

Review Article

PLANT-DERIVED PEST CONTROL: MOLECULAR, ECOLOGICAL & TECHNOLOGICAL PERSPECTIVES

ABSTRACT

Aims: To explore and synthesize current knowledge on botanical pest management, emphasizing plant-pest interactions from evolutionary, molecular, and ecological perspectives. This study evaluates plant-based compounds and biotechnological approaches as sustainable alternatives to synthetic pesticides.

Study Design: A comprehensive review of scientific literature on botanical pest management, focusing on interdisciplinary approaches.

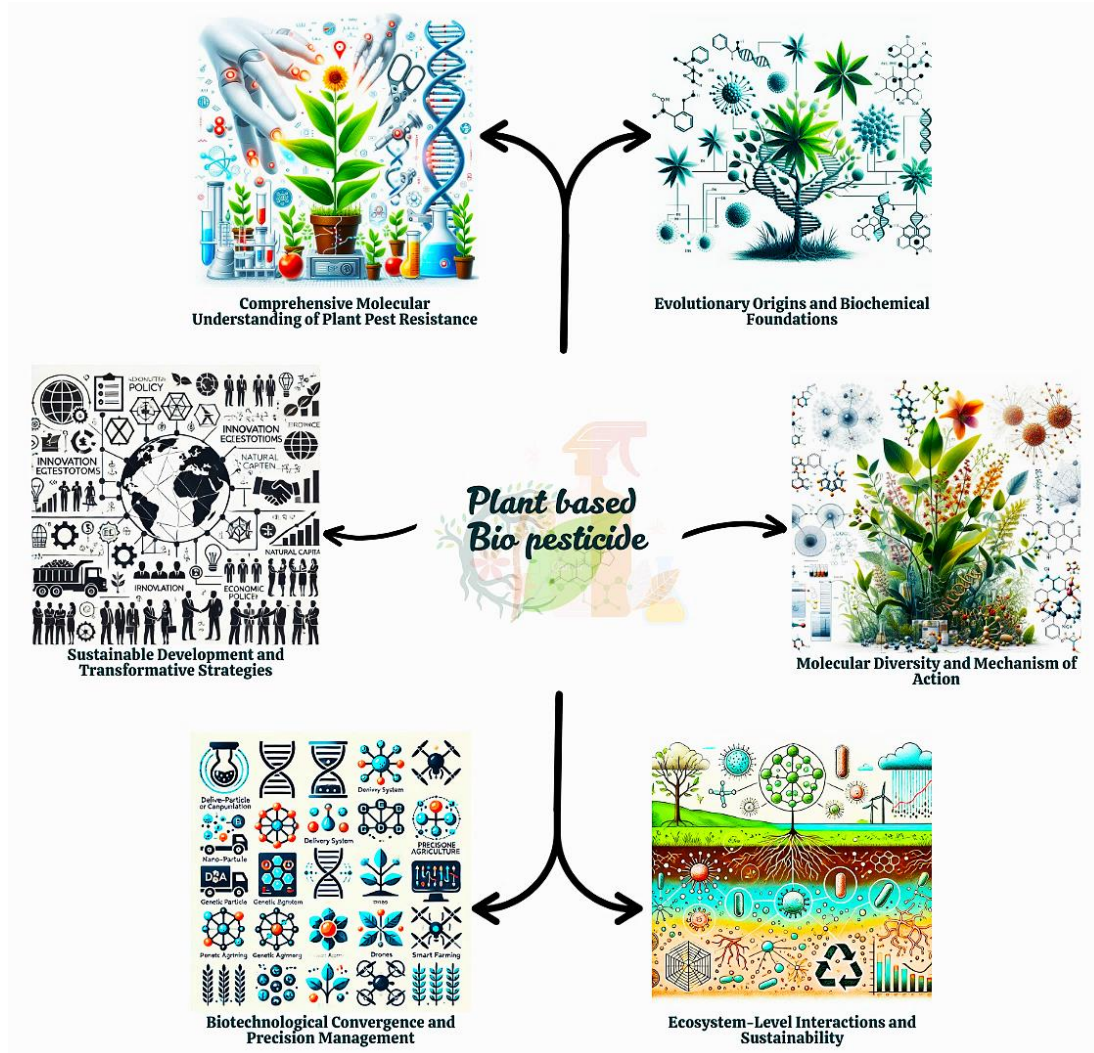
Methodology: The study reviews data on plant chemical defenses, molecular interactions, and biotechnological innovations for sustainable pest control. It analyzes plant-derived compounds' capacity to disrupt pest physiology with minimal ecological impact. Insights from genomics, molecular biology, and ecology are integrated to propose a sustainable pest management framework.

Results: Botanical pesticides demonstrated effectiveness in targeting pest physiological pathways while reducing ecological disturbances. Molecular studies revealed significant interactions between plant-derived compounds and pest systems, supported by advanced biotechnological methods. Genomic and ecological research underscored a balanced approach to enhancing agricultural productivity while minimizing environmental harm.

Conclusion: Botanical pest management is a promising, sustainable alternative to synthetic pesticides. It addresses current agricultural challenges while fostering long-term ecological sustainability. The findings highlight the potential of plant-based strategies to advance precise, eco-friendly pest control methods aligned with global sustainability goals. Further research is essential to validate and expand these solutions across diverse agricultural systems.

KEYWORDS: *Botanical pesticides, Plant defence mechanisms, Sustainable agriculture, Pest management, Ecological interactions*

GRAPHICAL ABSTRACT



1. INTRODUCTION

1.1 Evolution of Plant Chemical Defenses

Over millions of years, plants have developed various chemical defense mechanisms against pests (Huot et al., 2013; Zhu-Salzman et al., 2005). These defenses include constitutive and inducible strategies to protect against pathogens and herbivorous insects (Arnason & Bernards, 2010; Fürstenberg-Hägg et al., 2013). Constitutive defenses consist of preformed barriers, such as cutin and suberin, and biologically active inhibitors always present in plant tissues (Arnason & Bernards, 2010). Inducible defenses activate upon pest attack, involving complex physiological and biochemical processes such as jasmonic acid and salicylic acid pathways, calcium flux, reactive oxygen species burst, and mitogen-activated protein kinase activation (Wang et al., 2023). Plants generate a wide range of bioactive molecules, including antimicrobial, antifeedant, and phototoxic compounds, to counter evolving pest strategies (Arnason & Bernards, 2010; Fürstenberg-Hägg et al., 2013). They have also evolved cost-effective strategies such as producing glandular trichomes, latex, accumulating specific metabolites, and preparing defense pathways in advance for transmission to descendants (Zhou et al., 2022). Some plants engage external organisms or cooperate with relatives for protection, reducing defense costs (Zhou et al., 2022). The evolutionary arms race with pests has led to diverse and redundant defense mechanisms, crucial for slowing pest resistance to host-plant defenses (Arnason & Bernards, 2010; Huot et al., 2013).

