Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(3), 732-738 | ISSN:2251-6727

The Role of Natural Products in Advancing Eco-Friendly Pest Management: A Review on Bio-pesticides

Veena Kumari[1], Rekha Jethi[1], Santosh Kumar[2], Vaishali Koul[3]*, Swati[4], Ankit Kumar[3]

[1]*JBIT College of Pharmacy, Dehradun, 248197, India*

[2] *Doon College of Pharmacy, Selaqui, 248197, Dehradun, India*

[3]*College of Pharmacy, Shivalik Campus, Dehradun, 248197, India*

[4]School of Basic & Applied Sciences, Shri Guru Ram Rai University, Dehradun, India

(Received: 16 March 2025 Revised: 20 April 2025 Accepted: 01 May2025)

KEYWORDS

Integrated pest management (IPM), Pesticide resistance, Eco-friendly, Insect growth Regulator (IGR)

ABSTRACT:

Introduction: Pest management plays a vital role in agriculture and environmental protection, as pests can significantly harm crops, livestock, and human well-being. Although synthetic pesticides have traditionally dominated pest control, their long-term use has raised serious concerns regarding environmental pollution, human health risks, and the emergence of pesticide-resistant pest populations. These challenges have driven a shift toward exploring natural, sustainable alternatives. Natural products derived from plants, animals, and microorganisms have shown promise as biopesticides due to their eco-friendly profiles, safety, and targeted action against pests.

Objective: To explore the potential of natural products as eco-friendly alternatives to synthetic pesticides by reviewing their sources, mechanisms of action, and effectiveness in pest control, along with the challenges and future scope of their integration into sustainable pest management strategies.

Materials and Methods: An extensive literature review was conducted using databases such as PubMed, Scopus, and Web of Science. Research articles published between 2000 and 2024 were reviewed, focusing on the role of natural products in pest management. The study emphasized the identification of sources, active constituents, and mechanisms of action of biopesticides derived from natural products.

Results: The review revealed a wide range of natural products exhibiting pesticidal activity through various mechanisms such as antifeedant, repellent, ovicidal, or growth-inhibiting effects. These include compounds derived from plants (e.g., neem, pyrethrum), microorganisms (e.g., Bacillus thuringiensis), insects, and nematodes. Many of these biopesticides demonstrated significant effectiveness against diverse pest species and offer a lower environmental footprint compared to synthetic pesticides. However, limitations such as stability, large-scale production, and regulatory hurdles remain challenges for broader implementation.

Conclusion: Natural products represent a promising and sustainable alternative in the realm of pest management. While they offer effective and environmentally safe options, their integration into mainstream agriculture requires overcoming formulation, regulatory, and awareness challenges. Continued research and development are crucial to optimize their use in Integrated Pest Management (IPM) programs, paving the way for greener and safer pest control practices.

1. Introduction

A pest refers to an unwanted organism, whether animal or plant, that inflicts harm or results in loss to crops, encompassing both medicinal and aromatic plants. Various categories of pests can impact medicinal plants, whether they are cultivated or wild. These include weeds, insects, non-insect organisms (both vertebrates and invertebrates), microorganisms, and nematodes [1]. Aphids (*Aphis species*) serve as prevalent

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(3), 732-738 | ISSN:2251-6727

insect pests that can infest medicinal plants such as *Matricaria chamomilla* (Chamomile), ultimately reducing their yield and quality [2]. Powdery mildew (*Erysiphe cichoracearum*) represents a fungal disease that has the potential to infect medicinal plants, including *Echinacea* species, thereby influencing their medicinal attributes [3]. Leaf hoppers are prevalent insect pests that can infest medicinal plants like *Mentha* species (Mint) and facilitate the spread of viral diseases, resulting in diminished plant vigor and medicinal qualities [4]. Root-knot nematodes (*Meloidogyne* species) are tiny roundworms that can invade the roots of medicinal plants such as Ginseng (*Panax* species), leading to root galling, stunted growth, and diminished yield [5]. The management of pests plays a crucial role in agriculture and environmental conservation, given that pests can lead to considerable losses in the cultivation of medicinal and aromatic plants, crop production, livestock farming, and human health. The extensive application of synthetic pesticides for pest control has resulted in numerous challenges. These include the emergence of pesticide resistance among pest populations, detrimental impacts on non-target species, and the contamination of soil, water, and food with pesticide residues [6].

