



BIOSTIMULANT AND PLANT GROWTH REGULATOR: APPLICATIONS AND SIGNALING MECHANISM

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Eco-Friendly Pest Control: A Comprehensive Review of Plant-Derived Biopesticides for Sustainable Agriculture

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Abstract

The extensive dependence on synthetic chemical pesticides has resulted in significant ecological disturbances, including pesticide resistance, bioaccumulation, and adverse effects on non-target organisms (Isman, 2006; Saxena & Khan, 2021). As an environmentally sustainable alternative, plant-derived biopesticides have gained prominence within the framework of Integrated Pest Management (IPM), offering eco-friendly pest control solutions (Govindarajan et al., 2016). Many plant species produce secondary metabolites with potent insecticidal properties, such as alkaloids, flavonoids, terpenoids, and tannins, which effectively target insect pests while minimizing environmental harm (Gonzalez-Coloma et al., 2020). This review highlights the efficacy of botanicals, including *Azadirachta indica*, *Vitex negundo*, *Calotropis gigantea*, *Acacia nilotica* (Babul), *Bauhinia blakeana* and *Lantana camara*, in controlling agricultural and vector pests. These plant-based bioactive compounds exhibit significant larvicidal, ovicidal, antifeedant, and repellent activities, contributing to sustainable pest management strategies (Rajakumar & Rahuman, 2011; Sharma & Kumar, 2020). The integration of biopesticides into IPM can mitigate the harmful consequences of chemical pesticides while ensuring long-term agricultural productivity and ecological balance. This review underscores the significance of plant-derived biopesticides in modern pest control and their role in promoting sustainable agriculture and vector management.

Keywords: Biopesticides, Plant-Derived Insecticides, Integrated Pest Management (IPM), Sustainable Agriculture, *Azadirachta indica*, *Calotropis gigantea*, *Vitex*

negundo, *Lantana camara*, *Acacia nilotica*, *Bauhinia blakeana*, Secondary Metabolites, Herbal Pest Management, Green Pesticide Alternatives.

Introduction

The widespread and indiscriminate application of synthetic pesticides has raised serious concerns regarding environmental sustainability, human health, and the development of pesticide resistance in insect populations (Isman, 2006). Synthetic pesticides contribute to soil and water contamination, disrupt ecological food webs, and harm non-target organisms, including pollinators and natural predators of pests (Mancini et al., 2019). Additionally, bioaccumulation of pesticide residues in agricultural produce poses significant risks to human health, leading to neurological disorders, endocrine disruption, reproductive toxicity, and even carcinogenic effects upon prolonged exposure (Mostafalou & Abdollahi, 2017). As a sustainable alternative, Integrated Pest Management (IPM) promotes the use of biological control agents and plant-derived biopesticides to mitigate these adverse effects while ensuring effective pest suppression (Saxena & Khan, 2021). Unlike synthetic pesticides, which persist in the environment and accumulate in the food chain, botanical pesticides degrade rapidly, reducing the risks of long-term toxicity (Gonzalez-Coloma et al., 2020). Plants have evolved complex defense mechanisms, synthesizing a wide range of secondary metabolites such as alkaloids, flavonoids, terpenoids, and tannins. These bioactive compounds exhibit insecticidal, antifeedant, ovicidal, and repellent properties, effectively controlling pest populations without

harming beneficial organisms (Tudi et al., 2021). Moreover, plant-derived biopesticides pose minimal risks to human health, making them promising alternatives for sustainable pest control. The shift toward botanical pesticides not only reduces pesticide-induced environmental degradation but also aligns with global efforts to promote sustainable agricultural practices. Their integration into IPM strategies can mitigate resistance development in insect populations, safeguard biodiversity, and contribute to safer food production systems, ensuring long-term ecological balance and public health safety.

