THE AGBIZ TODAY *E-Magazine*, Vol. -2 Issue-1, January 2025: 036 -043
Kumar et al.
https://sabm.scholics.in/

Plant-based pesticides and their role in sustainable agriculture

Neha Thakur[1], Nitesh Kumar[1], Saket Kumar[2], Arvind Kumar[3], Mamta Singh Pathania[4], Isha Thakur[1]*

[1]Department of Biosciences, Himachal Pradesh University, Shimla

[2]Department of Agriculture, K.P.S. Degree College Kakarua (Maheshpura) Lalitpur

[3]Department of Botany, T.J.C.M. Government Degree College, Sujanpur Tihra, Hamirpur, H.P.

[4]Shoolini Institute of Life Sciences and Business Management, the mall, Solan, H.P.

***Correspondence Author Email**: niteshchauhan7@gmail.com

ABSTRACT

Plant-based pesticides, derived from botanical sources, have gained attention as eco-friendly alternatives to synthetic agrochemicals in sustainable agriculture. These natural pesticides are sourced from plant metabolites such as alkaloids, terpenoids, flavonoids, and essential oils, offering effective pest management while minimizing environmental harm. Unlike synthetic counterparts, plant-based pesticides are biodegradable, reduce chemical residues in food, and mitigate risks to non-target organisms. Their role in promoting biodiversity, enhancing soil health, and reducing greenhouse gas emissions aligns with sustainable farming practices. However, challenges such as variability in efficacy, limited shelf life, and large-scale production must be addressed to mainstream their application. Continued research and technological innovations can expand their adoption, paving the way for a resilient and sustainable agricultural system.

Keywords: *Botanical pesticides, Sustainable agriculture, Natural pest control, Eco-friendly farming*

Introduction

Plant-based pesticides, commonly referred to as botanical pesticides are natural pest control agents derived from various parts of plants, including leaves, roots, seeds, bark, and flowers. These substances contain bioactive compounds that exhibit pesticidal properties (Okwute, 2012). Unlike synthetic chemical pesticides, which are artificially produced and often leave toxic residues in the environment, botanical pesticides are biodegradable and eco-friendly. Well-known examples include neem oil extracted from the neem tree (*Azadirachta indica*), pyrethrins derived from *Chrysanthemum* flowers, and rotenone obtained from the roots of certain tropical plants (Dalavayi Haritha et al., 2021). These natural pesticides are often specific in their action, targeting pests while being relatively harmless to helpful organisms such as soil microbes (Ngegba et al., 2022).

Importance of Sustainable Agriculture in the Context of Environmental Challenges

Sustainable agriculture is a farming method aimed at fulfilling present food and resource requirements while preserving the environment and ensuring future generations can meet their own needs (Smit & Smithers, 1993). This concept is crucial in the face of mounting ecological challenges, including water pollution, climate change, soil degradation, and biodiversity loss. The heavy reliance on synthetic chemical inputs in modern agriculture has exacerbated these issues, leading to depleted soil fertility, contaminated water resources, and disrupted ecosystems (Brodt et al., 2011). Furthermore, the extensive use of broad-spectrum chemical insecticides often harms non-target species, including beneficial insects, and aquatic life, contributing to a decline in biodiversity (Welch & Graham, 1999).

In the era of climate change, agricultural systems face additional pressures such as unpredictable weather patterns, increased pest outbreaks, and reduced crop yields. Sustainable agriculture addresses these challenges by promoting practices that conserve natural resources, enhance soil health, and protect ecosystems (Desai & Pujari, 2014). Key strategies include integrated pest management (IPM), crop rotation, biological farming, and the use of renewable, eco-friendly inputs such as plant-based pesticides (Verma et al., 2023).