In recent years, there has been an increasing focus on utilizing natural products as viable alternatives to synthetic pesticides for sustainable pest management [7]. Various methods are commonly employed in pest control or management, including cultural, agricultural, biological, mechanical, and chemical approaches, depending on the type of pest involved. Multiple techniques are presently employed globally by cultivators to safeguard their crops, farming practices, and health, a tradition that dates back to ancient times. These include crop rotation, mixed cropping or intercropping, soil solarization, hand picking, pest traps, and the collection and destruction of eggs and larvae, as well as the use of chemical pesticides [4-5, 8-10]. In addition, the production of plants that are resistant to pests and insects through the use of genetic engineering is another contemporary method that is being utilized all over the world in both developed and developing countries [11, 12]. Natural products derived from a range of sources including plants, animals, and microorganisms, and have historically been utilized for their pesticidal characteristics. These alternatives present numerous benefits compared to synthetic pesticides, such as their efficacy in pest control, safety for non-target species, low toxicity levels, biodegradability, and sustainable practices [13]. Natural products exhibit a variety of mechanisms, such as repellency, toxicity, anti-feedant properties, growth inhibition, and alteration of pest behavior. These characteristics render them appropriate for incorporation into integrated pest management (IPM) strategies, which seek to reduce dependence on synthetic pesticides and encourage sustainable pest control methods [14].

This review provide a comprehensive examination of the function of natural products in pest management, emphasizing their mechanisms of action, effectiveness against various pest types, and their potential as substitutes for synthetic pesticides. The review emphasizes the challenges and future prospects of utilizing natural products in pest management, underscoring the necessity for additional investigation to enhance their application in integrated pest management strategies.

2. Natural Products as Bio-pesticide

Natural products used in pest management exert their effects through various modes of action such as repellency, toxicity, anti-feedant property, growth inhibition and disruption of pest behavior etc. Essential oils derived from *Azadirachta indica*, *Cymbopogon nardus* and *Corymbia citriodora* have been found to repel mosquitoes and other insects [13]. Pyrethrins, which are natural insecticides derived from *Chrysanthemum cinerariaefolium*, have been widely used to control various insect pests due to their rapid knockdown and low mammalian toxicity [14]. *Azadirachta indica* oil effectively deters feeding on *Vicia faba* (fava beans) and significantly reduced weevil damage and larval populations relative to control plants (Reddy & Guerrero, (2010). Azadirachtin, has anti-feedant activity and inhibits the feeding and growth of many insect pest [13]. The insect growth regulator (IGR) ecdysone agonist, derived from the plant *Peganum harmala*, interferes with the molting process in insects, causing abnormal development and mortality [15]. The

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(3), 732-738 | ISSN:2251-6727

pheromones, which are natural compounds released by insects to communicate with each other, can be used as lures or repellents to manipulate the behavior of pests, such as the mating disruption technique used against fruit flies [14]. Similarly, essential oils from plants such as *Thymus vulgaris*, *Mentha piperita*, and *Allium sativum* have shown insecticidal activity against various pests [15]. Natural products, such as extracts and oils, have shown efficacy against mite pests, including spider mites, rust mites, and eriophyid mites. The clove oil (*Syzygium aromaticum*) has been shown to be effective against spider mites on greenhouse crops [14]. The extracts of marigold (*Tagetes* species.) and tobacco (*Nicotiana* species.), have shown nematicidal activity against plant-parasitic nematodes [15]. The extracts of garlic (*Allium sativum*) and cinnamon (*Cinnamomum* species) have shown anti-microbial activity against various plant pathogens [14]. Table 1 provides a summary of biopesticides sourced from natural origins, including plants, microorganisms, insects, and nematodes. It details their sources, scientific names, active chemical constituents, and the mechanisms by which they act against pests.