1.2 Biochemical Pathways in Plant Resistance

Plant resistance strategies involve intricate biochemical pathways comprising signaling molecules, hormones, and metabolites, leading to defensive compounds and immune responses. Phytohormones, such as salicylic acid, jasmonic acid, ethylene, and abscisic acid, regulate responses to pathogens like *Botrytis cinerea* (Abuqamar et al., 2017). Salicylic acid, crucial for resistance, is synthesized via the isochorismate and phenylalanine ammonia-lyase pathways (Ding & Ding, 2020). Pipecolic acid, derived from lysine catabolism, enhances defense responses and systemically acquired resistance (Zeier, 2013). Amino acid metabolism, particularly Asp-derived amino acid biosynthesis, affects pathogen resistance, with imbalances in homoserine or threonine levels potentially increasing immunity against oomycetes (Zeier, 2013). Phyto-oxylipins, generated by oxidative transformation of unsaturated fatty acids, contribute to defense mechanisms (Blée, 2002). Understanding these complex biochemical networks is essential for developing enhanced resistance through genetic engineering and breeding (Abuqamar et al., 2017; Jirschitzka et al., 2012).

1.3 Genomic insights into plant-pest interactions

Comparative genomic analysis serves as a powerful tool for elucidating the universal principles of plant-pest interactions. Through the utilization of high-throughput sequencing and bioinformatics, conserved genetic mechanisms in plant defense and pest virulence across species are identified. (Sironi et al., 2015; Sturdevant et al., 2010). Studies have shown that genes involved in plant defense and pathogen virulence are highly polymorphic, reflecting the evolutionary arms race between plants and pests (Karasov et al., 2014). This genetic diversity results from complex ecological interactions and selective pressures. Comparative analyses have uncovered common gene expression responses in host cells to various infectious stimuli, indicating some universal defense mechanisms (Diehn & Relman, 2001). However, there is often a disconnect between real-world plant-pest interactions and the simplified models used (Karasov et al., 2014). To address this, integrative approaches combining comparative genomics with transcriptomics, proteomics, and metabolomics are used to assess insect resistance at multiple biological levels (Gado and Alviar, 2022). Novel methods, such as using non-target sequencing reads as phenotyping proxies, show promise for studying natural variation in plant pest resistance efficiently (Galanti et al., 2024). Advances in ecological genomics will likely reveal more universal principles governing plant-pest interactions.

2. MOLECULAR DIVERSITY AND MECHANISM OF ACTION

2.1 Structure and Efficacy of Plant-Derived Pesticides

Plant-derived pesticides have structural features influencing their pest control efficacy. Botanical pesticides contain various active components contributing to diverse action modes and effectiveness (Miresmailli, 2013; Oliveira et al., 2019). These components often synergize to enhance activity and reduce pest resistance (Koul & Walia, 2009; Oliveira et al., 2019). Their chemical structure affects stability, volatility, and release mechanisms, impacting efficacy (Miresmailli, 2013; Oliveira et al., 2019). The release of eugenol and cinnamaldehyde from nanoparticles is temperature-sensitive, affecting bioavailability (Oliveira et al., 2019). Odorant binding proteins (OBPs) in insect sensory organs bind and transport hydrophobic odorant molecules, influencing behaviors like host location, mating, and oviposition (Rana et al., 2024). Botanical pesticide efficacy varies by pest species; tobacco-derived insecticides are more effective against citrus aphids than citrus psyllids (Wuryantini et al., 2021). Volatilization patterns of botanical insect repellents can vary with time and factors like gender, ethnicity, and skin condition (Miresmailli, 2013). Understanding these factors is crucial for developing effective, sustainable botanical pesticides for integrated pest management (Dao et al., 2021; Oliveira et al., 2019; Villaverde et al., 2016).

2.2 Phytochemical Variations in Pest Management

Phytochemical variations significantly affect pest management strategies and integrated pest management (IPM) efficacy. Utilizing phytochemicals through host plant resistance is crucial for IPM, particularly in field crops like maize and alfalfa, where insecticide use is often uneconomical (Horn, 2019). However, extreme temperatures can induce stress in arthropods and host plants, potentially altering their resistance mechanisms (Horn, 2019). Chemical ecology, including pheromones and semiochemicals, offers promising alternatives to broad-spectrum toxicants (Pickett et al., 1997). Phytochemical-based methods can be integrated with host-masking agents, repellents, antifeedants, or oviposition deterrents in a multifaceted approach known as the stimulo-deterrent diversionary strategy (SDDS) to manipulate pest behaviour and reduce conventional pesticide use (Pickett et al., 1997). Incorporating host plant resistance, semiochemicals, and other phytochemical-based methods into IPM programs aligns with public preference for bio-rational pest control alternatives (VanRyckeghem, 2011) and supports the development of innovative and sustainable agricultural practices.

2.3 Molecular Interactions in Pest Disruption

Molecular interactions disrupting pest physiology involve various mechanisms. SubCELL, a database of subcellular compartment-specific interactions (SCSIs) among DNAs, RNAs, and proteins, facilitates understanding and potential disruption of pest physiology at the molecular level (Zhang et al., 2024). Kairomones mediate host-plant selection and enhance natural enemy effectiveness in biocontrol (Murali-Baskaran et al., 2017). Molecular markers study pest genetics, population dynamics, and predator-prey relationships to identify molecular targets (Ibrahim et al., 1997). Modifying bacterial symbiont relationships in heteropteran pests through paratransgenesis could yield new control methods (Prado & Zucchi, 2012). Climate change alters pest physiology and behavior through thermal traits and environmental interactions, influencing weed-crop competition and feeding patterns (Patterson et al., 1999; Terblanche et al., 2015). Targeting SCSIs, kairomone-mediated behaviours, symbiotic relationships, and climate-induced changes, aided by molecular biology, biochemistry, and environmental studies, offers enhanced pest control strategies.

3. ECOSYSTEM-LEVEL INTERACTIONS AND SUSTAINABILITY

3.1 Ecological Impact of Botanical Pesticides

Botanical pesticides, derived from plant compounds, are a promising alternative to synthetic pesticides, modulating ecological networks with minimal adverse effects on non-target organisms and the environment (Jyoti, 2024; Ahmed et al., 2022). Targeting specific pests, these pesticides leave minimal residues and possess insecticidal, antifeedant, or repellent properties, making them ideal for organic food production and post-harvest protection

(Ahmed et al., 2022). Botanical pesticides are less disruptive to trophic interactions and ecosystems compared to synthetic pesticides, aligning better with integrated pest management strategies (Beringue et al., 2024; Jyoti, 2024). However, their impact on soil microbial biodiversity varies, with some extracts decreasing and others increasing microbial populations (Salamiah & Aidawati, 2022), highlighting the complexity of ecological networks and the need for careful consideration when using these pesticides. Botanical pesticides offer a selective and environmentally friendly approach to pest management, but further research is necessary to fully understand their ecosystem effects and optimize their use in integrated pest management strategies (Jyoti, 2024; Dang et al., 2012).

