



Allelopathy in Weed Management: A Comprehensive Review

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ABSTRACT

Allelopathy, the process by which plants release biochemicals called allelochemicals to influence the growth and development of neighbouring plants, offers promising avenues for weed management. This comprehensive review explores the diverse mechanisms, nature, and applications of allelopathy in weed control. Allelopathic interactions occur through various means such as root exudates, volatilization, leaching, and decomposition of plant residues, affecting weed germination, growth, and reproduction. Allelopathic compounds, including phenolic acids, terpenoids, and alkaloids, inhibit key physiological processes in target plants, presenting opportunities for sustainable weed management. The review discusses the role of allelopathy in agriculture, highlighting the potential of allelopathic crops, cover crops, and plant extracts in suppressing weeds and reducing reliance on synthetic herbicides. Additionally, allelopathy's

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ecological significance in shaping plant communities and its implications for invasive species management are explored. Integrating allelopathy into weed management strategies holds promise for promoting environmentally friendly and economically viable agricultural practices.

Keywords: *Allelopathy; allelochemicals; weed management; mechanisms, applications; agriculture; sustainable; phenolic acids; terpenoids, alkaloids; crop rotation; cover crops; invasive species; ecological significance; integrated weed management.*

1. INTRODUCTION

A crucial biological process by which plants release certain secondary metabolites into the environment is called allelopathy (Muzell Trezzi et al., 2016). Certain biochemicals that are produced during the breakdown of organic matter are also produced by microbes. In the soil, these biochemicals also have allelopathic effects. Allelopathy plays an important role in the natural environment or ecosystem by releasing allelochemicals through a variety of mechanisms, including exudation from roots in the soil rhizosphere, volatilization, leaching, and the breakdown of plant wastes (Zeng et al., 2014). Allelochemicals are mostly chemical substances that function in a variety of ecological contexts through stimulatory and inhibitory pathways. The concentration of allelochemicals in soil influences the chelation of useful nutrients, the regulation of microbes, and plant defense.

According to Cheng et al. (2015), one of the key mechanisms of action or interactions between donor and receptor plants that asserts either positive or negative effects—such as crop protection, weed suppression or weed control, biological invasion, soil sickness, autotoxicity, etc.—is allelopathic activity (Sies, 2018). Consequently, it is crucial to employ cultivation techniques that take advantage of the stimulatory or inhibitory plant allelopathic impact to regulate the survival, development, and growth of the plant while ignoring the autotoxicity of allelopathy in order to ensure the sustainable growth of agriculture. Complex in nature, allelopathic substances with inhibitory effects involve interactions across various chemical classes, including terpenoids, flavonoids, coumarins, steroids, alkaloids, and so forth.

Allelochemicals inhibit plant germination and growth, allowing crops to grow and develop with less excess phytotoxic material in the soil and water. This enables wastewater treatment and recycling (Usman et al., 2023). Despite the fact that the specificity and efficacy of different allelochemicals are limited, Bhadoria (2011)

claimed that these can be effective substitutes for synthetic or chemical herbicides as they do not have harmful or lingering effects. According to Fang et al. (2010), if an allelopathic plant species is subjected to either biotic stress (such as being infested by disease pathogens, insect pests, or weeds) or abiotic stress (such as drought, frost, nutrient shortages, etc.), the concentration of allelochemicals produced and exuded will be higher.

Therefore, allelochemicals play a vital role in the plant having the defensive mechanism against adverse conditions or stresses, specifically biotic stresses including infestation by insect pests and diseases, damage by weeds, etc. Allelochemicals obtained from plant species are more highly biodegradable than traditionally used chemicals or herbicides, but it has unwanted impacts on off-target plant species (Krumisri et al., 2022).

