REVIEW

Check for updates
HISTORY
Received: 7 January 2024
Revised: 28 March 2025
Accepted: 16 April 2025
Published: 8 November 2025

Use of Allelopathic Phytochemicals for Sustainable Agriculture: A Systematic Review

Rinky Yadav[1], Shazia Akhtar[2] and Deepti Singh Vashishth[2*]

[1]Department of Environmental Science, Alpine Group of Institute, Dehradun, Uttarakhand, India
[2]Department of Environment Science, Graphic Era (Deemed to be University), Dehradun, India
* Corresponding author. Email: deepti8694@gmail.com

Abstract

The escalating global demand for food production necessitates a paradigm shift towards sustainable agricultural practices that minimize reliance on synthetic agrochemicals and environmental degradation. Allelopathy, the phenomenon of biochemical interactions between plants, offers a promising avenue through the use of allelopathic phytochemicals. These naturally occurring compounds, produced by various plant species, exhibit inhibitory or stimulatory effects on neighbouring organisms, including weeds, pests, and pathogens. This systematic review comprehensively examines the current state of research on the application of allelopathic phytochemicals in sustainable agriculture. We delve into the diverse classes of allelopathic compounds, their mechanisms of action, and their efficacy in weed, pest, and disease management. Additionally, we inspected the possibility of allelopathy to downgrade the environmental consequences of agriculture, maintain or upgrade the nutrient content and soil health. The article consolidate the documentation from research articles focussing applications, exceptions and future possibilities of allelopathic phytochemical employment in attaining adaptable and sustainable agriculture. To discover the significance of phytochemicals and to provide environment friendly and food secured future, we features the importance of assimilated ways of sustainable practices in combination of allelopathic techniques.

Keywords: Agriculture, Bioherbicides, Organic farming, Phytochemicals, Soil Health.

1. Introduction

Global agriculture faces unprecedented challenges in meeting the food demands of a rapidly growing population while mitigating the detrimental environmental consequences associated with conventional farming practices. The heavy reliance on synthetic pesticides, herbicides, and fertilizers, while initially boosting crop yields, has resulted in widespread environmental pollution, soil degradation, biodiversity loss, and the emergence of pesticide-resistant pests and herbicide-resistant weeds (Aktar et al. 2009; Tilman et al. 2002). These unsustainable practices not only threaten ecosystem health but also raise concerns about food safety and long-term agricultural productivity. Therefore, the transition towards sustainable agricultural systems is imperative to ensure food security for present and future generations while minimizing ecological footprint and promoting environmental stewardship (Reganold et al. 2016).

Sustainable agriculture encompasses a holistic approach that seeks to optimize crop production through ecologically sound practices, reducing dependence on synthetic inputs and maximizing the utilization of natural resources (Pretty, 2008). This paradigm shift necessitates exploring innovative and nature-inspired solutions for crop protection and resource management. Allelopathy, a well-documented ecological phenomenon, presents a compelling opportunity in this context. Coined by Hans Molisch in 1937, allelopathy refers to the direct or indirect chemical interactions between plants, mediated by the release of chemical compounds known as allelochemicals (Molisch, 1937). These allelochemicals, often secondary metabolites or phytochemicals, can exert a range of effects, including inhibition of germination, growth, and reproduction of neighboring plants (especially weeds), suppression of pests and pathogens, and even stimulation of beneficial soil microorganisms or crop growth (Bachheti, et al. 2020; Rice, 1985).

The vast diversity of the plant kingdom offers a rich reservoir of allelopathic phytochemicals. These compounds belong to various chemical classes, such as phenolics, terpenoids, alkaloids, flavonoids, and quinones, each exhibiting unique structural and functional properties. The allelopathic potential of numerous plant species has been demonstrated across various ecosystems, suggesting their ecological significance in plant community dynamics and natural weed suppression. Translating this natural phenomenon into agricultural systems holds immense promise for developing sustainable crop protection strategies and reducing reliance on synthetic agrochemicals (Duke et al. 2000; Kohli et al, 1997).

This systematic review aims to provide a comprehensive overview of the current state of research on the use of allelopathic phytochemicals for sustainable agriculture. We will synthesize evidence from research papers investigating the potential applications of these natural compounds in weed, pest, and disease management, as well as their impact on soil health and nutrient cycling. By critically evaluating the existing literature, we aim to identify successful applications, challenges, and promising avenues for future research and implementation of allelopathic strategies in diverse agricultural systems. Ultimately, this review seeks to contribute to the advancement of sustainable agriculture by highlighting the potential of allelopathic phytochemicals as a nature-based solution for crop protection and resource management.