3.2 Ecosystem Adaptations to Plant-Derived Interventions

Plant-derived interventions trigger long-term ecosystem adaptations through complex species-environment interactions. Changes in specific leaf area (SLA) indicate plant strategies for resource acquisition and environmental adaptation (Liu et al., 2022), influencing ecosystem structure and function. Long-term responses include shifts in species composition, changes in productivity, and alterations in ecosystem services. Short-term losses from plant interventions may be offset by long-term biodiversity and ecosystem health gains (Sun et al. 2012). It is essential to consider both the immediate and long-term effects when evaluating ecosystem responses. Environmental hormesis suggests that mild stressors can enhance plant resilience against stronger stressors (Erofeeva, 2021). Understanding these multilevel adaptations is crucial for predicting ecosystem dynamics and informing management strategies, despite the complexity and slow pace of some processes, necessitating ongoing research and monitoring (Maček et al., 2016).

3.3 Botanical Pesticides as Selective Pressures

Botanical pesticides can function as selective pressure mechanisms in agriculture, providing targeted pest management compared to synthetic pesticides. These plant-derived compounds possess specific modes of action that affect pests while minimizing harm to beneficial organisms (Dao et al., 2021). Their diverse mechanisms can target insect physiology, including the nervous system, resulting in loss of coordination, paralysis, and mortality (Gupta et al. 2024). This specificity enables precise pest control while preserving natural enemies and pollinators (Ndakidemi et al., 2016; Samanta et al., 2023). Neem seed extract demonstrated comparable effectiveness to synthetic emamectin benzoate in controlling lepidopteran pests on tomatoes, while proving more cost-effective (Akhter et al., 2023). Carlina oxide isolated from *Carlina acaulis* roots exhibited selective toxicity against the spider mite *Tetranychus urticae* without harming its natural predator *Neoseiulus californicus* (Rizzo et al., 2023). Despite being less harmful to non-target organisms, botanical pesticides can adversely affect beneficial insects if improperly utilized (Ndakidemi et al., 2016; Samanta et al., 2023). This can result in pest resurgence and secondary outbreaks. Consequently, their use should be optimized within integrated pest management programs, with appropriate dosages and selective application, to maintain ecological equilibrium (Gupta et al., 2024; Ndakidemi et al., 2016).

4. BIOTECHNOLOGICAL CONVERGENCE AND PRECISION MANAGEMENT

4.1 Biotechnology in Optimizing Plant-Based Pesticides

Biotechnological techniques, such as genetic engineering, CRISPR-Cas9, and RNA interference, optimize plant-based pesticides by enhancing pesticidal compound production, modifying plants to express insecticidal proteins, and specifically targeting pests while sparing non-target organisms (Sharma et al., 2024). Plant essential oils serve as broad-spectrum, low-toxicity biopesticides, and biotechnology refines their extraction, formulation, and delivery, with nanotechnology enhancing the stability and efficacy of nano-encapsulated essential oils (Mwamburi, 2022; Villarreal et al., 2023). Bioassay-directed isolation, chemical characterization, combinatorial chemistry, and high-throughput screening accelerate the discovery, optimization, and production of novel plant-based pesticides and their synthetic derivatives (Gonzalez-Coloma et al., 2010). These methods improve the efficacy, specificity, and environmental safety of plant-based pesticides, addressing traditional biopesticide

limitations while maintaining eco-friendly benefits (Bilgrami & Khan, 2022; Wend et al., 2024).

4.2 Innovative Delivery Technologies for Botanical Pesticides

Innovative delivery technologies have greatly improved the effectiveness of botanical pesticides, thereby addressing the challenges in agriculture and pest management. Microencapsulation enhances the formulation of plant essential oil active ingredients, enabling the development of new products (Paluch et al., 2011). This method addresses stability issues and other limitations that have hindered the large-scale use of botanical pesticides (Dao et al., 2021). Nano-encapsulation ensures precise pesticide delivery to plant tissues, increases effectiveness, and reduces chemical usage (Mmbando, 2024). The integration of nanotechnology with botanical pesticides has led to the development of efficient formulations that overcome degradation, instability, and volatilization (Oliveira et al., 2018). This amalgamation represents a sustainable agricultural approach, optimizing resource use and minimizing environmental impact. Ultimately, technologies such as microencapsulation, nano-encapsulation, and other nanotechnology-based methods are vital for enhancing botanical pesticide efficiency and improving stability, delivery precision, and overall efficacy. Ongoing research in this field promises more sustainable and effective pest management solutions for agriculture.

4.3 Precision Agriculture in Botanical Pest Management

Precision agriculture (PA) integrates advanced botanical pest management for sustainable crop protection, utilizing PA's technological capabilities with eco-friendly pest control methods for targeted pest management. Technologies like GPS, remote sensing, and data analytics enhance botanical pest strategies (Balaji et al., 2024; Tangkesalu et al., 2023). Drones with multispectral sensors detect early pest infestations or plant stress, enabling timely botanical pesticide application (Aldosari, 2024; Gundreddy et al., 2024). This precision reduces pesticide use, minimizes environmental impacts, and supports sustainability (Kayastha et al., 2024; Sharma, 2023). AI and machine learning analyze complex datasets, including soil, weather, and pest data, to optimize pest control strategies (Aldosari, 2024; Divyajyothi et al., 2024). These technologies predict pest outbreaks and tailor botanical pesticide interventions. Integrating advanced botanical pest strategies with PA offers sustainable crop protection, combining precision with ecological benefits for effective management and reduced environmental impacts (Khan, 2024; Khokhar et al., 2024). Challenges like technology access and farmer training must be addressed for widespread adoption (Anand et al., 2023; Sharma, 2023).

5. SUSTAINABLE DEVELOPMENT AND TRANSFORMATIVE STRATEGIES

5.1 Botanical Pest Management and Sustainability Goals

Botanical pest management supports global sustainability by providing eco-friendly alternatives to conventional pesticides, aligning with United Nations Sustainable Development Goals (SDGs) on food security, environmental protection, and sustainable production. Plant-based pesticides in grain storage offer sustainable pest control with low non-target toxicity and compatibility with integrated pest management (Jyoti, 2024), promoting Responsible Consumption and Production (SDG 12). Biologically based pest management strategies, including plant defense mechanisms, enhance sustainable integrated pest management programs (Chidawanyika et al., 2012), contributing to SDG 2 (Zero Hunger) by ensuring food security and reducing environmental impacts. Botanical gardens, like the University of British Columbia Botanical Garden, advance sustainable pest management and contribute to 12 of the 17 SDGs through ex situ plant conservation, sustainability education, and community engagement (Lopez-Villalobos et al., 2022). These institutions serve as crucial research and education centers for sustainable pest management, essential for achieving the SDGs and ensuring long-term ecological and economic sustainability in agriculture, particularly as climate change affects pest dynamics.