2. ALLELOPATHY

The term allelopathy was first used by Molisch in 1937, despite the fact that plants have been affected by it since ancient times. The phrase is derived from two Greek words: "Allelon," which means to refer to one another, and "Pathos," which means to suffer (Jabran & Jabran, 2017). Allelopathy, on the other hand, is any process or action whereby bacteria, fungi, viruses, and plant species produce secondary metabolites that impact the formation, growth, and sustenance of other biological and agricultural systems (Sangeetha and Baskar, 2015). Animals also serve as allelopathic donors and receivers. Further, allelopathic interaction is becoming an important factor that contributes to the distribution of plant species, and copiousness within the communities of plant species and also can be vital for the advancement of intrusive or invasive plants (Zheng et al., 2015) including spotted knapweed (Reinhart et al., 2011), water hyacinth (Cheng et al., 2021), etc. Allelochemicals are only released from various parts of plants that have an allelopathic effect or activity on others. However, the allelochemical

Table 1. Mechanism of action of allelochemicals

Allelochemicals	Mechanism of action	Reference
Cinnamic acid, coumarin	Inducing growth by Inhibiting the cell division and cell elongation	Hsiung et al., (2013)
Scopoletin, polyphenols and quinones	Inhibition and stimulation of stomatal functions.	Yan et al., (2016)
	Reduces photosynthesis and porphyrin synthesis	Araniti et al., (2017)
Aldehydes and simple phenol	Inhibition and stimulation of respiration	Ren et al., (2017)
All phenolic acids	Inhibition of mineral nutrient uptake	Torabi et al., (2015)
Benzoic acid, polyphenols and simple phenols	Inhibition and stimulation of specific enzymes	Nowicka (2017)
	Inhibition of haemoglobin synthesis	Kurtyka (2016)
Scopoletin and polyphenols	Inducing growth by inhibiting the concentration of gibberellic acid and indole acetic acid	Babula (2014)

concentration may differ significantly in the plant tissues. In stress conditions, the effect of allelopathy of the allelopathic plants increases. Currently, allelopathic crops can be observed in agriculture as component crops of intercropping and crop rotation, green manure, or cover crops (Haider et al., 2015).

3. ALLELOCHEMICALS

Allelopathy is a simple biological process that involves biochemicals produced by one organism that affect the development, survival, reproduction, and growth of another organism. These biochemicals released from microorganisms are called allelochemicals and have both detrimental and beneficial impacts on target plants or organisms (Cheng et al., 2015). Moreover, allelochemicals play a dominant role in agriculture as they can be used effectively in the form of herbicides, growth regulators, antimicrobial products of crop protection, and insecticides.

4. NATURE OF ALLELOPATHIC COMPOUNDS

Prince and Pohnert (2010) described that allelopathic compounds are the chemicals or secondary metabolites produced or synthesized by microorganisms, viruses, fungi, and plants affecting agricultural and biological systems. Activity and concentration of the allelochemicals varied based on their occurrence in different plant parts such as stems, pollen, leaves, and flowers in the growing period (Gatti et al., 2010). It is necessary for the donor plant to release secondary metabolites or allelochemicals to

affect the target organisms or plant species. Allelochemicals are released into the rhizosphere or atmosphere by four means such as leaching, volatilization, exudation from the root, and compounds from decomposing residues. For instance, leaching of allelochemicals from the Black walnut's (*Juglans nigra*) leaves with the rainwater restricts the growth and development of the plant species grown under Black walnut (Jose, 2012). Sometimes, the mixture of allelopathic compounds has a greater effect than isolated compounds alone (Krumisri et al., 2022).

5. MECHANISMS OF ACTION OF ALLELOCHEMICAL

After releasing from donor plants in the soil, Allelochemicals have to go through a complex system to influence target plants. There are several diverse factors in plant-soil systems which affect the availability and effectiveness of allelochemicals in the soil such as solubility and concentration of allelochemicals, biomass production, phenological stages and the population density of the donor plants (Araniti et al., 2020).

Allelochemicals are added to the system through different plant-specific processes. The concentration of allelochemicals can be reduced if leaching, microbial breakdown, plant uptake and physiochemical processes are more active in the soil system (Sánchez et al., 2012). Organic matter and clay particles can fix allelochemicals in their surface to make them unavailable such as herbicide fixation. The concentration of catechin allelochemical, released by *Centaurea maculosa*, is decreased in sandy loam and silt

loam soil (Gniazdowska et al., 2015). The primary factors like oxidation and sorption are responsible for the disappearance of some allelochemicals. Soil texture is also involved in influencing of leaching of allelochemicals (García-Sánchez et al., 2012).