2. Methodology

The review followed a rigorous methodology to ensure comprehensive and unbiased assessment of the literature on the use of allelopathic phytochemicals for sustainable agriculture. The focus remained on recent publications (within the last two decades) to reflect contemporary advancements and applications. The extracted data were synthesized qualitatively and quantitatively. A narrative synthesis was performed to describe the diversity of allelopathic phytochemicals, their mechanisms of action, and their applications in different agricultural contexts. Thematic analysis was used to identify recurring themes, challenges, and opportunities in the utilization of allelopathic phytochemicals for sustainable agriculture (Figure 1).

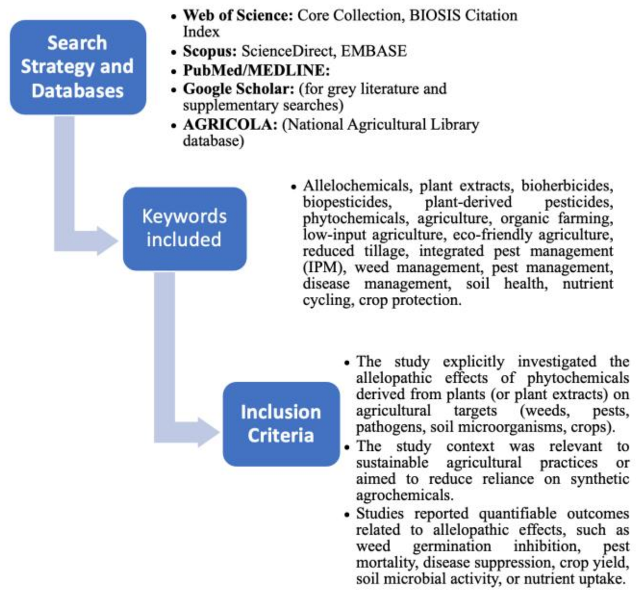

Figure 1: Search Strategy for the review

3. Results and Discussion

The literature search identified a substantial body of research investigating the use of allelopathic phytochemicals in sustainable agriculture. After screening and applying inclusion/exclusion criteria, a total of 115 research articles were included in this systematic review. The results are synthesized and presented in the following thematic sections:

3.1. Diversity of Allelopathic Phytochemicals and their Mechanisms of Action:

The reviewed literature highlighted the remarkable chemical diversity of allelopathic phytochemicals, encompassing a wide range of compound classes. The strongest allelochemicals published are from phenolic group including flavonoids like quercetin & rutin, phenolic acids such as cinnamic acid, benzoic acid & salicylic acid and tannins (Rice-Evans et al. 1996; Chung et al. 2001). Some other studies reported terpenoids like mono, sesqui and diterpenes and few alkaloids such as indole and iso-quinoline alkaloids. Coumarins, cyanogenic glycosides, quinones, glucosinolates and VOCs. These distinctive allelochemicals have different mechanism of action and often attack one or more physiological process of recipient. The predominant mechanism noted in literature is following:

- **Inhibition of Seed Germination and Seedling Growth:** Allelochemicals can interfere with seed imbibition, disrupt cell division, inhibit enzyme activity involved in germination, and reduce seedling vigor (Gniazdowska and Bogatek, 2005). The extracts of allelopathic plants like *Sorghum*, *Brassica*, *Helianthus*, and *Juglans* substantially reduces germination rate and seedling growth of various weeds (Nicolescu et al. 2020; Uremis et al. 2005; Cheema et al. 2002).

- **Disruption of Photosynthesis and Respiration:** Some allelochemicals can interfere with photosynthetic electron transport, reduce chlorophyll synthesis, and inhibit respiration, leading to energy depletion and growth inhibition in sensitive plants. For instance, juglone from *Juglans nigra* and artemisinin from *Artemisia annua* have been shown to disrupt photosynthesis and respiration in susceptible weed species (Nicolescu et al. 2020; Duke et al. 1987).

- **Interference with Nutrient Uptake and Assimilation:** Allelochemicals can alter membrane permeability, inhibit nutrient transporters, and interfere with nutrient assimilation pathways, leading to nutrient deficiency and impaired plant growth. Phenolic acids from *Secale cereale* have been shown to reduce nitrate uptake in weeds (Reigosa et al. 1999).

- **Alteration of Plant Hormone Balance:** Allelochemicals can disrupt the biosynthesis, transport, or signalling of plant hormones like auxin, gibberellins, cytokinins, and abscisic acid, leading to abnormal growth and development. For example, some flavonoids can act as auxin antagonists, inhibiting cell elongation and root growth **(Weir et al. 2004).**

- **Induction of Oxidative Stress:** Certain allelochemicals can induce the production of reactive oxygen species (ROS) in plant cells, leading to oxidative damage to cellular components, including lipids, proteins, and DNA, ultimately causing cell death. Caffeic acid and ferulic acid have been shown to induce oxidative stress in weeds (Li et al. 2019; Dayan et al. 2000).