5.2 Economic Valuation of Ecological Pest Management

Economic models valuing ecological pest management services reflect the complex dynamics of agricultural ecosystems and market forces. Microeconomic models estimate the value of natural enemy species richness for biological pest control by analyzing market outcomes affected by crop yield changes, supply shifts, and price elasticities (Letourneau et al., 2015). Dynamic bioeconomic optimization models integrate pest and predator dynamics, crop growth, yield damage functions, and managerial decisions to determine optimal insecticide use while considering natural pest control (Zhang & Swinton, 2009). Market forces and technological substitutes can significantly affect ecosystem service valuations over time, even with constant ecosystem functions. For instance, the pest control value provided by Mexican free-tailed bats declined by 79% over 18 years due to Bt cotton adoption, falling cotton prices, and reduced cotton acreage (López-Hoffman et al., 2014). Effective economic models must integrate ecological processes, market dynamics, and management decisions. Economic surplus models (Zhang et al., 2018), benefit-transfer approaches (Wiederholt et al., 2016), and expert-based models (Riggi et al., 2024) have also been used. However, challenges in capturing these systems' complexity require further interdisciplinary collaboration for more comprehensive valuation methods (Naranjo et al., 2015).

5.3 Policy Support for Botanical Pest Control

Policy frameworks are crucial for advancing innovative botanical pest control technologies within Integrated Pest Management (IPM) and sustainable agriculture. Supportive pest management policies are vital for promoting IPM and botanical alternatives (Munyua, 2006). Government backing is essential for the broad adoption of alternative pest management. Policy frameworks can tackle issues like formulation complexities, limited chemical data, and regulatory barriers hindering plant-based pesticides in grain storage (Jyoti, 2024). Despite benefits such as low toxicity to non-target organisms and IPM compatibility, botanical pest control technologies face social and psychological adoption barriers (Jyoti, 2024; Munyua, 2006). Therefore, policies should foster technological innovation and address social adoption aspects. Effective policies should emphasize regulatory support, training, and collaborative research to overcome botanical pest control challenges (Jyoti, 2024; Quiroz et al., 2019). Integrating these solutions into storage practices and agriculture can enhance food security and reduce the risks of synthetic pesticides. Furthermore, policies should encourage participatory approaches and knowledge exchange among stakeholders to facilitate changes in pest management practices (Munyua, 2006; Zhou et al., 2024).

6. ADVANCED MOLECULAR DECODING OF PLANT DEFENCE MECHANISMS

6.1 Secondary Metabolites in Chemical Defence

Plant secondary metabolites are vital for chemical defense against biotic and abiotic stresses (Dhruv et al., 2022). These compounds defend against pathogens and herbivory and play a key role in plant ecological interactions (Gani et al., 2020). They enable plants to swiftly detect and respond to herbivore attacks under changing conditions (Divekar et al., 2022). Secondary metabolites directly poison insect pests, trigger anti-xenosis, and indirectly protect plants by recruiting herbivorous enemies (Divekar et al. 2022). Recent evidence indicates that some secondary metabolites also regulate immune responses, such as callose deposition and programmed cell death, beyond serving as antibiotics (Piasecka et al., 2015). Overall, plant secondary metabolites act via multiple pathways, including direct toxicity, anti-xenosis, indirect protection, and immune regulation. Their diverse nature and ability to accumulate in various tissues at different growth stages make them essential for plant defense (Dhruv et al., 2022; Divekar et al., 2022).

6.2 Molecular Interactions in Pest Disruption

Selective pest control exploits neuropeptide-receptor interactions, endocrine disruption, and charge-based molecular recognition to disrupt essential insect processes (Nachman et al., 1993; Tebourbi et al., 2011; Gelmi et al., 2012). Peptide mimetics designed as agonists or antagonists can disrupt pest survival, while pesticides acting as endocrine disruptors affect

hormone secretion or receptor binding, impacting reproduction and development (Nachman et al., 1993; Tebourbi et al., 2011). Pesticides can also disrupt biochemical processes or generate reactive oxygen species, causing toxicity (Tebourbi et al., 2011). Thiabendazole (TBZ) exemplifies selective targeting by disrupting a specific human β -tubulin isotype (TUBB8), affecting endothelial cell microtubules and angiogenesis (Garge et al., 2020). Understanding molecular mechanisms of pesticide action is crucial for developing selective and sustainable pest control strategies while minimizing unintended effects on non-target organisms (Garge et al., 2020).

6.3 Ethnobotanical Insights into Pest Management

Ethnobotanical knowledge can uncover hidden pest management strategies, as several studies have shown. Indigenous communities have preserved effective, eco-friendly, and cost-efficient pest control practices using local plant materials and animal by-products (Meena et al., 2021). Modern agricultural extension officers often overlook sustainable alternatives to chemical pesticides. In the Thulamela municipality, a study found that 71% of extension officers relied on chemical methods, with only 3.2% being aware of biological control using natural enemies (Thovhogi et al., 2022). Farmers in the state of Andhra Pradesh, India have traditionally used leaves of *Vitex negundo*, locally known as "nirgundi," to protect stored grains from pests. Research has confirmed the efficacy of *V. negundo* extracts against several storage pests, highlighting the scientific basis of this traditional practice (Hebbalkar et al., 1992). This gap between traditional and modern practices highlights the potential of ethnobotanical knowledge to achieve the Sustainable Development Goals (SDGs) for sustainable agriculture and environmental conservation (Kumar et al., 2021; Kumar, 2021). To harness this potential, better documentation, validation, and integration of traditional knowledge with modern science are needed (Reyes-García et al., 2007).

7. CONCLUSION

Botanical pest management represents a comprehensive approach to sustainable agriculture that integrates the biochemical, molecular, and ecological mechanisms of plant defense. Exploiting plant-derived compounds with specific molecular interactions and targeted modes of action provides an environmentally sensitive alternative to synthetic pesticides. This approach leverages complex plant defense mechanisms, biotechnological innovations, and precise intervention strategies to disrupt pest physiological processes while minimizing ecological disruption. These methods demonstrate significant potential for developing more sustainable and ecologically balanced pest management systems that align with global agricultural sustainability objectives.

