ACTA BOTANICA PLANTAE

Journal Homepage: https://www.actabotanica.org/

Review Article
ISSN: 2583-7400

Exploring the Allelopathic Potential of Rice for Sustainable Agriculture: A Review

Chandan Das

Department of Botany, M.U.C. Women's College,B.C. Road, Burdwan- 713 104, West Bengal, India

Citation: Chandan Das (2025). Exploring the Allelopathic Potential of Rice for Sustainable Agriculture: A Review. *Acta Botanica Plantae.* **https://doi.org/10.51470/ABP.2025.04.03.107**

Corresponding Author: **Chandan Das** | E-Mail: **(cdburdwan@gmail.com)**

Received 20 September 2025 | Revised 25 October 2025 | Accepted 22 November 2025 | Available Online 20 December 2025

ABSTRACT

This study reviews rice allelopathy as a promising strategy for sustainable agriculture. It explores various allelochemicals such as phenolic acids, fatty acids, indoles, and terpenes released by rice plants through the root exudates and decomposing residues, which inhibit the growth of neighboring plants. These compounds play a vital role in rice's defense or protection mechanisms, enhancing its competitiveness. The review also highlights potential genes involved in rice allelopathy and discusses how allelopathic rice varieties could contribute to more sustainable agrosystems, particularly in the context of climate change.

Keywords: *Rice Allelopathy; Allelochemicals; Agriculture; Allelopathic Rice Varieties; Environmental Challenges.*

Introduction

In 1937, Austrian scientist Hans Molisch coined the term "allelopathy" to describe the chemical interactions occurring among plants. This ecological process significantly influences how plants adapt and coexist within their natural environments. [1],[2]. Allelopathy is a natural ecological phenomenon that has been observed and utilized in agriculture for centuries[3],[4]. The effects of allelopathy can be both beneficial and detrimental. Many studies have emphasized the benefits of allelopathic effects in agriculture, particularly in weed management[5],[6],[7]. Allelochemicals have the potential to either promote or suppress plant growth and development, offering a natural means to reduce reliance on synthetic herbicides and lessen environmental contamination. Although certain allelochemicals exhibit limited effectiveness or target specificity, they are widely regarded as a safer substitute for chemical pesticides because they leave minimal residues and possess low toxicity. [8].Allelopathy is the phenomenon in which a plant releases allelochemicals into the agroecosystem, which disrupt the physiology, seed germination, growth, development, and lifespan of neighbouring plants[9].Research on allelopathy aims to apply its observed effects to agricultural production, promote sustainable development of agricultural systems, and provide effective methods for reducing environmental pollution. Allelopathic plants (crops) are currently being used in agriculture as components of crop rotations, for intercropping, as cover crops or green manure, and have shown successful results in improving crop productivity and protecting the environment in Pakistan [10],[11].The application of allelopathy in agriculture has gained significant interest among researchers because of its potential to provide eco-friendly solutions for managing weeds, insect pests, and crop diseases, while also aiding in the conservation of nitrogen within agricultural soils.

Additionally, developing new agrochemicals inspired by allelochemicals presents a promising direction for advancing research and innovation in this area.Rice allelopathy is a phenomenon that has attracted the attention of many researchers over the years. It refers to the ability of rice plants to produce chemical compounds that can inhibit the growth of other plants in their vicinity. This phenomenon has important implications for agriculture, ecology, and the environment[12].One of the key aspects of rice allelopathy is its interaction with nature. Rice plants can produce a wide variety of allelochemicals, including phenolic compounds, terpenoids, and fatty acids. These compounds can have a significant impact on the growth and development of other plants, as well as on the microorganisms that live in the soil[13].The allelopathic effects of rice plants can be both positive and negative. On the one hand, they can help to suppress the growth of weeds and other unwanted plants, which can be beneficial for rice cultivation. This can lead to improved crop yields and reduced dependence on herbicides and other chemical inputs[14].On the other hand, rice allelopathy can also have only negative effects on the environment. For example, it can lead to the depletion of soil nutrients and the loss of biodiversity in the surrounding ecosystem. In addition, allelopathic compounds can be toxic to certain types of microorganisms, which can have negative implications for soil health and fertility[15].Rice cultivars possessing allelopathic traits can generate and secrete allelochemicals that suppress weed germination and growth, making them a valuable component of integrated weed management approaches. [16].Although certain limitations exist, interest in utilizing allelopathy as a sustainable approach to agriculture continues to increase. Scientists are investigating methods to exploit the natural allelopathic properties of rice to enhance crop productivity while minimizing chemical input. Research has demonstrated that incorporating rice straw or other plant residues into the soil can improve soil quality and boost crop yields. In summary, exploring rice allelopathy and its ecological interactions is a crucial field of study with great promise for enhancing agricultural sustainability and productivity. Gaining deeper insight into the underlying mechanisms of this process can enable scientists to design innovative crop management strategies that are both eco-friendly and cost-effective.