Allelochemicals influence the basic metabolisms of target plants through several physiological and biochemical processes. Most of the allelochemicals show their allelopathic effect by inhibiting the germination ability of the susceptible plant species (Lazarotto et al., 2014).

5.1 Crop on Weed

Crop residues have considerable allelopathic potential against several weeds. The inhibitory effect depends especially on crop varieties. Some crops show the allelopathic effect when they are cultivated as green manure or cover crops. Water-soluble allelochemical compounds

are very phytotoxic to some weeds like *Rumex dentatus*, *Convolvulus arvensis* and *Chenopodium album* (Macías et al., 2019).

5.2 Weed on Weed

Though weeds are the major cause of crop losses, several weeds can suppress some specific weeds. Obnoxious weeds are problematic due to their huge proliferation in several industries, especially agriculture (Weston et al., 2012). Different phenolic compounds such as ferulic, anisic, chlorogenic and caffeic, released by them, are responsible for inhibiting the growth of weeds like *Oscimum Americanum*, *Cassia tora* etc. Root and leaf extract of some weeds can be used to decrease root growth and dry matter accumulation (Scognamiglio et al., 2013). For some weeds, the radicle and plumule length are also affected along with germination (Bartesaghi et al., 2018).

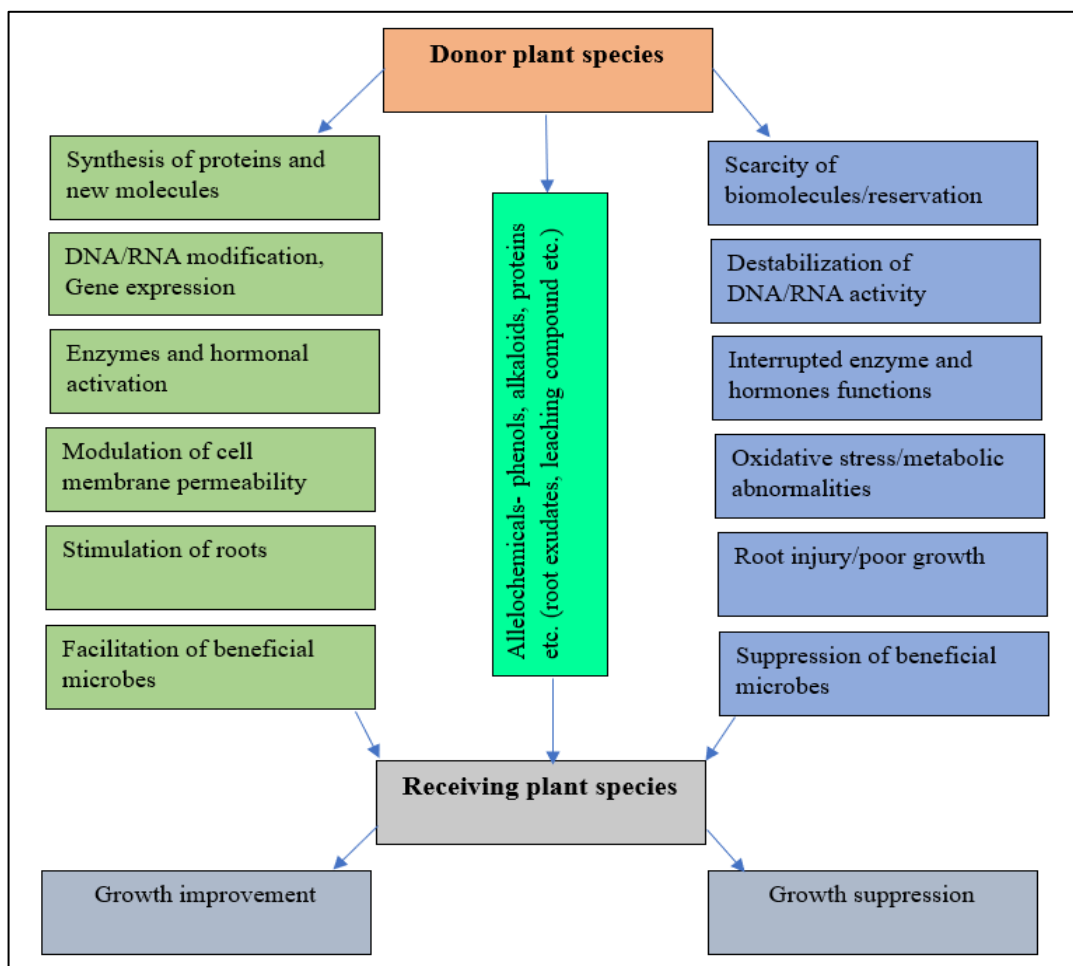


Fig. 1. Mechanisms of action of allelochemicals

List 1. Allelopathic effect of some field on weeds are discussed below

Crop name	Names of Suppressed weeds	Different ways of allelopathic effect	Reference
Rice	<i>Echinochloa crusgalli</i> , <i>Cyperus difformis</i>	Allelopathic rice varieties effect the secondary growth of <i>Echinochloa crusgalli</i> by reducing the root elongation process. Momilactone B diterpenoid is one of the most important allelochemicals for suppressing weed in rice.	Chowhan et al., (2014),