CONSENT - NOT APPLICABLE

ETHICAL APPROVAL - NOT APPLICABLE

REFERENCES

1. Akhter, W., Shah, F. M., Yang, M., Mkindi, A. G., Akram, H., Ali, A., Razaq, M., Freed, S., Mahmood, K., & Hanif, M. (2023). Botanical biopesticides have an influence on tomato quality through pest control and are cost-effective for farmers in developing countries. *PLOS ONE*, 18(11), e0294775. <https://doi.org/10.1371/journal.pone.0294775>
2. Rizzo, R., Ragusa, E., Spinozzi, E., Ferrati, M., Maggi, F., Benelli, G., Sinacori, M., Tsolakis, H., Zeni, V., Lo Verde, G., & Petrelli, R. (2023). Lethal and sublethal effects of carlina oxide on *Tetranychus urticae* (Acari: Tetranychidae) and *Neoseiulus californicus* (Acari: Phytoseiidae). *Pest Management Science*, 80(3), 967–977. <https://doi.org/10.1002/ps.7827>
3. Abuqamar, S., Moustafa, K., & Tran, L. S. (2017). Mechanisms and strategies of plant defense against *Botrytis cinerea*. *Critical Reviews in Biotechnology*, 37(2), 262–274. <https://doi.org/10.1080/07388551.2016.1271767>
4. Ahmed, N., Saeed, M., Alam, M., Shahjeer, K., Ahmed, S., Awadh Al-Mutairi, K., Fathy Khater, H., Iqbal, T., Salman, M., Ullah, R., Abd Aleem Hassan Ahmed, N., & Ullah, H. (2022). Botanical Insecticides Are a Non-Toxic Alternative to Conventional Pesticides in the Control of Insects and Pests. *intechopen*. <https://doi.org/10.5772/intechopen.100416>
5. Aldosari, H. M. (2024). An Expert Model Using Deep Learning for Image-based Pest Identification with the TSLM Approach for Enhancing Precision Farming. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, 15(3), 160–183. <https://doi.org/10.58346/jowua.2024.i3.012>
6. Anand, J., Yusoff, N., Ghani, H., & Thoti, K. (2023). Technological Applications in Smart Farming: A Bibliometric Analysis. *Advanced Sustainable Technologies (ASET)* 2(2). <https://doi.org/10.58915/aset.v2i2.334> Chidawanyika, F., Mudavanhu, P., & Nyamukondiwa, C. (2012). Biologically Based Methods for Pest Management in Agriculture under Changing Climates: Challenges and Future Directions. *Insects*, 3(4), 1171–1189. <https://doi.org/10.3390/insects3041171>
7. Arnason, J. T., & Bernards, M. A. (2010). Impact of constitutive plant natural products on herbivores and pathogens The present review is one of the special series of reviews on animal–plant interactions. *Canadian Journal of Zoology*, 88(7), 615–627. <https://doi.org/10.1139/z10-038>
8. Balaji, B., Pampareddy, P., T, C., & Shudeer, S. (2024). Role of Entomology in the Era of Precision Agriculture: A Review. *Annual Research & Review in Biology*, 39(9), 122–129. <https://doi.org/10.9734/arrb/2024/v39i92126>
9. Beringue, A., Queffelec, J., Le Lann, C., & Sulmon, C. (2024). Sublethal pesticide exposure in non-target terrestrial ecosystems: From known effects on individuals to potential consequences on trophic interactions and network functioning. *Environmental Research*, 260, 119620. <https://doi.org/10.1016/j.envres.2024.119620>
10. Bilgrami, A. L., & Khan, A. (2022). Chapter 13 - Merits, demerits, risks, and restrictions of biopesticides. In *Plant Nematode Biopesticides* (pp. 207–215). *elsevier*. <https://doi.org/10.1016/b978-0-12-823006-0.00015-2>
11. Blée, E. (2002). Impact of phyto-oxylipins in plant defence. *Trends in Plant Science*, 7(7), 315–322. [https://doi.org/10.1016/s1360-1385\(02\)02290-2](https://doi.org/10.1016/s1360-1385(02)02290-2)
12. Dao, H. T., Vu, D. H., Le Dang, Q., Dao, V. H., & Lam, T. D. (2021). APPLICATION OF BOTANICAL PESTICIDES IN ORGANIC AGRICULTURE PRODUCTION: POTENTIAL AND CHALLENGES. *Vietnam Journal of Science and Technology*, 59(6). <https://doi.org/10.15625/2525-2518/59/6/16217>
13. Dao, H. T., Vu, D. H., Le Dang, Q., Dao, V. H., & Lam, T. D. (2021). Application of botanical pesticides in organic agriculture production: potential and challenges. *Vietnam Journal of Science and Technology*, 59(6). <https://doi.org/10.15625/2525-2518/59/6/16217>
14. Dao, H. T., Vu, D. H., Le Dang, Q., Dao, V. H., & Lam, T. D. (2021). Application of botanical pesticides in organic agriculture production: potential and challenges. *Vietnam*

Journal of Science and Technology, 59(6). <https://doi.org/10.15625/2525-2518/59/6/16217>