- **Inhibition of Microbial Activity:** Some allelochemicals exhibit antimicrobial activity, inhibiting the growth and activity of soil microorganisms, including plant pathogens and beneficial microbes (Lattanzio et al. 2006). However, the effects on microbial communities can be complex and context-dependent, with some allelochemicals selectively inhibiting specific pathogens while sparing beneficial microbes or even promoting their activity at lower concentrations (Bais et al. 2006; Walker et al. 2003).

It is important to note that the allelopathic effect of a particular phytochemical is influenced by several factors, including the concentration of the compound, the sensitivity of the target organism, environmental conditions (soil type, pH, temperature, moisture), and the presence of other interacting compounds in plant extracts or exudates. Furthermore, allelopathic effects can be species-specific, with some phytochemicals exhibiting strong inhibitory effects on certain weed species while having minimal impact on others or even stimulating crop growth in some cases.

3.2. Allelopathy for Weed Management in Sustainable Agriculture:

Weed management is a major challenge in sustainable agriculture, and allelopathic phytochemicals have emerged as promising bioherbicidal agents. The review highlighted numerous studies demonstrating the efficacy of allelopathic plant extracts, plant residues, and intercropping systems in suppressing weed growth and reducing reliance on synthetic herbicides.

- Bioherbicidal Plant Extracts: Extracts from various plant species, including *Sorghum bicolor*, *Brassica juncea*, *Eucalyptus globulus*, *Azadirachta indica*, and *Tagetes patula*, showed significant herbicidal activity against a wide range of weed species in both laboratory and field settings (Abd El–Hamid et al. 2017; Dudai et al. 1999). Essential oils from *Eucalyptus* and *Tagetes* exhibited contact and fumigant herbicidal activity against several weed species (Belaid et al. 2025; Walia et al. 2017). Studies also explored the synergistic effects of combining extracts from different allelopathic plants to enhance herbicidal efficacy (Dilipkumar and Chuah 2013).

- Allelopathic Plant Residues and Cover Cropping: Incorporation of allelopathic plant residues into the soil or using allelopathic cover crops has shown promise in long-term weed suppression. Residues of *Brassica* species (e.g., mustard, canola), *rye* (*Secale cereale*), and *sunflower* (*Helianthus annuus*) released allelochemicals into the soil, reducing weed emergence and growth in subsequent crops.

Allelopathic cover crops, when incorporated into crop rotations, can provide sustained weed suppression and improve soil health simultaneously (Rawat et al. 2017; Narwal et al. 1999; Teasdale et al. 1996) Studies showed that cover cropping with rye or hairy vetch (*Vicia villosa*) significantly reduced weed density and biomass in corn, soybean, and vegetable cropping systems (Rector, 2019; Sung et al. 2010).

- Allelopathic Intercropping and Crop Rotation: Intercropping allelopathic crops with susceptible crops and incorporating allelopathic crops into rotation systems are other promising strategies. Intercropping *Sorghum* or sunflower with maize or soybean has been shown to reduce weed infestation and improve overall crop productivity. Rotating allelopathic crops like *rye* or *mustard* with susceptible crops can break weed cycles and reduce weed pressure over time (Kandhro et al. 2014; Mahmood et al. 2013; Cheema et al. 2004).

Despite the promising results, the efficacy of allelopathic weed management can be variable depending on environmental conditions, weed species, soil type, crop type, and application method. Further research is needed to optimize application strategies, identify consistently effective allelopathic sources, and develop integrated weed management systems that combine allelopathy with other sustainable practices like mechanical weeding, biological control, and crop diversification.

3.3. Allelopathy for Pest and Disease Management in Sustainable Agriculture:

Beyond weed management, allelopathic phytochemicals have also demonstrated potential for managing insect pests and plant diseases in sustainable agriculture. Research explored the use of allelopathic plant extracts and essential oils as biopesticides and biofungicides.

- Biopesticidal Activity: Extracts and essential oils from plants like *Azadirachta indica* (neem), *Chrysanthemum cinerariifolium* (pyrethrum), *Ocimum basilicum* (basil), and *Mentha piperita* (peppermint) exhibited insecticidal, repellent, and antifeedant activity against various agricultural pests (Isman, 2006; Shaaya et al. 1991; Kogan and Paxton, 1983). Neem extracts, rich in azadirachtin, are well-known for their broad-spectrum insecticidal properties (Kilani-Morakchi et al. 2021; Schmutterer, 1990). Pyrethrum extracts, containing pyrethrins, are effective contact insecticides (Casida and Quistad, 1995). Essential oils from basil and peppermint demonstrated repellent and toxic effects against insect pests like aphids, whiteflies, and caterpillars. Studies also explored the use of allelopathic plant extracts to manage nematodes and mites (Ntalli and Caboni, 2012; Marcic, 2012).