Wheat	<i>Agropyron repens</i> , <i>Digitaria ciliaris</i> , <i>Portulaca oleracea</i> , <i>Galinsoga ciliate</i> , <i>Chenopodium album</i>	Wheat has an allelopathic activity for managing weeds, releasing numerous allelochemicals including phenolic and hydroxamic acids.	Saleh & Kebeish (2018),
Barley	<i>Echinochloa crusgalli</i>	Barley releases several phytotoxic compounds such as ferulic and vanillic which have an influential effect on <i>Echinochloa crusgalli</i> .	Talukder et al., (2020),
Rye	<i>Avena fatua</i> , <i>Chenopodium album</i>	Phenolic acids and hydroxamic acids are the main components of allelochemicals released from the roots of rye when it cultivated as green manure or cover crop.	Szwed et al., (2019),
Sorghum	<i>Chenopodium album</i> , <i>Phalaris minor</i> , <i>Convolvulus arvensis</i>	Sorgoleone, the hydrophobic benzoquinones is released from the living roots of sorghum. This allelochemical works as a diuron-type herbicide as it inhibits the oxygen evolution in plants.	M'barek et al., (2019),
Black Mustard	<i>Sonchus asper</i> , <i>Matricaria inodora</i> , <i>Echinochloa crusgalli</i> , <i>Alopecurus myosuroides</i> , <i>Amaranthus hybridus</i>	Isothiocyanates, released from mustard, have a strong potential to suppress several weeds including <i>Alopecurus myosuroides</i> , <i>Echinochloa crusgalli</i> , <i>Sonchus asper</i> and <i>Matricaria inodora</i> . Black mustard is also responsible for hampering the germination and growth of <i>Avena fatua</i> .	Mahdavikia & Saharkhiz (2015), Mahdavikia et al., (2017)
Legumes	<i>Echinochloa crusgalli</i> , <i>Amaranthus hypochondriacus</i>	The aqueous solution of <i>Pueraria thunbergiana</i> contains xanthoxins which reduce the growth of lettuce. <i>Canavalia ensiformis</i> , <i>Lysiloma latisiliguun</i> , <i>Mucuna deeringiana</i> and <i>Leucaena leucocephala</i> are effective to control <i>Amaranthus hypochondriacus</i> and <i>Echinochloa crusgalli</i> .	Schieber & Chandel (2014)
Sunflower	<i>Phalaris minor</i>	Sunflower contains different substances which have allelopathic properties such as triterpenes, phenolic compounds and diterpenes which are beneficial for reducing the population of <i>Phalaris minor</i> .	Laxa et al., (2019),