15. De La Cruz Quiroz, R., Rostro Alanis, M. D. J., Cruz Maldonado, J. J., Parra Saldívar, R., & Torres, J. A. (2019). Fungi-based biopesticides: shelf-life preservation technologies used in commercial products. *Journal of Pest Science*, 92(3), 1003–1015. <https://doi.org/10.1007/s10340-019-01117-5>
16. De Oliveira, J. L., Campos, E. V. R., De Andrade, D. J., Vechia, J. F. D., Lima, R., Polanczyk, R. A., Do Nascimento, J., Germano-Costa, T., Fraceto, L. F., Soares, S. T., & Gonçalves, K. C. (2019). Association of zein nanoparticles with botanical compounds for effective pest control systems. *Pest Management Science*, 75(7), 1855–1865. <https://doi.org/10.1002/ps.5338>
17. Dhruv, J., Dobaría, J., & Shukla, Y. (2022). Plant secondary metabolites in stress: An overview. *Indian Journal of Agricultural Biochemistry*, 35(2), 120–132. <https://doi.org/10.5958/0974-4479.2022.00018.1>
18. Diehn, M., & Relman, D. A. (2001). Comparing functional genomic datasets: lessons from DNA microarray analyses of host–pathogen interactions. *Current Opinion in Microbiology*, 4(1), 95–101. [https://doi.org/10.1016/s1369-5274\(00\)00171-5](https://doi.org/10.1016/s1369-5274(00)00171-5)
19. Ding, P., & Ding, Y. (2020). Stories of Salicylic Acid: A Plant Defence Hormone. *Trends in Plant Science*, 25(6), 549–565. <https://doi.org/10.1016/j.tplants.2020.01.004>
20. Divekar, P. A., Ray, A., Rani, V., Singh, A. K., Singh, A. K., Gadratagi, B. G., Singh, R. P., Kumar, A., Singh, V., Meena, R. S., Behera, T. K., Kumar, R., Narayana, S., & Divekar, B. A. (2022). Plant Secondary Metabolites as Defence Tools against Herbivores for Sustainable Crop Protection. *International Journal of Molecular Sciences*, 23(5), 2690. <https://doi.org/10.3390/ijms23052690>
21. Divyajyothi, M. G., Jopate, R., Abdulrahim Abdulsalam Albalushi, R., & Abdullah Saleh Al Balushi, S. (2024). AI Precision for Irrigation, Crop Management, and Pest Control for Sustainable Agriculture in Oman. *IOP Conference Series: Earth and Environmental Science*, 1401(1), 012005. <https://doi.org/10.1088/1755-1315/1401/1/012005>
22. Ellis, W. (2018). Plant knowledge: transfers, shaping and states in plant practices. *Anthropology Southern Africa*, 41(2), 80–91. <https://doi.org/10.1080/23323256.2018.1476165>
23. Erofeeva, E. A. (2021). Environmental hormesis of non-specific and specific adaptive mechanisms in plants. *Science of The Total Environment*, 804, 150059. <https://doi.org/10.1016/j.scitotenv.2021.150059>
24. Fürstenberg-Hägg, J., Bak, S., & Zagrobelny, M. (2013). Plant defence against insect herbivores. *International Journal of Molecular Sciences*, 14(5), 10242–10297. <https://doi.org/10.3390/ijms140510242>
25. Gado, J., & Alviar, K. (2022). Quantitative Trait Locus Mapping of Host-plant Resistance against Insect Pests. *scienceopen*. <https://doi.org/10.14293/s2199-1006.1.sor.pppt98l.v1>
26. Galanti, D., Galanti, D., Jung, J. H., Müller, C., & Bossdorf, O. (2024). Discarded sequencing reads uncover natural variation in pest resistance in *Thlaspi arvense*. *elife sciences*. <https://doi.org/10.7554/elife.95510>
27. Gani, U., Vishwakarma, R. A., & Misra, P. (2020). Membrane transporters: the key drivers of transport of secondary metabolites in plants. *Plant Cell Reports*, 40(1), 1–18. <https://doi.org/10.1007/s00299-020-02599-9>
28. Garge, R. K., Kachroo, A. H., Wallingford, J. B., Lee, C., Marcotte, E. M., Cha, H. J., & Gollihar, J. D. (2020). Antifungal benzimidazoles disrupt vasculature by targeting one of nine β -tubulins. *cold spring harbor laboratory*. <https://doi.org/10.1101/2020.09.15.298828>
29. Gelmi, A., Wallace, G. G., & Higgins, M. J. (2012). Resolving Sub-Molecular Binding and Electrical Switching Mechanisms of Single Proteins at Electroactive Conducting Polymers. *Small*, 9(3), 393–401. <https://doi.org/10.1002/sml.201201686>
30. Gonzalez-Coloma, A., Reina, M., Fraga, B. M., & Diaz, C. E. (2010). Natural Product-Based Biopesticides for Insect Control (Vol. 3, pp. 237–268). *elsevier*.

- <https://doi.org/10.1016/b978-008045382-8.00074-5>Paluch, G., Bessette, S., & Bradbury, R. (2011). Development of Botanical Pesticides for Public Health. *Journal of ASTM International*, 8(4), 1–7. <https://doi.org/10.1520/jai103468>
31. Gundreddy, R. R., Reddy, B. T., M, S., E, V. M., Alekhya, G., Gaddam, N. R., Bv, J., & Darjee, S. (2024). Actuation Drones in Agriculture: Advancing Precision Pest Management through Biocontrol and Modern Techniques. *Journal of Experimental Agriculture International*, 46(9), 825–835. <https://doi.org/10.9734/jeai/2024/v46i92879>
 32. Gupta, S., Gupta, R. K., Dash, P. P., & Mishra, A. (2024). Exploring the Efficacy and Sustainability of Natural Pesticides in Plant Protection. *Current Functional Foods*, 03. [https://doi.org/10.2174/0126668629301079240816072818Wend, K., Zorrilla, L., Freimoser, F. M., & Gallet, A. \(2024\). Microbial pesticides – challenges and future perspectives for testing and safety assessment with respect to human health. *Environmental Health*, 23\(1\). <https://doi.org/10.1186/s12940-024-01090-2>](https://doi.org/10.2174/0126668629301079240816072818Wend, K., Zorrilla, L., Freimoser, F. M., & Gallet, A. (2024). Microbial pesticides – challenges and future perspectives for testing and safety assessment with respect to human health. Environmental Health, 23(1). https://doi.org/10.1186/s12940-024-01090-2)
 33. Horn, D. J. (2019). Temperature Synergism in Integrated Pest Management (pp. 125–140). *crc*. <https://doi.org/10.1201/9780429308581-5>
 34. Hebbalkar, D. S., Hebbalkar, G. D., Sharma, R. N., Joshi, V. S., & Bhat, V. S. (1992). Mosquito repellent activity of oils from *Vitex negundo* Linn. leaves. *The Indian Journal of Medical Research*, 95, 200-203.
 35. Huot, O. B., Tamborindeguy, C., & Nachappa, P. (2013). The evolutionary strategies of plant defences have a dynamic impact on the adaptations and interactions of vectors and pathogens. *Insect Science*, 20(3), 297–306. <https://doi.org/10.1111/1744-7917.12010>
 36. Ibrahim, K. M., Symondson, W. O. C., & Liddell, J. E. (1997). The Ecology of Agricultural Pests: Biochemical Approaches. *The Journal of Applied Ecology*, 34(2), 545. <https://doi.org/10.2307/2404902>
 37. Jirschitzka, J., Mattern, D. J., Gershenson, J., & D'Auria, J. C. (2012). Learning from nature: new approaches to the metabolic engineering of plant defence pathways. *Current Opinion in Biotechnology*, 24(2), 320–328. <https://doi.org/10.1016/j.copbio.2012.10.014>
 38. Jyoti . (2024). Effect of Plant Based Pesticides in Grain Storage Management. *International Journal For Multidisciplinary Research*, 6(4). <https://doi.org/10.36948/ijfmr.2024.v06i04.24964>
 39. Jyoti U. (2024). Effect of Plant Based Pesticides in Grain Storage Management. *International Journal For Multidisciplinary Research*, 6(4). <https://doi.org/10.36948/ijfmr.2024.v06i04.24964>
 40. Karasov, T. L., Horton, M. W., & Bergelson, J. (2014). Genomic variability as a driver of plant–pathogen coevolution? *Current Opinion in Plant Biology*, 18, 24–30. <https://doi.org/10.1016/j.pbi.2013.12.003>
 41. Kayastha, S., Sahoo, J. P., Behera, A., & Mahapatra, M. (2024). Growing Green: Sustainable Agriculture Meets Precision Farming: A Review. *Bhartiya Krishi Anusandhan Patrika, Of*. <https://doi.org/10.18805/bkap697>
 42. Khan, N. (2024). Unlocking Innovation in Crop Resilience and Productivity: Breakthroughs in Biotechnology and Sustainable Farming. *Innovation Discovery*, 1(4), 28. <https://doi.org/10.53964/id.2024028>
 43. Khokhar, H., Kumar, C., & Kaushik, N. (2024). Safeguarding Tomato Cultivation: Challenges and Integrated Pest Management Strategies in North India. *BIO Web of Conferences*, 110, 01009. <https://doi.org/10.1051/bioconf/202411001009>
 44. Letourneau, D. K., Ando, A. W., Jedlicka, J. A., Narwani, A., & Barbier, E. (2015). Simple-but-sound methods for estimating the value of changes in biodiversity for biological pest control in agriculture. *Ecological Economics*, 120(120), 215–225. <https://doi.org/10.1016/j.ecolecon.2015.10.015>
 45. Liu, Z., Liu, C., Ren, T., He, N., Zhao, M., & Zhang, H. (2022). Divergent response and adaptation of specific leaf area to environmental change at different spatio-temporal scales jointly improve plant survival. *Global Change Biology*, 29(4), 1144–1159. <https://doi.org/10.1111/gcb.16518>