3. Integrated pest management (IPM)

IPM is a sustainable approach to pest management that aims to reduce the use of synthetic pesticides and promote the use of multiple pest control strategies in a complementary manner. Natural products play a crucial role in IPM, as they can be used as part of a holistic approach to pest management. The use of natural products in IPM can reduce the dependence on synthetic pesticides, which can have harmful effects on the environment, non-target organisms, and human health. Natural products offer a safer alternative to control pests without causing harm to the ecosystem, and they can be used in rotation or combination with other pest control methods to reduce the risk of resistance development in pests [15,19]. Natural products are derived from renewable sources and can be produced using sustainable methods, making them an environmentally friendly option for pest management. Many natural products are biodegradable and have low toxicity to non-target organisms, which minimizes the potential for negative impacts on beneficial insects, wildlife, and aquatic organisms [14]. Natural products are widely used in organic agriculture, where the use of synthetic pesticides is restricted or prohibited. Natural products provide an important tool for organic farmers to manage pests while complying with organic certification standards. For example, Neem derived products, pyrethrum-based products, and botanical oils are commonly used in organic farming for pest control [15,19]. Natural products represent a vast and largely untapped source of potential bioactive compounds for pest management. Many plants, particularly those in traditional systems of medicine such as Ayurveda or Chinese system of medicine, have not been extensively studied for their pest control properties. Continued research on natural products can lead to the discovery of new compounds with potent pesticidal activity, providing innovative solutions for pest management [15,19].

4. Conclusion: It has been shown that the farmers or cultivators have limited knowledge about the use and safe handling of synthetic pesticides may suffer exposure which results in adverse health effects. Natural products have emerged as promising alternatives for pest management, offering effective and environmentally friendly options for controlling pests in various agricultural and horticultural systems. Their mode of action, efficacy against pests, and potential for use in integrated pest management approaches make them valuable tools for sustainable pest management. Further research and exploration of natural products from diverse sources hold great potential for discovering new compounds with pesticidal activity. The use of natural products in pest management can contribute to sustainable agriculture, minimize the negative impacts of synthetic pesticides on the environment, and protect human health and biodiversity.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(3), 732-738 | ISSN:2251-6727

Table 1: Natural Bio-pesticides – Origin, Scientific Name, Active Constituents, and Mechanisms against Pests

S. No.	Name of Natural Product	Scientific Name (Active Constituent)	Mechanism of action against pests
		Plants	
1.	Neem (oil and extracts)	*Azadirachta indica* (Azadirachtin)	Acts as an insect growth regulator, disrupts the feeding and reproductive abilities of pests, and repels pests. Acts as a broad-spectrum insecticide, antifeedant, and growth regulator, disrupting the feeding, growth, and reproduction of pests [13].
2.	Pyrethrum	*Chrysanthemum cinerariaefolium* (Pyrethrins)	Acts as a contact insecticide and disrupts the nervous system of pests, causing paralysis and death [13,16].
3.	Garlic (oil)	*Allium sativum* (Allicin)	Acts as a repellent, inhibits feeding and growth of pests, and disrupts the metabolism of pests [17].
4.	Eucalyptus (oil)	*Eucalyptus globulus* (Eucalyptol)	Acts as a contact insecticide, disrupts the respiratory system of pests, and repels pests. Acts as a repellent, antifeedant, and oviposition deterrent against pests [15,18].
5.	Tuba root	*Derris elliptica/ Lonchocarpus nicou* (Rotenone)	Acts as a stomach poison and inhibits cellular respiration in pests [19].
6.	Capsaicin	*Capsicum* species (*Capsaicinoids*)	Acts as a contact insecticide and repellent, causing irritation and paralysis in pests [20].
7.	Tobacco	*Nicotiana* species (Nicotine)	Acts as a neurotoxin, disrupting the nervous system of pests and causing paralysis and death [21].
8.	Ryania	*Ryania speciosa* (Ryanodine)	Acts as a stomach poison, causing paralysis and death in pests [22].
9.	Quassia	*Quassia amara* (Quassinoids)	Acts as a stomach poison, inhibiting feeding and growth of pests [23].
10.	Thyme	*Thymus vulgaris* (Thymol)	Acts as a contact insecticide, disrupting the nervous system of pests and causing paralysis and death [24].
		Micro-organism/ Insects/ Nematodes	
11.	Acrobe	*Bacillus thuringiensis* (Beta-exotoxin-Thuringiensin)	Acts as a biological insecticide, producing toxins that specifically target and kill certain insect pests, such as caterpillars and mosquitoes [25].
12.	Icing sugar fungus	*Beauveria bassiana*	Acts as a biological insecticide, infecting and killing a wide range of insect pests, such as whiteflies, aphids, thrips, and beetles, through direct penetration of the insect cuticle and subsequent colonization of the host [26].
13.	Green muscardine fungus	*Metarhizium anisopliae*	Acts as a biological insecticide, infecting and killing a wide range of insect pests, such as grasshoppers, locusts, beetles, and termites, through direct penetration of the insect cuticle and subsequent colonization of the host [27].