List 2. Allelopathic effects of some weeds are discussed below

Weed name	Names of Suppressed weeds	Different ways of allelopathic effect	Reference
Congress grass (<i>Parthenium hysterophorus</i> L.)	<i>Oscimum americanum</i> , <i>Crotalaria mucronate</i> , <i>cassia tora</i> , <i>Oscimum basilicum</i> ,	Congress grass shows allelopathic effects because of the presence of parthenin in all parts of the plant. Parthenin has a specific inhibitory potential to control the growth of <i>Crotalaria mucronate</i> .	Araniti et al., (2020),
Canary grass (<i>Phalaris minor</i>)	<i>Chenopodium album</i> , <i>Cirsium arvense</i> , <i>Convolvulus arvensis</i> , <i>Melilotus indica</i> , <i>Rumex acetosella</i>	Canary grass shows allelopathic effects in several weeds such as <i>Chenopodium album</i> , <i>Cirsium arvense</i> , <i>Convolvulus arvensis</i> , <i>Melilotus indica</i> and <i>Rumex acetosella</i> .	Scognamiglio et al., (2013),
Morning Glory (<i>Ipomoea tricolor</i>)	<i>Amaranthus viridis</i> , <i>Euphorbia hirta</i> , <i>Phyllanthus niruri</i> , <i>Coccinia indica</i>	The growth of <i>Ipomoea tricolor</i> is promoted before the cultivation of sugarcane to inhibit some seasonal weeds.	Kong et al., (2019)
<i>Croton bonplandianum</i>	<i>Medicago hispida</i> , <i>Melilotus alba</i> , <i>Vicia sativa</i>	Leaves of <i>Croton bonplandianum</i> contain several allelochemical compounds which are responsible for inhibiting the seedling growth of <i>Melilotus alba</i> , <i>Medicago hispida</i> and <i>Vicia sativa</i> .	Das et al., (2021), Saraf et al., (2014)
<i>Agropyron repens</i>	<i>Echinochloa crusgalli</i> , <i>Lactuca sativa</i> , <i>Panicum miliaceum</i> , <i>Medicago sativa</i>	<i>Agropyron repens</i> inhibit the growth of several weed species including <i>Medicago sativa</i> , <i>Panicum miliaceum</i> , <i>Lactuca sativa</i> and <i>Echinochloa crusgalli</i> .	Muzell Trezzi et al., (2016), Soltys et al., (2013)
Chenopodiaceae species	<i>Chenopodium album</i> , <i>Chenopodium murale</i>	<i>Atriplex bumburyana</i> , <i>Maireana georgei</i> , <i>Enchylaena tomentosa</i> and <i>Atriplex codonocarpa</i> are the weed species from Chenopodiaceae, which have allelopathic potential to suppress the growth of lettuce, <i>Chenopodium album</i> and <i>Chenopodium murale</i> .	Mushtaq et al., (2020)

6. APPLICATIONS OF ALLELOPATHY IN WEED MANAGEMENT

Allelopathy holds promise as a component of integrated weed management strategies. Allelopathic crops, cover crops, and plant extracts can be utilized to suppress weed growth and reduce the reliance on synthetic herbicides. Intercropping systems incorporating allelopathic species have shown potential for weed control while enhancing soil fertility and biodiversity. Moreover, allelopathic plant residues can be incorporated into soil as green manure or mulch to inhibit weed germination and growth.