46. López-Hoffman, L., Medellín, R. A., Bagstad, K. J., Russell, A., Sansone, C., Diffendorfer, J. E., Cryan, P., Lasharr, K., Wiederholt, R., Mccracken, G., Goldstein, J., Semmens, D., Loomis, J., & Srygley, R. B. (2014). Market Forces and Technological Substitutes Cause Fluctuations in the Value of Bat Pest-Control Services for Cotton. *PLoS ONE*, 9(2), e87912. <https://doi.org/10.1371/journal.pone.0087912>
47. Lopez-Villalobos, A., Lewis, P., Kubeck, K., Bunsha, D., Hill, A., Douglas, J., Caddy, L., Stormes, B., Sugiyama, R., Austin, D., & Moreau, T. (2022). Aligning to the UN Sustainable Development Goals: Assessing Contributions of UBC Botanical Garden. *Sustainability*, 14(10), 6275. <https://doi.org/10.3390/su14106275>
48. Luiz De Oliveira, J., Ramos Campos, E. V., & Fraceto, L. F. (2018). Recent Developments and Challenges for Nanoscale Formulation of Botanical Pesticides for Use in Sustainable Agriculture. *Journal of Agricultural and Food Chemistry*, 66(34), 8898–8913. <https://doi.org/10.1021/acs.jafc.8b03183>
49. Maček, I., Pfanz, H., Vodnik, D., Dumbrell, A. J., & Low-Décarie, E. (2016). Locally Extreme Environments as Natural Long-Term Experiments in Ecology (Vol. 55, pp. 283–323). *elsevier*. <https://doi.org/10.1016/bs.aecr.2016.08.001>
50. Meena, N., Kanojia, Y., Meena, R., Roat, B., & Dangi, N. (2021). Indigenous approaches of pest management in vegetables with special reference to coriander in southern Rajasthan, India. *Indian Journal of Traditional Knowledge*, 20(4). <https://doi.org/10.56042/ijtk.v20i4.42765>
51. Miresmailli, S. (2013). Personalized Pesticides – A New Paradigm (pp. 145–152). *american chemical society*. <https://doi.org/10.1021/bk-2013-1141.ch010>
52. Mmbando, G. S. (2024). The use of nanotechnology in genetic modification: a recent promising technology for enhancing crop productivity. *Journal of Crop Improvement*, 38(6), 618–638. <https://doi.org/10.1080/15427528.2024.2385818>
53. Munyua, C. N. (2006). Challenges in the implementation of integrated pest management: the need for enabling structures and strategies in developing countries. *International Journal of Agriculture and Rural Development*, 6(1). <https://doi.org/10.4314/ijard.v6i1.2601>
54. Murali-Baskaran, R. K., Sharma, K. C., Kaushal, P., Kumar, J., Parthiban, P., Senthil-Nathan, S., & Mankin, R. W. (2017). Role of kairomone in biological control of crop pests-A review. *Physiological and Molecular Plant Pathology*, 101, 3–15. <https://doi.org/10.1016/j.pmpp.2017.07.004>
55. Mwamburi, L. A. (2022). Role of Plant Essential Oils in Pest Management (pp. 157–185). *springer nature singapore*. https://doi.org/10.1007/978-981-16-3989-0_6
56. Nachman, R. J., Holman, G. M., & Haddon, W. F. (1993). Leads for insect neuropeptide mimetic development. *Archives of Insect Biochemistry and Physiology*, 22(1–2), 181–197. <https://doi.org/10.1002/arch.940220115>
57. Naranjo, S. E., Frisvold, G. B., & Ellsworth, P. C. (2015). Economic value of biological control in integrated pest management of managed plant systems. *Annual Review of Entomology*, 60(1), 621–645. <https://doi.org/10.1146/annurev-ento-010814-021005>
58. Ndakidemi, B., Ndakidemi, P. A., & Mtei, K. (2016). Impacts of Synthetic and Botanical Pesticides on Beneficial Insects. *Agricultural Sciences*, 07(06), 364–372. <https://doi.org/10.4236/as.2016.76038>
59. Opende Koul, O. K., & Suresh Walia, S. W. (2009). Comparing impacts of plant extracts and pure allelochemicals and implications for pest control. *CABI Reviews*, 2009(049), 1–30. <https://doi.org/10.1079/pavsnr.20094049>
60. Piasecka, A., Bednarek, P., & Jedrzejczak-Rey, N. (2015). Secondary metabolites in plant innate immunity: conserved function of divergent chemicals. *New Phytologist*, 206(3), 948–964. <https://doi.org/10.1111/nph.13325>
61. Pickett, J. A., Wadhams, L. J., & Woodcock, C. M. (1997). Developing sustainable pest control from chemical ecology. *Agriculture, Ecosystems & Environment*, 64(2), 149–156. [https://doi.org/10.1016/s0167-8809\(97\)00033-9](https://doi.org/10.1016/s0167-8809(97)00033-9)