Overview of How Plant-Based Pesticides Align with Sustainable Practices

Plant-based pesticides align seamlessly with sustainable agriculture principles by offering an environmentally responsible alternative to synthetic pesticides. These natural substances degrade rapidly in the environment, reducing the risk of long-term contamination in soil and water systems. Their selective toxicity minimizes harm to non-target organisms, including beneficial pollinators like bees and butterflies and natural predators that help control pest populations (Atapattu et al., 2024). Botanical pesticides also support soil health by preserving the delicate balance of microbial communities that are essential for nutrient cycling and soil fertility. Unlike synthetic chemicals, which often disrupt these systems, plant-based pesticides foster a thriving soil ecosystem. Moreover, because botanical pesticides often contain multiple bioactive compounds with varied modes of action, they help stop the development of pest resistance, a growing issue with synthetic pesticides (Baweja et al., 2020). Farmers can reduce their dependency on chemical inputs by incorporating botanical pesticides, promote ecological balance, and contribute to a more sustainable and resilient agricultural organization. This approach addresses immediate pest control needs and ensures the environment's long-term health, aligning agricultural practices with global efforts to mitigate environmental degradation and promote sustainability (Pretty & Bharucha, 2014).

Types of Plant-Based Pesticides

Plant-based pesticides encompass a diverse range of natural substances derived from various plants, each with unique pesticidal properties. These bioactive compounds target pests effectively while posing minimal harm to the environment and non-target organisms. The main types of plant-based pesticides are:

1. Neem-Based Pesticides (*Azadirachta indica*): Neem-based pesticides are among the most widely used botanical pesticides, derived from the seeds, leaves, and bark of the *Azadirachta indica*. The primary active compound is azadirachtin, which disrupts the growth, reproduction, and feeding behavior of pests. Neem pesticides are effective against a broad spectrum of pests, including aphids, whiteflies, beetles, and nematodes (Chaudhary et al., 2017). Neem products work through multiple modes of action, such as acting as antifeedants, insect growth regulators, and repellents. These qualities make them highly valuable in integrated pest management (IPM) programs, as they help prevent pest resistance. Neem

pesticides are also biodegradable, non-toxic to humans, and safe for beneficial insects like bees and butterflies (Agbo et al., 2019).

2. Pyrethrum (Derived from *Chrysanthemum* Flowers): Pyrethrum is a naturally occurring insecticide derived from the dried blooms of *Chrysanthemum cinerariifolium***.** (Wandahwa et al., 1996). The active components, pyrethrins, affect the nervous systems of insects, leading to paralysis and death. Pyrethrum is highly effective in controlling various insect pests, such as mosquitoes, flies, ants, and moths. While pyrethrins are fast-acting and potent, they degrade quickly in sunlight, reducing their persistence in the environment and making them less likely to cause long-term ecological damage. However, care must be taken in their application, as they can be toxic to fish and certain beneficial insects if misused (Singh et al., 2022).

3. Rotenone (From *Derris elliptica* and *Lonchocarpus* utilis): Rotenone is a natural pesticide derived from the roots and stems of *Derris elliptica* and *Lonchocarpus utilis*. It is primarily used to control leaf-eating insects, caterpillars, and certain aquatic pests. Rotenone works by interfering with cellular respiration in pests, leading to energy depletion and death. Although effective, rotenone is less commonly used due to its toxicity to fish and aquatic organisms. It is biodegradable and breaks down rapidly in the environment, making it a suitable choice for targeted pest control in specific scenarios (Zubairi et al., 2016).

4. Essential Oils (e.g., *Eucalyptus*, and Clove)

Essential oils extracted from aromatic plants are gaining popularity as natural pesticides. These oils contain volatile compounds that act as repellents, insecticides, or antifungal agents. Citronella oil, derived from *Cymbopogon* species, is widely used to repel mosquitoes and other biting insects (Wany et al., 2013). *Eucalyptus* oil has insecticidal and antifungal properties, making it effective against pests like mites and fungal infections in crops (Danna et al., 2024). Clove oil, rich in eugenol, is used to control aphids, whiteflies, and fungal pathogens. Essential oils are non-toxic to humans and animals, degrade rapidly, and are considered safe for organic farming (Kumar et al., 2022).