Allelopathy offers promising avenues for effective weed management in agricultural systems through various applications. One key strategy involves utilizing allelopathic cover crops, such as rye (*Secale cereale*) and sorghum-sudangrass (*Sorghum bicolor* x *Sorghum sudanense*), which release allelochemicals into the soil, inhibiting weed seed germination and growth (Macias et al., 2019). These cover crops not only suppress weeds but also contribute to soil erosion control, nutrient cycling, and improved soil structure (Kong et al., 2019). Additionally, incorporating allelopathic crops into crop rotation systems disrupts weed growth cycles and reduces herbicide use, thereby promoting sustainable weed management practices (Talukder et al., 2020). Furthermore, applying allelopathic plant residues or mulches to fields creates a weed-suppressive barrier that inhibits weed emergence and competition with crops (Araniti et al., 2020). Mulching with materials such as black walnut (*Juglans nigra*) leaves or rice straw effectively reduces weed populations while improving soil health (Mahdavia & Saharkhiz, 2015). Moreover, allelopathic extracts derived from plants can be formulated into bioherbicides for targeted weed control, offering sustainable alternatives to synthetic herbicides with minimal environmental impact (Soltys et al., 2013). These extracts contain allelochemicals that disrupt weed growth processes and can be applied as spot treatments or pre-emergence treatments in agricultural fields (Chowhan et al., 2014). Finally, adopting allelopathic intercropping and companion planting systems, combining allelopathic and non-allelopathic plant species, can effectively suppress weed growth while enhancing crop productivity and biodiversity (Mushtaq et al., 2020). Integrating allelopathy into weed management strategies holds promise for

promoting environmentally friendly and economically viable agricultural practices.

Allelopathy, a fascinating ecological phenomenon, holds great potential for revolutionizing weed management practices by harnessing the natural chemical interactions between plants. This intricate process involves the release of allelochemicals—bioactive compounds synthesized by one plant species—that affect the growth, development, or survival of neighboring plants. The application of allelopathy in weed management is multifaceted, offering diverse strategies to mitigate weed competition and enhance crop yields sustainably.

One of the key applications of allelopathy lies in agricultural systems, where certain crops exhibit allelopathic properties that inhibit the germination and growth of weeds. For instance, crops like rice and wheat release allelochemicals into the soil, creating an inhibitory effect on weed species, thus reducing the need for synthetic herbicides (Olofsdotter et al., 2002). By incorporating allelopathic crops or cover crops into rotation systems, farmers can disrupt weed growth cycles and suppress weed populations effectively (Weston, 1996). This integrated approach not only minimizes the environmental impact of herbicide use but also promotes soil health and biodiversity in agroecosystems.

Understanding the allelopathic interactions between different plant species opens avenues for developing novel bioherbicides derived from allelochemicals. These natural compounds, which have evolved over time as part of plant defense mechanisms, offer a sustainable alternative to conventional herbicides (Macias et al., 2007). Research into the identification and synthesis of allelochemicals with potent herbicidal properties presents exciting opportunities for the development of eco-friendly weed management solutions.

Allelopathy extends beyond agricultural settings to natural ecosystems, where it plays a crucial role in shaping plant communities and influencing ecosystem dynamics. Invasive plant species often exploit allelopathic mechanisms to outcompete native vegetation, highlighting the significance of allelopathy in ecological restoration efforts and biodiversity conservation (Rice, 1984). By understanding and harnessing allelopathic interactions, conservationists can devise strategies to manage invasive species and restore balance to disturbed ecosystems.

Allelopathy offers a holistic and environmentally sustainable approach to weed management, encompassing agricultural, ecological, and conservation contexts. By leveraging the natural chemical warfare between plants, we can develop innovative strategies to suppress weed growth, enhance crop productivity, and promote ecological resilience.

7. CONCLUSION

Allelopathy emerges as a promising approach for sustainable weed management, offering effective and environmentally friendly alternatives to synthetic herbicides. The intricate interactions between allelochemicals and target plants provide opportunities for innovative weed control strategies in agricultural and ecological settings. By harnessing allelopathic mechanisms, such as incorporating allelopathic crops, cover crops, or plant extracts, weed suppression can be achieved while enhancing soil health and biodiversity. Furthermore, allelopathy's role in shaping plant communities and influencing invasive species dynamics underscores its ecological significance. Embracing allelopathy as part of integrated weed management practices can contribute to resilient agricultural systems and ecosystem conservation. Continued research into allelopathic interactions and the development of practical applications will facilitate the implementation of allelopathy for sustainable weed management in diverse agricultural and ecological contexts.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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