- Biofungicidal Activity: Extracts and essential oils from plants like *Allium sativum* (garlic), *Melaleuca alternifolia* (tea tree), *Thymus vulgaris* (thyme), and *Rosmarinus officinalis* (rosemary) showed antifungal activity against various plant pathogens, including fungi and bacteria. Garlic extracts, rich in allicin, exhibited broad-spectrum antifungal activity (Block, 2010; Aqil et al. 2010; Benkeblia, 2004; Dorman and Deans, 2000). Tea tree oil and thyme oil demonstrated efficacy against fungal pathogens like *Fusarium*, *Rhizoctonia*, and *Botrytis* (Carson et al. 2006; Trombetta et al. 2005). Rosemary oil showed antifungal and antibacterial activity against several plant pathogens (Özcan and Chalchat, 2008).

The mechanisms of action of biopesticidal and biofungicidal phytochemicals include neurotoxicity, enzyme inhibition, disruption of insect or fungal physiology, and induction of plant defense responses. However, similar to bioherbicides, the efficacy of biopesticides and biofungicides can be variable and influenced by environmental factors, pest/pathogen species, and application methods. Formulation and delivery of plant extracts and essential oils are crucial for enhancing their stability, persistence, and efficacy under field conditions. Integrated pest and disease management strategies that combine allelopathic approaches with other biological control agents, cultural practices, and resistant varieties are essential for sustainable crop protection (Waghunde et al. 2021; Dayan et al. 2009).

3.4. Allelopathy for Soil Health and Nutrient Cycling in Sustainable Agriculture:

Beyond direct pest and weed suppression, allelopathic phytochemicals can also contribute to improved soil health and nutrient cycling, indirectly enhancing crop productivity and sustainability.

- Improvement of Soil Microbial Communities: While some allelochemicals can have inhibitory effects on certain microorganisms, others can selectively promote the growth and activity of beneficial soil microbes, such as nitrogen-fixing bacteria, mycorrhizal fungi, and phosphate-solubilizing bacteria (Zeng et al.

Sus. Sci. Lett. (2025), 1(1): 2-11
https://doi.org/10.xxx/ssl2025xxxx

2008). For instance, flavonoids and phenolic acids can stimulate the activity of nitrogen-fixing bacteria in the rhizosphere (Dong and Song, 2020). Certain terpenoids can enhance mycorrhizal colonization of plant roots (Akiyama et al. 2005). Altering soil microbial communities through allelopathic interventions can improve nutrient availability, enhance disease suppression, and promote overall soil health (Javaid, 2009).

- Enhanced Nutrient Cycling: Decomposition of allelopathic plant residues can release organically bound nutrients back into the soil, contributing to nutrient cycling and reducing reliance on synthetic fertilizers. Allelopathic cover crops and green manures can improve soil organic matter content, water retention, and nutrient availability. Some allelochemicals can also influence nutrient mobilization and uptake by plants. For example, certain organic acids released from plant roots can enhance phosphorus availability in the soil (Snapp et al. 2005; Lal, 2004; Marschner, 1995).
- Suppression of Soil-borne Pathogens: Some allelopathic phytochemicals can suppress soil-borne plant pathogens, contributing to disease management and improved soil health. Glucosinolates from *Brassica* species, upon hydrolysis, release isothiocyanates, which are potent soil fumigants and can suppress a range of soil-borne pathogens and nematodes (Mithen, 2001). Incorporation of *Brassica* green manures into the soil has been shown to reduce soil-borne diseases in various crops (Shaw et al. 2021).

The complex interactions between allelopathic phytochemicals and soil microbial communities require further investigation. Understanding the long-term effects of allelopathic interventions on soil ecology and nutrient cycling is crucial for optimizing their use in sustainable agriculture.

4. Challenges and Limitations:

Despite the promising potential of allelopathic phytochemicals for sustainable agriculture, several challenges and limitations need to be addressed for their wider adoption and effective implementation.