Secondary Metabolites as Insecticidal Agents

Secondary metabolites are naturally occurring bioactive compounds produced by plants as part of their defense mechanisms against herbivores, pathogens, and environmental stressors. Among these, alkaloids, flavonoids, terpenoids, tannins, and essential oils have been extensively studied for their potent insecticidal properties (Sengottayan et al., 2013). These compounds exhibit diverse modes of action, disrupting various physiological and biochemical processes in insect pests, ultimately affecting their feeding behavior, development, reproduction, and survival. Alkaloids, such as nicotine and rotenone, act as neurotoxins, interfering with neurotransmission and causing paralysis or death in insect populations. Flavonoids, known for their antioxidant properties, disrupt metabolic pathways, impairing digestion and

nutrient absorption in pests. Terpenoids, including azadirachtin from *Azadirachta indica* (neem), function as growth regulators by inhibiting molting and development in insect larvae (Jeyasankar et al., 2022). Tannins, commonly found in *Acacia* and *Calotropis* species, exert antifeedant effects, reducing insect herbivory by interfering with enzyme activity in the digestive system of pests. Essential oils, extracted from aromatic plants like *Eucalyptus globulus* and *Lantana camara*, have been reported to possess strong fumigant and repellent properties, further contributing to insect control (Rattan, 2010). Numerous studies have demonstrated the efficacy of plant-derived secondary metabolites in controlling various insect pests while posing minimal risks to non-target species and beneficial organisms (Pavela et al., 2019). Unlike synthetic pesticides, which often lead to resistance development, these bioactive compounds degrade rapidly in the environment, reducing the likelihood of long-term toxicity and ecological disruption. Their selective action against insect pests makes them valuable components of eco-friendly pest management strategies, reinforcing the role of botanical insecticides in sustainable agriculture and vector control.

Review of Selected Plant-Derived Biopesticides

➤ *Azadirachta indica*

Neem (*Azadirachta indica*) is one of the most extensively studied botanical insecticides, renowned for its broad-spectrum efficacy against various insect pests. The primary bioactive compound, azadirachtin, exhibits strong antifeedant, growth-disrupting, and repellent

properties, making neem-based biopesticides a valuable component of Integrated Pest Management (IPM) strategies (Isman, 2020). Unlike synthetic pesticides, neem-derived compounds act selectively on target pests while exhibiting minimal toxicity to non-target organisms, making them environmentally sustainable alternatives for pest control. Azadirachtin disrupts insect growth and development by interfering with the hormonal regulation of molting and metamorphosis. It functions as an insect growth regulator (IGR), preventing larvae from successfully transitioning into the next developmental stage, ultimately leading to mortality. Additionally, neem extracts inhibit feeding behavior in a wide range of insect species, including lepidopteran pests, aphids, whiteflies, and mosquito larvae (Govindarajan et al., 2016). The repellent properties of neem also deter insect vectors, reducing their population densities and minimizing the spread of vector-borne diseases. Several studies have demonstrated the effectiveness of neem-based formulations against agricultural pests and disease-carrying vectors. For instance, neem oil and neem seed extracts have shown significant larvicidal activity against *Aedes aegypti* and *Anopheles stephensi*, the primary vectors of dengue and malaria, respectively (Sohail et al., 2021). Furthermore, neem-derived products have been successfully incorporated into organic farming systems as seed treatments, foliar sprays, and soil amendments to manage pest infestations while preserving soil health.

➤ *Vitex negundo*

Vitex negundo, commonly known as the five-leaved chaste tree, is a medicinal

plant widely recognized for its insecticidal and repellent properties. The bioactive compounds found in *V. negundo*, including flavonoids, alkaloids, terpenoids, and essential oils, contribute to its potent larvicidal, ovicidal, and insect-repellent activities. Recent studies have demonstrated the effectiveness of different solvent extracts of *V. negundo* against *Spodoptera litura*, revealing significant antifeedant and insecticidal properties. These findings highlight the plant's potential as a natural biopesticide for pest management in agriculture and support its integration into sustainable Integrated Pest Management (IPM) programs (Shewale et al., 2022). Studies have demonstrated that extracts from *V. negundo* leaves exhibit strong larvicidal activity against mosquito species such as *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus*, which are primary vectors of dengue, malaria, and filariasis, respectively (Tiwari et al., 2021). The flavonoids and alkaloids present in *V. negundo* interfere with the normal physiological processes of insect larvae, leading to developmental disruption and mortality. Additionally, the repellent properties of its essential oils help in reducing the risk of vector-borne disease transmission by deterring adult mosquitoes from human dwellings. *V. negundo* extracts have also been found effective against stored grain pests such as *Sitophilus oryzae* (rice weevil) and *Tribolium castaneum* (red flour beetle), which cause significant losses in agricultural produce (Rajashekar et al., 2017). The bioactive compounds exert contact toxicity and inhibit feeding behavior in these pests, reducing their populations in storage environments.