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(3), 732-738 | ISSN:2251-6727

14.	Green mold	*Trichoderma* species – *T. harzianum, T. viride,* and *T. virens*	Acts as a biocontrol agent, suppressing the growth and activity of plant pathogens, such as fungi and nematodes, through competition for resources, antibiosis, and enzyme production [28, 29].
15.	Codling moth	*Cydia pomonella* granulovirus- CpGV	Acts as a biological insecticide, infecting and killing specific insect pests, such as codling moths, armyworms, and cotton bollworms, through ingestion and subsequent viral replication, leading to the death [30].
16.	Nuclear polyhedrosis virus	*Helicoverpa armigera* nucleopolyhedrovirus - HaNPV	Acts as a biological insecticide, infecting and killing specific insect pests, such as codling moths, armyworms, and cotton bollworms, through ingestion and subsequent viral replication, leading to the death [30].
17.	Twisted fungus or Twisted spore-forming bacteria	*Streptomyces* Species- AN090126, JCK-805	Acts as a biocontrol agent, producing antibiotics and enzymes that inhibit the growth and activity of plant pathogens, such as bacteria, fungi, and nematodes, through antibiosis and enzyme-mediated degradation [31-33].
18.	Bacillus polymyxa	*Paenibacillus polymyxa*	Acts as a biocontrol agent, producing antibiotics and enzymes that inhibit the growth and activity of plant pathogens, such as bacteria, fungi, and nematodes, through antibiosis and enzyme-mediated degradation [34].
19.		Pseudomonas spp- *P. chlororaphis, P. fluorescens*	Acts as a biocontrol agent, producing antibiotics and enzymes that inhibit the growth and activity of plant pathogens, such as bacteria, fungi, and nematodes, through antibiosis and enzyme-mediated degradation [35,36].
20.	Ladybugs	*Coccinellidae* species- *C. septempunctata*)	Acts as natural predators or parasitoids of pests, feeding on or laying eggs on pests, leading to their control or suppression [37].
21.	Predatory mites	*Phytoseiidae* species	Acts as natural predators or parasitoids of pests, feeding on or laying eggs on pests, leading to their control or suppression [37].
22.	Parasitic wasps	*Tymenopteran* species	Acts as natural predators or parasitoids of pests [37].
23.	Lacewings	*Chrysoperla rufilabris*	Acts as natural predators or parasitoids of pests [37].
24.	Nematodes	*Steinernema* species *Heterorhabditis* species	Acts as biological control agents, infecting and killing pests, such as grubs, weevils, and caterpillars, through parasitism [38].