- **Variability in Efficacy:** The efficacy of allelopathic phytochemicals can be highly variable depending on environmental conditions (temperature, rainfall, soil type), target organism species and strains, application methods, plant genotype, and developmental stage. Inconsistent results across different locations and seasons can hinder reliable application (Scavo et al. 2021).
- **Phytotoxicity to Crops:** Some allelopathic phytochemicals may exhibit phytotoxicity to crops at higher concentrations or under certain environmental conditions. Careful selection of allelopathic sources and optimization of application rates are crucial to minimize or avoid crop damage. Selective allelopathy, targeting weeds or pests while sparing crops, is a key goal in allelopathic crop protection. (Duke et al. 2020; Weston and Duke, 2003).
- **Isolation and Formulation Challenges:** Isolation and purification of specific allelopathic phytochemicals from plant sources can be complex, costly, and environmentally demanding. Formulation of plant extracts and essential oils for enhanced stability, persistence, and delivery to target sites is another challenge [93, 94]. Development of cost-effective and environmentally friendly extraction and formulation techniques is crucial for commercial viability (Mondal et al. 2024, Kamil et al. 2019).
- **Environmental Fate and Persistence:** The environmental fate and persistence of allelopathic phytochemicals in soil and water need to be carefully evaluated. While generally considered less persistent than synthetic pesticides, some phytochemicals may still accumulate in the environment or undergo transformation into potentially harmful products. Research on the environmental degradation pathways and ecological impacts of allelopathic phytochemicals is essential (Kostina-Bednarz et al. 2023; Inderjit et al. 2005).
- **Standardization and Quality Control:** Plant extracts and plant-based products are complex mixtures of compounds, and their composition can vary depending on plant species, genotype, growth conditions, and extraction methods. To assure the consistent efficiency the standardization of plant extracts and qaulty control measure are important (Kostina-Bednarz et al. 2023; Inderjit et al. 2005).
- **Large scale Field application and Economic Viability:** The detailed analysis of allelopathic techniques, application at large scale farms, economic feasibility and incorporation with traditional farming

Sus. Sci. Lett. (2025), 1(1): 2-11
https://doi.org/10.xxx/ssl2025xxxx

methods is required to demonstrated the importance of allelopathic approaches to farmers. So that they can adapt these techniques over conventional techniques for sustainable agriculture.

- **Regulatory Hurdles:** The systematic and standard approaches are needed for registration and marketing of allelopathic products. As there are different and complex rules for registration of plant based bio-herbicides and bio-pesticides across the globe.

- **Consumer insight and acquiescence:** To nurture the consumer's assurance, it is important to educated the them about the benefits and safety of the allelopathic products so that they can accept these products (Ukwe, 2003).

4. Conclusion and Future directions

This systematic review provides compelling evidence for the significant potential of allelopathic phytochemicals in advancing sustainable agriculture. Research has demonstrated the efficacy of these natural compounds in weed, pest, and disease management, as well as their contribution to improved soil health and nutrient cycling. For environment friendly and sustainable farming allelopathic phytochemicals provide a natural plant-based alternative to harmful artificial agrochemicals.

As the field is emerging right now, so for extensive and productive application of allelopathic techniques in agriculture, there are many issues to be negotiated such as formulation, phytotoxicity, efficacy, delivery and regulatory related issues are to be resolved by research. Identification of allelochemicals, illustration of their mode and mechanism of action, extraction techniques and optimizing formulation and large scale trails should be the focus of future of allelopathy. Allelopathic phytochemical can be very beneficial for sustainable and environment friendly agriculture, if we focus on these issues and subsidize the chances emphasized in this review which can lead to furnish global food security.

The field of allelopathy in sustainable agriculture is rapidly evolving, and several promising avenues for future research and development exist:

- Exploring the vast plant biodiversity to discover novel allelopathic phytochemicals with potent and selective bioactivity is crucial. Advanced metabolomics and bioassay-guided fractionation techniques can accelerate the identification and characterization of new allelochemicals.

- Further elucidating the detailed mechanisms of action of allelopathic phytochemicals at the molecular and physiological levels is essential for optimizing their application and developing targeted strategies. Omics approaches (genomics, transcriptomics, proteomics, metabolomics) can provide deeper insights into allelopathic interactions

- Research is needed to enhance the selectivity of allelopathic phytochemicals, targeting weeds and pests while minimizing phytotoxicity to crops. Strategies include chemical modification of allelochemicals, formulation with safeners, and optimization of application timing and dosage.

- Developing efficient, cost-effective, and environmentally friendly extraction methods for allelopathic phytochemicals and advanced formulation technologies for enhanced stability, delivery, and controlled release are critical for practical application. Nano-formulation and microencapsulation technologies may offer promising solutions.

- Focusing on integrated approaches that combine allelopathic strategies with other sustainable agricultural practices, such as crop rotation, cover cropping, biological control, mechanical weeding, and resistant varieties, is essential for robust and resilient weed, pest, and disease management.

- Conducting more field trials under diverse agro-ecological conditions and large-scale demonstration projects are crucial to validate the efficacy and economic viability of allelopathic strategies in real-world farming systems.

- Exploring the genetic basis of allelopathy in plants and utilizing genetic engineering or marker-assisted selection to enhance allelopathic potential in crops could be a transformative approach for sustainable agriculture.

- Conducting comprehensive socio-economic and environmental impact assessments of allelopathic approaches compared to conventional practices is necessary to evaluate their overall sustainability and promote wider adoption.

- Raising consumer awareness about the benefits of allelopathic strategies and plant-based crop protection products is important for fostering public acceptance and demand for sustainably produced food.