5. Alkaloids (e.g., Nicotine)

Alkaloids are nitrogen-containing compounds found in plants that exhibit pesticidal properties. Nicotine, derived from the tobacco plant (*Nicotiana tabacum*), is one of the earliest known plant-based insecticides. It acts on the nervous systems of pests, causing paralysis and death. Although effective, nicotine is highly toxic to mammals and aquatic organisms, and its use has declined due to the availability of safer alternatives (Dalton, 2015). The diversity of plant-based pesticides offers a wide array of tools for sustainable pest management. These natural products, with their unique modes of action, contribute to reducing reliance on synthetic chemicals while supporting environmental and human health. From neem-based pesticides to essential oils, each type plays a crucial role in fostering eco-friendly agricultural practices (Rahul et al., 2018).

Mechanisms of Action of Plant-based Pesticides

Plant-based pesticides exert their effects through various mechanisms, making them effective tools for pest management while minimizing environmental harm. The primary modes of action include disrupting insect development cycles, inhibiting feeding and reproduction, and repelling or directly intoxicating pests. Each mechanism targets specific aspects of pest biology, reducing populations and preventing infestations.

1. Disruption of Insect Development Cycles: One of the key mechanisms of plant-based

pesticides is their ability to interfere with the normal progress and development of insects. Compounds such as azadirachtin, found in neem-based pesticides, act as insect growth regulators (IGRs) by mimicking or blocking hormones essential for molting and metamorphosis (Dauer et al., 2012).

Molting inhibition: Insects require precise hormonal signals to shed their exoskeleton during growth. Botanical pesticides like azadirachtin disrupt these signals, preventing immature insects (larvae or nymphs) from progressing to the next developmental stage.

Prevention of metamorphosis: By interfering with the juvenile hormone balance, botanical pesticides can halt the transition from larvae to adult stages, effectively reducing the pest population's reproductive potential.

Egg development inhibition: Certain plant-based compounds reduce the viability of eggs or prevent females from laying eggs entirely. This mechanism ensures that pest populations decline over time, as fewer insects reach reproductive maturity (Chippendale, 1982).

2. Inhibition of Feeding and Reproduction: Many plant-based pesticides work as antifeedant, deterring pests from consuming plant material. These compounds alter the taste or make plants unpalatable, reducing the damage caused by chewing or sucking insects (Coulaud et al., 2015).

Antifeedant effects: Neem-based products are notable antifeedant. Azadirachtin, for example, disrupts the sensory devices insects use to identify and feed on suitable hosts. As a result, pests either stop feeding or consume less, eventually dying from starvation.

Inhibition of reproduction: Botanical pesticides can also suppress reproductive behaviors in pests. Compounds like rotenone or pyrethrins affect the mating activity or fertility of insects, reducing egg production.

Sterility induction: Some botanical compounds cause sterility in adult pests, ensuring that even if they survive, they cannot contribute to the population. Plant-based pesticides ensure long-term population control by disrupting these critical life functions (Agatz et al., 2013).

3. Repellency and Toxicity to Pests: Plant-based pesticides often act as repellents, driving pests away from treated areas, or as toxic agents that directly harm or kill pests upon contact or ingestion (Khursheed et al., 2022).

Repellency: Essential oils, such as eucalyptus, and clove oil, are highly effective repellents. These oils emit strong odors that pests find unpleasant, deterring them from settling, feeding, or reproducing in treated areas. For example, citronella oil is a well-known mosquito repellent, while eucalyptus oil deters mites and aphids.

Contact toxicity: Pyrethrum, derived from *Chrysanthemum* flowers, and nicotine from tobacco plants act quickly by targeting the pest's nervous system. Pyrethrins, for instance, disrupt sodium ion channels in the nerves, causing paralysis and death.

Ingestion toxicity: Certain plant-based compounds are lethal when ingested by pests. Rotenone, for example, inhibits cellular respiration, depleting energy reserves and causing death. The dual action of repellency and toxicity ensures immediate and long-term pest control while raising the chances of pests developing resistance (Ogendo et al., 2012).