➤ *Calotropis gigantea*

Calotropis gigantea, commonly known as the milkweed or giant milkweed plant, is a widely distributed medicinal plant known for its potent insecticidal properties. This plant produces a milky latex rich in bioactive compounds, particularly cardenolides (cardiac glycosides), flavonoids, alkaloids, and terpenoids, which contribute to its toxicity against various insect pests. These compounds act as natural defense mechanisms, deterring herbivory and providing a sustainable alternative to synthetic pesticides in Integrated Pest Management (IPM) programs. Recent studies have demonstrated the significant antifeedant activity of *C. gigantea* extracts against *Spodoptera litura*, highlighting its potential as an eco-friendly biopesticide (Lawand & Shewale, 2024). The cardenolides present in *C. gigantea* primarily disrupt the nervous and cardiac systems of insects by inhibiting Na^+/K^+ -ATPase, a crucial enzyme in nerve signal transmission (Senthil-Nathan, 2019). This leads to paralysis and eventual mortality in targeted insect populations. Several studies have demonstrated that extracts derived from different parts of *C. gigantea*, including leaves, flowers, and latex, exhibit strong insecticidal activity against mosquitoes such as *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus* (Rajakumar & Rahuman, 2011). These mosquito species are responsible for transmitting life-threatening diseases such as dengue, malaria, and filariasis, making *C. gigantea* a valuable plant for vector control strategies.

C. gigantea extracts have also shown remarkable toxicity against lepidopteran

larvae, such as *Spodoptera litura* and *Helicoverpa armigera*, which are major agricultural pests (Murugan et al., 2012). The latex-derived compounds interfere with larval growth and development, causing feeding inhibition, developmental deformities, and increased mortality rates. Additionally, the plant's secondary metabolites exhibit antifeedant and repellent properties, reducing crop damage by deterring insect herbivores.

➤ ***Acacia nilotica***

Acacia nilotica, commonly known as babul or gum arabic tree, is a leguminous plant widely recognized for its potent insecticidal, antimicrobial, and medicinal properties. The plant is particularly rich in tannins, flavonoids, alkaloids, and phenolic compounds, which contribute to its strong bioactivity against a range of insect pests. The high tannin content in *A. nilotica* plays a crucial role in disrupting insect digestive processes by forming complexes with proteins, thereby reducing nutrient absorption and leading to growth inhibition and mortality (Ali et al., 2018). The presence of these bioactive compounds makes *A. nilotica* a promising botanical pesticide, offering an eco-friendly alternative to conventional chemical insecticides.

Several studies have demonstrated the efficacy of *A. nilotica* extracts against key agricultural and vector pests. Its leaf and bark extracts have shown significant toxicity against cotton pests such as *Helicoverpa armigera* and *Spodoptera litura*, which are major threats to cotton crops (Kumar et al., 2019). Additionally, *A. nilotica* extracts exhibit strong repellent and larvicidal effects against

stored grain pests like *Sitophilus oryzae* (rice weevil) and *Callosobruchus chinensis* (pulse beetle), reducing post-harvest losses in storage systems (Sharma & Gupta, 2021). Furthermore, aqueous and ethanol extracts of *A. nilotica* have demonstrated substantial larvicidal activity against mosquito species such as *Aedes aegypti* and *Culex quinquefasciatus*, which are responsible for transmitting diseases like dengue and filariasis (Ali et al., 2018). These findings highlight the potential of *A. nilotica* in sustainable pest management, supporting its integration into organic farming and vector control programs.