Author Contributions: Conceptualization – Rinky Yadav and Deepti Singh Vashishth; Data curation, Investigation, and Methodology – Rinky Yadav and Shazia Akhtar; Supervision, Validation, and Visualization – Deepti Singh Vashishth; Writing – Rinky Yadav and Shazia Akhtar Editing – Deepti Singh Vashishth.

Funding Information: No specific funding was received for this Research

Acknowledgments: The author wishes to thank Manoj Singh for the support.

Conflicts of Interest: The author(s) declare that there is no conflict of interest regarding the publication of this manuscript. The research was conducted independently, without any financial or personal relationships that could influence or bias the results and conclusions presented in this work. Furthermore, the authors affirm that no competing interests exist in relation to this study, its data, or its outcomes.

Institutional/Ethical Approval: This article does not contain any studies with human and animal participants performed by any of the authors.

References

Abd El–Hamid, H. A., Ibrahim, L. M., Ammar, M. Y., & Helmy, M. A. (2017). Allelopathic effect of neem (*Azadirachta indica* A. Juss) aqueous leaf extract on the germination and growth of some selected crops and weeds. *Biolife*, *5*, 428-436.

Akiyama, K., Matsuzaki, K. I., & Hayashi, H. (2005). Plant sesquiterpenes induce hyphal branching in arbuscular mycorrhizal fungi. *Nature*, *435*(7043), 824-827.

Aktar, M. W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary toxicology*, *2*(1), 1.

Aqil, F., Zahin, M., Ahmad, I., Owais, M., Khan, M. S. A., Bansal, S. S., & Farooq, S. (2010). Antifungal activity of medicinal plant extracts and phytocompounds: a review. *Combating fungal infections: problems and remedy*, 449-484.

Bachheti, A., Sharma, A., Bachheti, R. K., Husen, A., & Pandey, D. P. (2020). Plant allelochemicals and their various applications. *Co-evolution of secondary metabolites*, 441-465.

Bais, H. P., Weir, T. L., Perry, L. G., Gilroy, S., & Vivanco, J. M. (2006). The role of root exudates in rhizosphere interactions with plants and other organisms. *Annu. Rev. Plant Biol.*, *57*(1), 233-266.

Belaid, S., Gonzalez-Coloma, A., Andres, M. F., Elfalleh, W., Idoudi, S., Romdhane, M., & Saadaoui, E. (2025). Exploring Chemical Profiles, Antifeedant, Nematicidal and Phytotoxic Potentials of Seven Essential Oils from Eucalyptus Species. *Chemistry & Biodiversity*, e202402960.

Benkeblia, N. (2004). Antimicrobial activity of essential oil extracts of various onions (*Allium cepa*) and garlic (*Allium sativum*). *LWT-food science and technology*, *37*(2), 263-268.

Block, E. (2010). Allium botany and cultivation, ancient and mdern. *Garlic and other alliums: the lore and the science*, 1-32.

Carson, C. F., Hammer, K. A., & Riley, T. V. (2006). Melaleuca alternifolia (tea tree) oil: a review of antimicrobial and other medicinal properties. *Clinical microbiology reviews*, *19*(1), 50-62.

Casida, J. E., & Quistad, G. B. (1995). Pyrethrum flowers: production, chemistry, toxicology, and uses. Oxford University Press

Cheema, Z. A., Iqbal, M., & Ahmad, R. (2002). Response of wheat varieties and some rabi weeds to allelopathic effects of sorghum water extract. International Journal of Agriculture and Biology, 4(1), 52-55.

Cheema, Z. A., Khaliq, A., & Saeed, S. (2004). Weed control in maize (*Zea mays* L.) through sorghum allelopathy. *Journal of Sustainable Agriculture*, *23*(4), 73-86.

Chung, I. M., Ahn, J. K., & Yun, S. J. (2001). Assessment of allelopathic potential of barnyard grass (*Echinochloa crus-galli*) on rice (*Oryza sativa* L.) cultivars. *Crop protection*, *20*(10), 921-928.

Dayan, F. E., Romagni, J. G., & Duke, S. O. (2000). Investigating the mode of action of natural phytotoxins. *Journal of Chemical Ecology*, *26*, 2079-2094.

Dayan, F. E., Cantrell, C. L., & Duke, S. O. (2009). Natural products in crop protection. *Bioorganic & medicinal chemistry*, *17*(12), 4022-4034.

Dilipkumar, M., & Chuah, T. S. (2013). Is combination ratio an important factor to determine synergistic activity of allelopathic crop extract and herbicide?. *International Journal of Agriculture & Biology*, *15*(2).

Dong, W., & Song, Y. (2020). The significance of flavonoids in the process of biological nitrogen fixation. *International journal of molecular sciences*, *21*(16), 5926.