Benefits of Plant-Based Pesticides in Sustainable Agriculture

Eco-Friendliness

- Plant-based pesticides are biodegradable, breaking down naturally without accumulating in the environment.
- They are less toxic to non-target organisms, such as birds, aquatic life, and mammals, than synthetic pesticides (Dalavayi Haritha et al., 2021).

Reduced Chemical Residues

- Their natural composition leaves minimal residues on crops, enhancing food safety.
- This reduces the risk of long-term health issues associated with consuming chemically treated produce (Khursheed et al., 2022).

Biodiversity Preservation

- Plant-based pesticides have a selective action, meaning they target pests while having minimal impact on beneficial insects (e.g., pollinators) and soil microbes.
- They contribute to maintaining ecological balance in agricultural ecosystems (Dalavayi Haritha et al., 2021).

Resource Efficiency

- Many plant-based pesticides are derived from locally available plants, promoting resource efficiency.
- Their production and use reduce dependency on imported synthetic chemicals, lowering costs and fostering self-reliance in farming communities (Khursheed et al., 2022).

Challenges and Limitations

- **Limited Efficacy:** Plant-based pesticides are often less potent than synthetic alternatives, requiring higher doses or frequent applications to achieve the desired pest control. This can increase labor and production costs for farmers (Souto et al., 2021).
- **Short Shelf Life:** These pesticides degrade quickly due to their natural composition, leading to a shorter storage life. This makes them less suitable for long-term use and distribution over large geographical areas (Khursheed et al., 2022).
- **Scalability:** Mass production of plant-based pesticides is challenging due to variability in the availability and quality of raw materials. Standardizing their formulations for consistent efficacy can be technically and economically demanding (Souto et al., 2021).
- **Knowledge Gap:** Limited awareness among farmers about the benefits and proper application techniques hinders adoption. Training and extension programs are often insufficient to bridge this gap, especially in remote or resource-poor areas (Khursheed et al., 2022).

Future Prospects

- **Advances in Extraction and Formulation Techniques**: As research into plant-based pesticides continues to grow, innovations in extraction methods and formulation techniques are expected to improve the efficacy and stability of these natural solutions. Advances in biotechnology and molecular biology may lead to the development of more potent plant-based compounds with broader pest control activity. Moreover, improvements in formulation techniques—such as encapsulation or nano-technology—could help protect active ingredients from rapid degradation, extending their shelf life and enhancing their effectiveness in

diverse environmental conditions. These advancements will make plant-based pesticides more competitive with synthetic chemicals, offering farmers a viable, sustainable alternative for pest management (Shahbaz et al., 2022).

- **Policy and Subsidy Support for Botanical Pesticides**: Governments and international organizations are beginning to recognize the importance of sustainable agricultural practices. In the future, there may be increased policy and financial support for plant-based pesticides, including subsidies, grants, or tax incentives to encourage their adoption. Supporting research and development of plant-based pesticide alternatives could become a priority for agricultural ministries, helping to make these products more accessible and affordable for smallholder farmers. Policies promoting organic farming and integrated pest management (IPM) systems could further boost the demand for eco-friendly pesticides, creating a conducive environment for their widespread use (Sola et al., 2014).
- **Integration with Other Sustainable Practices**: The future of plant-based pesticides is not only in their stand-alone use but also in their integration with broader sustainable agricultural practices. When combined with techniques like crop rotation, intercropping, and biological control, plant-based pesticides can help create more resilient agricultural ecosystems. For instance, integrating plant-based pesticides with the use of beneficial insects (such as ladybugs or predatory mites) or biocontrol agents can lead to a more holistic pest management system that reduces dependency on any single approach. Furthermore, these pesticides can be incorporated into agroecological farming systems, which emphasize biodiversity, soil health, and climate resilience. This integration will enhance the overall sustainability of farming systems, promoting long-term agricultural productivity while minimizing negative environmental and health impacts (Muhie, 2022).