Reference

1. Ehler, L. E. Integrated Pest Management (IPM): Definition, Historical Development and Implementation, and the Other IPM. Pest Manag. Sci. 2006, 62 (9), 787–789.
2. Abbott, R. Aphids on Medicinal Plants. In Insect Pests of Medicinal Plants; Romeo, J., Ed.; CRC Press: Boca Raton, FL, 2018; pp 21–38.
3. Miller, M. T. Powdery Mildew of Medicinal Plants. In Diseases of Medicinal Plants; Mirza, S. S., Ed.; Springer: Cham, 2016; pp 157–175.
4. Choudhary, N.; Sharma, R. Pest Management in Medicinal Plants. In Pest Management in

Horticultural Ecosystems; Kanwar, S. S., Ed.; Springer: Singapore, 2019; pp 125–160.
5. Chitwood, D. J. Research on Plant-Parasitic Nematode Biology Conducted by the United States Department of Agriculture-Agricultural Research Service. Pest Manag. Sci. 2003, 59 (6–7), 748–753.
6. Damalas, C. A.; Eleftherohorinos, I. G. Pesticide Exposure, Safety Issues, and Risk Assessment Indicators. Int. J. Environ. Res. Public Health 2011, 8 (5), 1402–1419.
7. Souto, A. L.; Sylvestre, M.; Tölke, E. D.; Tavares, J. F.; Barbosa-Filho, J. M.; Cebrián-Torrejón, G. Plant-Derived Pesticides as an Alternative to Pest Management and Sustainable Agricultural Production: Prospects, Applications and Challenges. Molecules 2021, 26 (16), 4835. https://doi.org/10.3390/molecules26164835.
8. Foy, C. L. Weed Management in Medicinal Plants. In Weed Management in Horticultural Crops; Parvatha Reddy, P., Ed.; New India Publishing Agency: New Delhi, 2012; pp 325–340.
9. Karuppuchamy, P.; Venugopal, S. Integrated Pest Management. In Ecofriendly Pest Management for Food Security; Omkar, Ed.; Academic Press: London, 2016; pp 651–684.
10. Barzman, M.; Bàrberi, P.; Birch, A. N. E.; Boonekamp, P.; Dachbrodt-Saaydeh, S.; Graf, B.; Hommel, B.; Jensen, J. E.; Kiss, J.; Kudsk, P.; Lamichhane, J. R.; Messéan, A.; Moonen, A. C.; Ratnadass, A.; Ricci, P.; Sarah, J. L.; Sattin, M. Eight Principles of Integrated Pest Management. Agron. Sustain. Dev. 2015, 35 (4), 1199–1215.
11. Gatehouse, A. M.; Ferry, N.; Edwards, M. G.; Bell, H. A. Insect-Resistant Biotech Crops and Their Impacts on Beneficial Arthropods. Philos. Trans. R. Soc. Lond. B Biol. Sci. 2011, 366 (1569), 1438–1452. https://doi.org/10.1098/rstb.2010.0330.
12. Hamdan, M. F.; Tan, B. C. Genetic Modification Techniques in Plant Breeding: A Comparative Review of CRISPR/Cas and GM Technologies. Hortic. Plant J. 2024. https://doi.org/10.1016/j.hpj.2024.01.001.
13. Isman, M. B. Botanical Insecticides, Deterrents, and Repellents in Modern Agriculture and an Increasingly Regulated World. Annu. Rev. Entomol. 2006, 51, 45–66.
14. Isman, M. B. Plant Essential Oils for Pest and Disease Management. Crop Prot. 2015, 76, 17–21.
15. Regnault-Roger, C. The Potential of Botanical Essential Oils for Insect Pest Control. In Integrated Pest Management and Pest Control: Current and Future Tactics; InTech: Rijeka, 2012; pp 191–220.
16. Palumbo, J. C.; Horowitz, A. R. Pyrethrum: A Safe and Effective Natural Insecticide. University of Arizona Cooperative Extension Publication AZ1292, 2001.
17. Datta, S.; Singh, J. Botanicals as Pesticides: An Eco-Friendly Approach for Pest Management. In Integrated Pest Management: Current Concepts and Ecological Perspective; Abrol, D. P., Ed.; Springer: Dordrecht, 2016; pp 363–386.
18. Boukhris-Bouhachem, S.; Ben Slimane, M.; Daami-Remadi, M.; Zaouali, Y. Chemical Composition and Insecticidal Activity of Essential Oils from Tunisian Eucalyptus Species against Stored-Product Pests. J. Stored Prod. Res. 2021, 92, 101817.
19. Regnault-Roger, C.; Vincent, C.; Arnason, J. T. Essential Oils in Insect Control: Low-Risk Products in a High-Stakes World. Annu. Rev. Entomol. 2012, 57, 405–424.
20. Gómez-Pérez, D.; Perera-Moya, D. Capsaicin as a Botanical Pesticide: A Review of the Main Biopesticidal Mechanisms and Applications. Plants 2020, 9 (5), 647.
21. Singh, R.; Sharma, M.; Sharma, P. Nicotine as a Botanical Pesticide in Sustainable Agriculture: A Review. Proc. Natl. Acad. Sci. India Sect. B Biol. Sci. 2018, 88 (3), 1029–1040.
22. Isman, M. B. Ryania speciosa, a Botanical Insecticide Whose Time Has Come ... and Gone? Pest Manag. Sci. 2020, 76 (3), 1149–1153.
23. Ntalli, N. G.; Menkissoglu-Spiroudi, U. Pesticides of Botanical Origin: A Promising