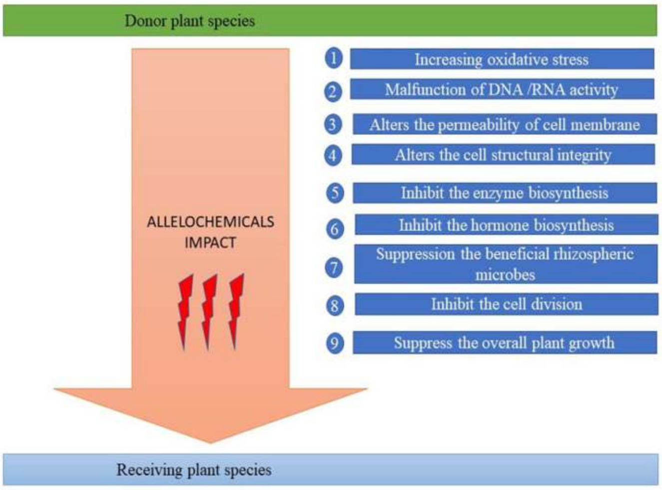

Fig 1: Negative influence of allelochemicals on receptor plants

Impact of allelochemicals on different physiological process of organism and structural integrity of ecology:

Allelochemicals are natural compounds synthesized by plants that affect the growth, development, and behavior of neighboring plants and organisms within their surroundings. Depending on their concentration and the responsiveness of the target species, these chemicals can exert either beneficial or harmful effects. Their mechanism of action is based on complex interactions between chemical signals and the biological processes of the receiving organism. This can include inhibition of germination, growth, or reproduction of the target species, or stimulation of defense mechanisms and secondary metabolite production.Allelochemicals can act directly on the target organism by binding to specific receptors or enzymes, or indirectly by modifying the physical or chemical properties of the soil or water [17]. Studies indicate that allelochemicals can modify the ion absorption rate in plants. Specifically, phenolic acids have been identified as inhibitors of the uptake of both macro and micronutrients. Additionally, research has demonstrated that ferulic acid has the capability to reduce the absorption of ammonium and nitrates in maize seedlings. Notably, the impact of ferulic acid on ammonium intake was observed to be less pronounced compared to its influence on nitrate absorption[12]. Research indicates that plants emit specific chemical compounds, known as allelochemicals, which influence the growth and development of surrounding plant species. Specifically, this suggests that the effects of ferulic acid, a type of cinnamic acid derivative that is found in many plants. Ferulic acid has been shown to have a range of impacts on plant physiology and biochemistry, including altering water utilization, inhibiting root elongation, affecting photosynthesis and respiration, and influencing nutrient uptake. Additionally, ferulic acid can become incorporated into the structure of cell walls, where it can contribute to the formation of lignin and restrict cell growth. This review highlights the significance of ferulic acid as an allelochemical and explores how it may exert its effects on plant growth and development[18].

The growth-inhibiting effects of isoliquiritigenin, a flavonoid, in allelopathy were found to be linked to oxidative stress. Isoliquiritigenin was observed to stimulate the making of reactive oxygen species (ROS), which in turn caused oxidative damage such as lipid peroxidation. As a result, cell viability decreased, and seedling growth was suppressed. The presence of isoliquiritigenin also altered proline and chlorophyll levels in lettuce seedlings, leading to higher proline content and reduced chlorophyll. These results indicate that reactive oxygen species (ROS) could play a central role in the allelopathic growth inhibition induced by isoliquiritigenin in lettuce seedlings [19].

Weeds present in rice field:

Weeds pose a significant threat to crop yields and quality, and can cause up to 100% reduction in rice yield without proper management [20a]. More than 1000 weed species have been reported in rice cultivation globally, but 13 species are particularly serious, including purple nutsedge, Bermuda grass, barnyardgrass, jungle rice, goosegrass, water hyacinth, purslane, lambsquarter, field bindweed, Johnson grass, spear grass, wild oat, and redroot pigweed[21. The specific weed species that infest rice crops depends on factors such as weather, temperature, latitude, and location of cultivation. For example, in Australia, dirty dora, waterwort, starfruit, and barnyardgrass are major noxious weeds. Overuse of herbicides leads to herbicide-resistant weed biotypes, which further complicates weed management. Worldwide, approximately 200 weed biotypes across 125 distinct species have evolved resistance to herbicides [22].Suppression of germination and growth in *Echinochloa crus-galli, Cyperus difformis*[23], root and shoot inhibition of *E. crus-galli*[24] byallelopathic rice. Conventional weed control in rice farming depended on factors such as rainfall, water management and hand weeding, but these approaches are both laborious and time-intensive. Currently, weed control in rice cultivation largely depends on synthetic herbicides, which have harmful effects on the environment and human healthiness. Hence, there is a need to develop new strategies for sustainable agriculture, particularly for biological weed management.