➤ ***Bauhinia blakeana***

Bauhinia blakeana, commonly known as the Hong Kong orchid tree, is a flowering plant that has gained attention for its bioactive properties, particularly in insect pest management. The floral extracts of *B. blakeana* are rich in secondary metabolites such as flavonoids, tannins, and alkaloids, which contribute to its strong insecticidal effects. Studies have demonstrated that these bioactive compounds interfere with insect growth and development, causing physiological disruptions that lead to high mortality rates in target pests (Ganesan et al., 2014). Among its notable applications, *B. blakeana* extracts have exhibited strong larvicidal activity against mosquito species, making it a promising natural alternative for controlling vector populations. Research indicates that the chloroform and acetone extract of *B. blakeana* flowers effectively target late third- and early fourth-instar mosquito larvae, causing significant mortality within a short exposure period. This suggests that the plant's bioactive compounds affect

larval metabolism, ultimately leading to death (Kumar et al., 2018). The eco-friendly nature of *B. blakeana* extracts presents an advantage over synthetic insecticides, as they pose minimal risk to non-target organisms and the environment. With further studies and formulation advancements, *B. blakeana* could be integrated into sustainable vector control programs, offering a plant-based alternative for mosquito management.

➤ *Lantana camara*

Lantana camara, an invasive shrub known for its medicinal and pesticidal properties, has been extensively studied for its insecticidal potential. The plant produces a variety of bioactive compounds, including essential oils, flavonoids, alkaloids, and phenolic compounds, which contribute to its effectiveness against insect pests. Essential oils extracted from *L. camara* leaves have been shown to exhibit strong repellent and toxic effects against mosquitoes, particularly *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus*—all known vectors of major diseases like dengue, malaria, and filariasis (Sharma & Kumar, 2020). Additionally, its insecticidal activity extends to agricultural pests such as aphids, whiteflies, and stored grain pests, making it a valuable natural alternative to synthetic pesticides. The mode of action of *L. camara* extracts is largely attributed to its phenolic and terpenoid compounds, which interfere with insect feeding, molting, and overall development. These compounds act as antifeedants, growth regulators, and neurotoxins, disrupting the normal physiology of target insects and

ultimately causing mortality (Gupta et al., 2019). Studies have shown that the leaf extracts not only reduce pest populations but also deter future infestations by affecting insect oviposition behavior.

Efficacy of plant-derived biopesticides against insect pests

Plant-derived biopesticides have gained significant attention as effective alternatives to synthetic chemical pesticides, providing sustainable pest management solutions with minimal environmental impact. Numerous studies have demonstrated the efficacy of botanical extracts against a wide range of agricultural and public health pests, including mosquitoes, aphids, lepidopteran larvae, and stored grain pests. The bioactive compounds present in these plant-based formulations, such as alkaloids, flavonoids, terpenoids, and tannins, exhibit insecticidal, antifeedant, repellent, and ovicidal properties that disrupt the life cycle of various insect species (Rajakumar & Rahuman, 2011). The efficacy of these botanical pesticides depends on the plant species, extraction method, and target pest, with some showing remarkable pest control potential comparable to synthetic insecticides. Among the most effective plant-based biopesticides, *Azadirachta indica* (Neem) and *Calotropis gigantea* have demonstrated over 80% mortality rates against mosquito larvae, significantly reducing vector populations responsible for transmitting diseases like malaria and dengue (Rajakumar & Rahuman, 2011). Similarly, *Vitex negundo* and *Lantana camara* extracts have shown strong antifeedant and ovicidal effects against stored grain pests such as *Sitophilus oryzae* and

Callosobruchus chinensis, effectively preventing post-harvest losses (Tiwari et al., 2021). These plant-based biopesticides not only provide effective pest control but also reduce the risk of pesticide resistance and ecological damage associated with synthetic chemicals.

Conclusion

Plant-derived biopesticides offer an eco-friendly and sustainable alternative to synthetic pesticides, reducing environmental contamination, pesticide resistance, and health risks. The bioactive compounds in botanicals such as *Azadirachta indica*, *Calotropis gigantea*, *Vitex negundo*, *Lantana camara*, *Acacia nilotica*, and *Bauhinia blakeana* exhibit potent insecticidal, antifeedant, ovicidal, and repellent properties, making them valuable tools in Integrated Pest Management (IPM).

Despite their proven efficacy, challenges such as formulation stability, extraction efficiency, and large-scale commercialization need to be addressed. Advancements in formulation technology and field validation will enhance their effectiveness and widespread adoption. Future research should focus on optimizing their application, exploring novel bioactive compounds, and promoting their integration into mainstream pest management. By overcoming these barriers, plant-derived biopesticides can contribute significantly to sustainable agriculture and public health pest control while preserving ecological balance.

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