Dorman, H. D., & Deans, S. G. (2000). Antimicrobial agents from plants: antibacterial activity of plant volatile oils. *Journal of applied microbiology*, *88*(2), 308-316.

Dudai, N., Poljakoff-Mayber, A., Mayer, A. M., Putievsky, E., & Lerner, H. R. (1999). Essential oils as allelochemicals and their potential use as bioherbicides. *Journal of Chemical Ecology*, *25*, 1079-1089.

Duke, S. O., Vaughn, K. C., Croom Jr, E. M., & Elsohly, H. N. (1987). Artemisinin, a constituent of annual wormwood (Artemisia annua), is a selective phytotoxin. *Weed science*, *35*(4), 499-505.

Duke, S. O., Dayan, F. E., Romagni, J. G. & Rimando, A. M. (2000). Natural products as sources of herbicides: current status and future trends. *Weed research*, *40*(1), 99-111.

Duke, S. O., Pan, Z., & Bajsa-Hirschel, J. (2020). Proving the mode of action of phytotoxic phytochemicals. *Plants*, *9*(12), 1756.

Gniazdowska A, Bogatek R (2005) Allelopathic interactions between plants. Multi-site action of allelochemicals. Acta Physiologiae Plantarum 27(3):395-407.

Inderjit, Weston, L. A., & Duke, S. O. (2005). Challenges, achievements and opportunities in allelopathy research. *Journal of Plant Interactions*, *1*(2), 69-81.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual review of entomology*, *51*(1), 45-66.

Javaid, A. (2009). Arbuscular mycorrhizal mediated nutrition in plants. *Journal of Plant Nutrition*, *32*(10), 1595-1618.

Kamil H. M., Saquib, M., & Faheem Khan, M. (2019). Techniques for extraction, isolation, and standardization of bio-active compounds from medicinal plants. *Natural Bio-active Compounds: Volume 2: Chemistry, Pharmacology and Health Care Practices*, 179-200.

Kandhro, M. N., Tunio, S., Rajpar, I., & Chachar, Q. (2014). Allelopathic impact of sorghum and sunflower intercropping on weed management and yield enhancement in cotton. *Sarhad Journal of Agriculture*, *30*(3).

Kilani-Morakchi, S., Morakchi-Goudjil, H., & Sifi, K. (2021). Azadirachtin-based insecticide: Overview, risk assessments, and future directions. *Frontiers in Agronomy*, *3*, 676208.

Kogan, M. & Paxton, J. (1983). Natural inducers of plant resistance to insects. *Plant resistance to insects*, *208*, 153-171.

Kohli, R. K., Batish, D., & Singh, H. P. (1997). Allelopathy and its implications in agroecosystems. *Journal of crop production*, *1*(1), 169-202.

Kostina-Bednarz, M., Płonka, J., & Barchanska, H. (2023). Allelopathy as a source of bioherbicides: challenges and prospects for sustainable agriculture. *Reviews in Environmental Science and Bio/Technology*, *22*(2), 471-504.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *science*, *304*(5677), 1623-1627.

Lattanzio, V., Lattanzio, V. M., & Cardinali, A. (2006). Role of phenolics in the resistance mechanisms of plants against fungal pathogens and insects. *Phytochemistry: Advances in research*, *661*(2), 23-67.

Li, Z. R., Amist, N., & Bai, L. Y. (2019). Allelopathy in sustainable weeds management. *Allelopathy J*, *48*(2), 109-138.

Mahmood, A., Cheema, Z. A., Mushtaq, M. N., & Farooq, M. (2013). Maize–sorghum intercropping systems for purple nutsedge management. *Archives of Agronomy and Soil Science*, *59*(9), 1279-1288.

Marcic, D. (2012). Acaricides in modern management of plant-feeding mites. *Journal of Pest Science*, *85*(4), 395-408.

Marschner, H. (1995). Mineral nutrition of higher plants. Academic press.

Mithen, R. (2001). Glucosinolates–biochemistry, genetics and biological activity. *Plant Growth Regulation*, *34*, 91-103.

Molisch, H. (1937). Der Einfluss einer Pflanze auf die andere, Allelopathie. *Fischer Jena*.

Mondal, S., Das, M., Debnath, S., Sarkar, B. K., & Babu, G. (2024). An overview of extraction, isolation and characterization techniques of phytocompounds from medicinal plants. *Natural Product Research*, 1-23.

Narwal, S. S., Singh, T., Hooda, J. S., & Kathuria, M. K. (1999). Allelopathic effects of sunflower on succeeding summer crops. I. Field studies and bioassays. *Allelopathy Journal*, *6*(1), 35-48.

Nicolescu, V. N., Rédei, K., Vor, T., Bastien, J. C., Brus, R., Benčať, T., ... & Štefančik, I. (2020). A review of black walnut (Juglans nigra L.) ecology and management in Europe. *Trees*, *34*, 1087-1112.