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(3), 732-738 | ISSN:2251-6727

Tool in Plant Protection. In Pesticides - Formulations, Effects, Fate; InTech: Rijeka, 2011; pp 1–23.
24. Pavela, R. Insecticidal Properties of Several Essential Oils on the House Fly (Musca domestica L.). Phytother. Res. 2014, 28 (2), 270–275.
25. Bravo, A.; Likitvivatanavong, S.; Gill, S. S.; Soberón, M. Bacillus thuringiensis: A Story of a Successful Bioinsecticide. Insect Biochem. Mol. Biol. 2011, 41 (7), 423–431.
26. Vega, F. E.; Kaya, H. K. Insect Pathology; Academic Press: San Diego, CA, 2012.
27. Jaronski, S. T. Ecological Factors in the Inundative Use of Fungal Entomopathogens. BioControl 2010, 55 (1), 159–185.
28. Harman, G. E.; Howell, C. R.; Viterbo, A.; Chet, I.; Lorito, M. Trichoderma Species—Opportunistic, Avirulent Plant Symbionts. Nat. Rev. Microbiol. 2004, 2 (1), 43–56.
29. Yao, X.; Guo, H.; Zhang, K.; Zhao, M.; Ruan, J.; Chen, J. Trichoderma and Its Role in Biological Control of Plant Fungal and Nematode Disease. Front. Microbiol. 2023, 14, 1160551.
30. Jehle, J. A. Baculovirus Pest Control in Lepidoptera. Annu. Rev. Entomol. 2004, 49, 337–358.
31. Loria, R.; Bignell, D. R.; Moll, S. Biotechnology and Genetics of the Genus Streptomyces. Appl. Microbiol. Biotechnol. 2008, 78 (6), 1249–1265.
32. Nguyen, L. T. T.; Park, A. R.; Van Le, V.; et al. Exploration of a Multifunctional Biocontrol Agent Streptomyces sp. JCK-8055 for the Management of Apple Fire Blight. Appl. Microbiol. Biotechnol. 2024, 108, 49. https://doi.org/10.1007/s00253-023-12874-w.
33. Le, K. D.; Yu, N. H.; Park, A. R.; Park, D. J.; Kim, C. J.; Kim, J. C. Streptomyces sp. AN090126 as a Biocontrol Agent against Bacterial and Fungal Plant Diseases. Microorganisms 2022, 10 (4), 791.
34. McSpadden Gardener, B. B. Ecology of Bacillus and Paenibacillus spp. in Agricultural Systems. Phytopathology 2004, 94 (11), 1252–1258.
35. Ganeshan, G.; Kumar, A. M. Pseudomonas fluorescens, a potential bacterial antagonist to control plant diseases. J. Plant Interact. 2005, 1 (3), 123–134.
36. 36. Anderson, A. J.; Kim, Y. C. Biopesticides produced by plant-probiotic Pseudomonas chlororaphis isolates. Crop Prot. 2018, 105, 62–69.
37. 37. Gurr, G. M.; Wratten, S. D.; Snyder, W. E. Biodiversity and Insect Pests: Key Issues for Sustainable Management; John Wiley & Sons: Hoboken, NJ, 2012.