62. Prado, S. S., & Zucchi, T. D. (2012). Host-Symbiont Interactions for Potentially Managing Heteropteran Pests. *Psyche: A Journal of Entomology*, 2012, 1–9. <https://doi.org/10.1155/2012/269473>
63. Rana, A., Sharma, D., Choudhary, K., Kumari, P., Ruchika, K., Yangchan, J., & Kumar, S. (2024). Insight into insect odorant binding proteins: An alternative approach for pest management. *Journal of Natural Pesticide Research*, 8, 100069. <https://doi.org/10.1016/j.napere.2024.100069>
64. Riggi, L. G. A., Aguilera, G., & Chopin, P. (2024). Expert-based model of the potential for natural pest control with landscape and field scale drivers in intensively managed cereal-dominated agricultural landscapes. *Ecological Indicators*, 159, 111684. <https://doi.org/10.1016/j.ecolind.2024.111684>
65. Salamia, S., & Aidawati, N. (2022). Microbial diversity of shallot plantation in peat-lands applied with three types of botanical pesticides. *IOP Conference Series: Earth and Environmental Science*, 976(1), 012032. <https://doi.org/10.1088/1755-1315/976/1/012032>
66. Samanta, S., Maji, A., Sutradhar, B., Shelar, V. B., Banerjee, S., Bansode, G. D., Yadav, S. V., & Khaire, P. B. (2023). Impact of Pesticides on Beneficial Insects in Various Agroecosystem: A Review. *International Journal of Environment and Climate Change*, 13(8), 1928–1936. <https://doi.org/10.9734/ijec/2023/v13i82149>
67. Sharma, P., Pandya, P., & Parikh, P. (2024). BIOTECHNOLOGICAL APPROACHES IN INSECT PEST MANAGEMENT (pp. 183–193). iterative selfpage developers pvt. <https://doi.org/10.58532/v3bfbt3p2ch7>
68. Sharma, S. (2023). Cultivating sustainable solutions: integrated pest management (ipm) for safer and greener agronomy. *Corporate Sustainable Management Journal*, 1(2), 103–108. <https://doi.org/10.26480/csmj.02.2023.103.108>
69. Sironi, M., Clerici, M., Cagliani, R., & Forni, D. (2015). Evolutionary insights into host-pathogen interactions from mammalian sequence data. *Nature Reviews Genetics*, 16(4), 224–236. <https://doi.org/10.1038/nrg3905>
70. Sturdevant, D. E., Heinzen, R. A., Kanakabandi, K., Celli, J., Ogundare, O., Castro, N., Virtaneva, K., Martens, C., Carlson, J. H., Porcella, S. F., Greenberg, D. E., Kennedy, A. D., Deleo, F. R., Beare, P. A., Bozinov, D., & Omsland, A. (2010). Host–Microbe Interaction Systems Biology: Lifecycle Transcriptomics and Comparative Genomics. *Future Microbiology*, 5(2), 205–219. <https://doi.org/10.2217/fmb.09.125>
71. Sun, T., Xu, J., & Yang, Z. F. (2012). Ecological adaptation as an important factor in environmental flow assessments based on an integrated multi-objective method (Vol. 9, Issue 5). copernicus gmbh. <https://doi.org/10.5194/hessd-9-6753-2012>
72. Tangkesalu, D., Judijanto, L., Pedro, J. C., Tooy, D., & Saprudin, S. (2023). Precision Agriculture: Integrating Technology for Enhanced Efficiency and Sustainability in Crop Management. *Global International Journal of Innovative Research*, 1(3), 213–219. <https://doi.org/10.59613/global.v1i3.37>
73. Tebourbi, O., Sakly, M., & Ben, K. (2011). Molecular Mechanisms of Pesticide Toxicity. institute for new technologies. <https://doi.org/10.5772/17952>
74. VanRyckeghem, A. (2011). Pheromones: a resourceful tool in modern urban pest management. (pp. 169–186). cabi. <https://doi.org/10.1079/9781845938031.0169>
75. Villarreal, G. U., Campos, E. V. R., De Oliveira, J. L., & Fraceto, L. F. (2023). Chapter 3 - Development and commercialization of pheromone-based biopesticides: a global perspective. In *Development and Commercialization of Biopesticides* (pp. 37–56). elsevier. <https://doi.org/10.1016/b978-0-323-95290-3.00008-x>
76. Villaverde, J. J., Alonso-Prados, J. L., López-Goti, C., Sandín-España, P., & Sevilla-Morán, B. (2016). Biopesticides from Natural Products: Current Development, Legislative Framework, and Future Trends. *BioResources*, 11(2). <https://doi.org/10.15376/biores.11.2.villaverde>

77. Wang, H., Hua, W., & Shi, S. (2023). Advances of herbivore-secreted elicitors and effectors in plant-insect interactions. *Frontiers in Plant Science*, 14. <https://doi.org/10.3389/fpls.2023.1176048>
78. Wiederholt, R., Bagstad, K. J., Mccracken, G. F., Diffendorfer, J. E., Loomis, J. B., Semmens, D. J., Russell, A. L., Sansone, C., Lasharr, K., Cryan, P., Reynoso, C., Medellín, R. A., & López-Hoffman, L. (2016). Improving spatio-temporal benefit transfers for pest control by generalist predators in cotton in the southwestern US. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 13(1), 27–39. <https://doi.org/10.1080/21513732.2016.1240712>
79. Wuryantini, S., Wicaksono, R. C., Yudistira, R. A., & Endarto, O. (2021). Utilization of plant waste as botanical pesticide for citrus pest control. *IOP Conference Series: Earth and Environmental Science*, 749(1), 012022. <https://doi.org/10.1088/1755-1315/749/1/012022>
80. Zeier, J. (2013). New insights into the regulation of plant immunity by amino acid metabolic pathways. *Plant, Cell & Environment*, 36(12), 2085–2103. <https://doi.org/10.1111/pce.12122>
81. Zhang, H., Garratt, M. P. D., Bailey, A., Potts, S. G., & Breeze, T. (2018). Economic valuation of natural pest control of the summer grain aphid in wheat in South East England. *Ecosystem Services*, 30, 149–157. <https://doi.org/10.1016/j.ecoser.2018.02.019>
82. Zhang, W., & Swinton, S. M. (2009). Incorporating natural enemies in an economic threshold for dynamically optimal pest management. *Ecological Modelling*, 220(9–10), 1315–1324. <https://doi.org/10.1016/j.ecolmodel.2009.01.027>
83. Zhang, Y., Jiang, W., Li, T., Xu, H., Zhu, Y., Fang, K., Ren, X., Wang, S., Chen, Y., Zhou, Y., & Zhu, F. (2024). SubCELL: the landscape of subcellular compartment-specific molecular interactions. *Nucleic Acids Research*. <https://doi.org/10.1093/nar/gkae863>
84. Zhou, H., Luo, S., Zhang, J., & Hua, J. (2022). Negative Interactions Balance Growth and Defence in Plants Confronted with Herbivores or Pathogens. *Journal of Agricultural and Food Chemistry*, 70(40), 12723–12732. <https://doi.org/10.1021/acs.jafc.2c04218>
85. Zhou, W., Bernal, J., Medina, R. F., Akbulut, M. E. S., Cisneros-Zevallos, L., & Arcot, Y. (2024). Integrated Pest Management: An Update on the Sustainability Approach to Crop Protection. *ACS Omega*, 9(40), 41130–41147. <https://doi.org/10.1021/acsomega.4c06628>
86. Zhu-Salzman, K., Bi, J.-L., & Liu, T.-X. (2005). Molecular strategies of plant defence and insect counter-defence. *Insect Science*, 12(1), 3–15. <https://doi.org/10.1111/j.1672-9609.2005.00002.x>
