to the discovery of compounds with unique modes of action, reducing the risk of resistance development in pest populations.

The integrated application of bio-priming agents with other bio-inputs is expected to become a mainstream strategy in pest management. This approach has the potential to offer broad-spectrum pest suppression while maintaining ecological safety, making it an innovation with high commercial and environmental value.

From a scientific standpoint, deeper biochemical and molecular investigations are needed to understand the genetic and transcriptional regulatory pathways triggered by BCA-derived

compounds, especially those linked to plant defense systems. For example, research could focus on evaluating the effectiveness of BCAs when applied to mulberry leaves at various concentrations, such as identifying the minimum effective dose in the range of 2-10 mg/mL compared to the standard 100 mg/mL. Additionally, studies on *Bacillus thuringiensis* (Bt) formulations derived from different *Aspergillus* isolates—and their effectiveness against various *Aspergillus flavus* strains—could provide valuable insights.

Future work should also emphasize comparative performance studies between different BCAs, moving beyond a narrow focus on *A. flavus* or mulberry fruits to include other economically significant pests and crop systems. Such comprehensive evaluations will help in identifying the most robust, cost-effective, and environmentally compatible solutions, ultimately ensuring that mulberry cultivation remains sustainable, productive, and resilient in the face of evolving pest pressures.

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