Conclusion

Plant-based pesticides play a vital role in reducing the environmental impacts connected with conventional chemical pesticides. By being biodegradable and less toxic to non-target organisms, they minimize harm to ecosystems, protect biodiversity, and reduce pollution in soil, water, and air. Their use supports the preservation of beneficial insects and soil microbes, key components of a healthy agricultural system. Moreover, plant-based alternatives offer a safer, low-residue option for consumers, reducing health risks for farmers and consumers alike. The potential of plant-based pesticides to drive a transition toward more sustainable agriculture is significant. As part of integrated pest management systems and coupled with practices like crop rotation and biological control, these natural pesticides can provide a balanced approach to pest management that maintains high agricultural productivity without relying on harmful synthetic chemicals. With advancements in formulation techniques, policy support, and greater farmer awareness, plant-based pesticides can become a key tool in achieving long-term sustainability in agriculture, ultimately supporting the shift towards eco-friendlier, resilient farming practices worldwide.

References

Agatz, A., Cole, T. A., Preuss, T. G., Zimmer, E., & Brown, C. D. (2013). Feeding inhibition explains effects of imidacloprid on the growth, maturation, reproduction, and survival of Daphnia magna. *Environmental science & technology*, *47*(6), 2909-2917.

Agbo, B., Nta, A., & Ajaba, M. (2019). Bio-pesticidal properties of Neem (Azadirachta indica). *Adv. Trends Agric. Sci*, *1*, 17-26.

Atapattu, A. J., Ranasinghe, C., Nuwarapaksha, T. D., Udumann, S. S., & Dissanayaka, N. S. (2024). Sustainable Agriculture and Sustainable Development Goals (SDGs). In *Emerging Technologies and Marketing Strategies for Sustainable Agriculture* (pp. 1-27). IGI Global.

Baweja, P., Kumar, S., & Kumar, G. (2020). Fertilizers and pesticides: Their impact on soil health and environment. *Soil health*, 265-285.

Brodt, S., Six, J., Feenstra, G., Ingels, C., & Campbell, D. (2011). Sustainable agriculture. *Nat. Educ. Knowl*, *3*(1).

Chaudhary, S., Kanwar, R. K., Sehgal, A., Cahill, D. M., Barrow, C. J., Sehgal, R., & Kanwar, J. R. (2017). Progress on Azadirachta indica based biopesticides in replacing synthetic toxic pesticides. *Frontiers in plant science*, *8*, 610.

Chippendale, G. M. (1982). Insect diapause, the seasonal synchronization of life cycles, and management strategies. *Entomologia Experimentalis et Applicata*, *31*(1), 24-35.

Coulaud, R., Geffard, O., Vigneron, A., Quéau, H., François, A., & Chaumot, A. (2015). Linking feeding inhibition with reproductive impairment in Gammarus confirms the ecological relevance of feeding assays in environmental monitoring. *Environmental toxicology and chemistry*, *34*(5), 1031-1038.

Dalavayi Haritha, M., Bala, S., & Choudhury, D. (2021). Eco-friendly plant based on botanical pesticides. *Plant Archives*, *21*(1), 2197-2204.

Dalton, H. (2015). *The regulation of defence chemistry in Nicotiana* Monash University].

Danna, C., Malaspina, P., Cornara, L., Smeriglio, A., Trombetta, D., De Feo, V., & Vanin, S. (2024). Eucalyptus essential oils in pest control: a review of chemical composition and applications against insects and mites. In: Elsevier.

Dauer, J. T., McEvoy, P. B., & Van Sickle, J. (2012). Controlling a plant invader by targeted disruption of its life cycle. *Journal of Applied Ecology*, *49*(2), 322-330.

Desai, B. K., & Pujari, B. T. (2014). *Sustainable agriculture: a vision for future*. New India Publishing.

Khursheed, A., Rather, M. A., Jain, V., Rasool, S., Nazir, R., Malik, N. A., & Majid, S. A. (2022). Plant based natural products as potential ecofriendly and safer biopesticides: A comprehensive overview of their advantages over conventional pesticides, limitations and regulatory aspects. *Microbial Pathogenesis*, *173*, 105854.

Kumar, S., Mahapatro, G. K., Yadav, D. K., Tripathi, K., Koli, P., Kaushik, P., Sharma, K., & Nebapure, S. (2022). Essential oils as green pesticides: An overview. *The Indian Journal of Agricultural Sciences*, *92*(11), 1298-1305.