Ntalli, N. G., & Caboni, P. (2012). Botanical nematicides: a review. *Journal of agricultural and food chemistry*, *60*(40), 9929-9940.

Özcan, M. M., & Chalchat, J. C. (2008). Chemical composition and antifungal activity of rosemary (Rosmarinus officinalis L.) oil from Turkey. *International journal of food sciences and nutrition*, *59*(7-8), 691-698.

Pretty, J. (2008). Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447-465.

Rawat, L. S., Maikhuri, R. K., Bahuguna, Y. M., Jha, N. K., & Phondani, P. C. (2017). Sunflower allelopathy for weed control in agriculture systems. *Journal of crop science and biotechnology*, *20*(1), 45-60.

Rector, L. S. (2019). *Herbicide carryover to cover crops and evaluation of cover crops for annual weed control in corn and soybeans* (Doctoral dissertation, Virginia Tech).

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature plants*, *2*(2), 1-8.

Reigosa, M. J., Sánchez-Moreiras, A., & González, L. (1999). Ecophysiological approach in allelopathy. *Critical reviews in plant sciences*, *18*(5), 577-608.

Rice, E. L. (1985). Allelopathy—an overview. *Chemically mediated interactions between plants and other organisms*, 81-105.

Rice-Evans, C. A., Miller, N. J., & Paganga, G. (1996). Structure-antioxidant activity relationships of flavonoids and phenolic acids. *Free radical biology and medicine*, *20*(7), 933-956.

Scavo, A., & Mauromicale, G. (2021). Crop allelopathy for sustainable weed management in agroecosystems: Knowing the present with a view to the future. *Agronomy*, *11*(11), 2104.

Schmutterer, H. (1990). Properties and potential of natural pesticides from the neem tree, Azadirachta indica. *Annual review of entomology*, *35*(1), 271-297.

Shaaya, E., Ravid, U., Paster, N., Juven, B., Zisman, U., & Pissarev, V. (1991). Fumigant toxicity of essential oils against four major stored-product insects. *Journal of chemical ecology*, *17*, 499-504.

Shaw, R. K., Shen, Y., Wang, J., Sheng, X., Zhao, Z., Yu, H., & Gu, H. (2021). Advances in multi-omics approaches for molecular breeding of black rot resistance in *Brassica oleracea* L. *Frontiers in Plant Science*, *12*, 742553.

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., ... & O'neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy journal*, *97*(1), 322-332.

Sung, J. K., Jung, J. A., Lee, B. M., Lee, S. M., Lee, Y. H., Choi, D. H., ... & Song, B. H. (2010). Effect of incorporation of hairy vetch and rye grown as cover crops on weed suppression related with phenolics and nitrogen contents of soil. *Plant production science*, *13*(1), 80-84.

Teasdale, J. R. (1996). Contribution of cover crops to weed management in sustainable agricultural systems. *Journal of production agriculture*, *9*(4), 475-479.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671-677.

Trombetta, D., Castelli, F., Sarpietro, M. G., Venuti, V., Cristani, M., Daniele, C., ... & Bisignano, G. (2005). Mechanisms of antibacterial action of three monoterpenes. *Antimicrobial agents and chemotherapy*, *49*(6), 2474-2478.

Ukwe, C. (2003). Scope and Potential of Bio-pesticides in the Emerging Environmental Concern. *Opinions expressed in the present publication do not necessarily reflect the views of the United Nations Industrial Development Organization (UNIDO) or the International Centre for Science and High Technology (ICS). Mention of the names of firms and commercial products does not imply endorsement by UNIDO or ICS.*, 175.

Waghunde, R. R., Shinde, C. U., Pandey, P., & Singh, C. (2021). Fungal biopesticides for agro-environmental sustainability. In *Industrially Important Fungi for Sustainable Development: Volume 1: Biodiversity and Ecological Perspectives* (pp. 479-508). Cham: Springer International Publishing.

Walia, S., Saha, S., Tripathi, V., & Sharma, K. K. (2017). Phytochemical biopesticides: some recent developments. *Phytochemistry reviews*, *16*, 989-1007.

Walker, T. S., Bais, H. P., Grotewold, E., & Vivanco, J. M. (2003). Root exudation and rhizosphere biology. *Plant physiology*, *132*(1), 44-51.

Weir, T. L., Park, S. W., & Vivanco, J. M. (2004). Biochemical and physiological mechanisms mediated by allelochemicals. *Current opinion in plant biology*, *7*(4), 472-479.

Weston, L. A., & Duke, S. O. (2003). Weed and crop allelopathy. *Critical reviews in plant sciences*, *22*(3-4), 367-389.

Zeng, R. S., Mallik, A. U., & Luo, S. M. (Eds.). (2008). Allelopathy in sustainable agriculture and forestry.