Muhie, S. H. (2022). Novel approaches and practices to sustainable agriculture. *Journal of Agriculture and Food Research*, *10*, 100446.

Ngegba, P. M., Cui, G., Khalid, M. Z., & Zhong, G. (2022). Use of botanical pesticides in agriculture as an alternative to synthetic pesticides. *Agriculture*, *12*(5), 600.

Ogendo, J. O., Deng, A. L., Birech, R. J., & Bett, P. K. (2012). Plant-Based Products as Control Agents of Stored-Product Insect Pests in the Tropics. *Progress in Food Preservation*, 581-601.

Okwute, S. K. (2012). Plants as potential sources of pesticidal agents: a review. *Pesticides–Advances in chemical and botanical pesticides*, *10*, 208-232.

Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of botany*, *114*(8), 1571-1596.

Rahul, S. N., Sherawat, A., & Singh, A. (2018). Benefits of pharmacologically active phytochemicals for integrated pest management. *Pharmacological Benefits of Natural Products, JPS Scientific Publications, India*, 116-129.

Shahbaz, M. U., Arshad, M., Mukhtar, K., Nabi, B. G., Goksen, G., Starowicz, M., Nawaz, A., Ahmad, I., Walayat, N., & Manzoor, M. F. (2022). Natural plant extracts: an update about novel spraying as an alternative of chemical pesticides to extend the postharvest shelf life of fruits and vegetables. *Molecules*, *27*(16), 5152.

Singh, A., Singh, A., Singh, P., Chakravarty, A., Singh, A., Singh, P., Mishra, M. K., Singh, V., Srivastava, A. K., & Aggarwal, H. (2022). Insecticidal activity, toxicity, resistance and metabolism of pyrethroids: A review. *Science and Technology Indonesia*, *7*(2), 238-250.

Smit, B., & Smithers, J. (1993). Sustainable agriculture: interpretations, analyses and prospects. *Canadian Journal of Regional Science*, *16*(3), 499-524.

Sola, P., Mvumi, B., Ogendo, J., Mponda, O., Kamanula, J., Nyirenda, S., Belmain, S., & Stevenson, P. (2014). Botanical pesticide production, trade and regulatory mechanisms in sub-Saharan Africa: making a case for plant-based pesticidal products. *Food Security*, *6*, 369-384.

Souto, A. L., Sylvestre, M., Tölke, E. D., Tavares, J. F., Barbosa-Filho, J. M., & Cebrián-Torrejón, G. (2021). Plant-derived pesticides as an alternative to pest management and sustainable agricultural production: Prospects, applications and challenges. *Molecules*, *26*(16), 4835.

Verma, N. S., Kuldeep, D. K., Chouhan, M., Prajapati, R., & Singh, S. K. (2023). A Review on Eco-Friendly Pesticides and Their Rising Importance in Sustainable Plant Protection Practices. *International Journal of Plant & Soil Science*, *35*(22), 200-214.

Wandahwa, P., Van Ranst, E., & Van Damme, P. (1996). Pyrethrum (Chrysanthemum cinerariaefolium Vis.) cultivation in West Kenya: origin, ecological conditions and management. *Industrial Crops and Products*, *5*(4), 307-322.

Wany, A., Jha, S., Nigam, V. K., & Pandey, D. M. (2013). Chemical analysis and therapeutic uses of citronella oil from Cymbopogon winterianus: A short review. *International Journal of Advanced Research*, *1*(6), 504-521.

Welch, R. M., & Graham, R. D. (1999). A new paradigm for world agriculture: meeting human needs: productive, sustainable, nutritious. *Field crops research*, *60*(1-2), 1-10.

Zubairi, S. I., Othman, Z. S., Sarmidi, M. R., & Aziz, R. A. (2016). Environmental friendly bio-pesticide Rotenone extracted from Derris sp.: A review on the extraction method, toxicity and field effectiveness. *Jurnal Teknologi*, *78*(8).