Allelochemicals present in rice plant:

The main allelochemicals found in rice, can be classified into two groups: phenolic acids and terpenoids/flavonoids[25]. Rice exudates contain a range of allelochemicals, including phenolics, fatty acids, benzoxazinoids, and terpenoids. Momilactone, which has been found to inhibit weed growth, is made up of several compounds, including a diterpenoid flavone (5,7,4′-trihydroxy-3′,5′- dimethoxyflavone or Tricin), a cyclohexanone flavone (5,7,4′-trihydroxy-3′,5′- dimethoxy flavone), and a cyclohexanone (3- isopropyl-5-acetoxycyclohex-2-enone), as described by Iqbal et al. in 2019 [26]. Additionally, Chung et al. (2002) reported that extracts from the husks of the Janganbyeo rice variety comprised nine distinct compounds, among which salicylic acid exhibited the strongest suppression of both seedling length and dry biomass in barnyard grass [27]. Phenolic acids likep-hydroxy benzoic acid, p-coumaric acid, ferulic acid, syringic acid and vanillic acid[28] and flavone likeTricin (5,7,4'-trihydroxy- 3',5'-dimethoxyflavone), 3-isopropyl-5-acetoxycyclohexene-2-one-1,5,4-dihydroxy-3,5-dimethoxy-7-D-b-glucopyranose and 7,4-dihydroxy-3,5-dimethoxy-5-D-b-glucopyranose releases from hull extract and root exudates of rice plant respectively[20a],[17].

Rice has been found to contain various allelochemicals such as 5-hydroxy-2-indolecarboxylic acid, 5-hydroxyindole-3-acetic acid, mercaptoacetic acid, 4-vinylphenol, trans-ferulic acid[29], ergosterol peroxide, 7-oxostigmasterol [8], 5,7-4-trihydroxy-3,5-dimethoxyflavone[30], 3-hydroxy-β-ionone, 9-hydroxy-4-megastigmen-3-one [31], azelaic acid, tetradecanoic acid, 1,2-benzenedicarboxylic acid bis (2-ethylhexyl) ester, 1H-indole-3-carboxylic acid, 1H-indole-5-carboxylic acid, 1H-indole-3-carboxyaldehyde, 3,4-dihydroxyhydrocinnamic acid, 3-hydroxy-4-methoxybenzoic acid, 4-hydroxycinnamic acid and 4-hydroxyhydrocinnamic acid [32].

A recent study revealed that 20 different allelochemicals in 9 (OM 2395, OM 3536, OM 4498, OM 5451, OM 5930, OM 6976, OM7347, OM 380, OM N406) varieties of rice (*Oryza sativa* L.). The frequency of detection for each allelochemical varied from 10% to 100% among the varieties. The allelochemicals that were detected most often were 3-hydroxybenzoic acid, 4-hydroxybenzoic acid, and cinnamic acid, which were found in 66.7%, 66.7%, and 88.9% of the varieties, respectively.The other allelochemicals that were detected in the study were: 2,4-dihydroxybenzaldehyde, 2,6-dimethoxybenzoic acid, 3,4-dihydroxyphenylacetic acid, 5-methoxysalicylic acid, 7-oxostigmasterol, benzoic acid, 2,4-dimethoxybenzoic acid, 2,5-dihydroxybenzoic acid, 3,4-dimethoxybenzoic acid, 3,5-dihydroxybenzoic acid, 3,5-dimethoxybenzoic acid, coumarin, ergosterol peroxide, p-hydroxycinnamic acid, and salicylic acid. The findings indicate that different rice cultivars produce a diverse range of allelochemicals capable of suppressing the growth of surrounding plant species. This could have implications for the use of rice as a bioherbicide, or for the management of weeds in rice fields[28].

Table 1: Allelochemicals in rice plant

Allelochemical	Source	Reference
Momilactone B	Rice roots and residues	[30],[31]
3-isopropyl-5-acetoxycyclohexene-2-one-1, 5,7,4'-trihydroxy-3',5'-dimethoxyflavone	Rice roots	[30]
p-hydroxybenzoic acid, p-coumaric acid, Ferulic acid, Syringic acid and Vanillic acid	Rice residues	[30]
Cinnamic acid, Benzoxazolinone (BOA), 6-methoxybenzoxazolinone (MBOA)&2,4-dihydroxy-1,4-benzoxazin-3-one (DIBOA), 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA), Caffeic acid, Protocatechuic acid, Gallic acid, Chlorogenic acid andSalicylic acid	Rice straw and hulls	[31]
Jasmonic acid, Methyl jasmonate (MeJA)	Rice leaves and stems	[33]

Allelopathic potential gene present in rice:

The rice variety PI312777 was found to have a high allelopathic potential for suppressing the growth of weeds when grown in a culture solution with low nitrogen content, while the non-allelopathic variety Lemont showed the opposite effect. To investigate the gene expression profiles of PI312777 under low nitrogen treatment, a forward subtractive hybridization suppression (SSH)-cDNA library was constructed, and 35 positive clones were sequenced and annotated. These genes were categorized into five functional groups associated with primary metabolic prcesses, phenolic allelochemical production, regulation of plant growth and cell division, stress signaling and response pathways, as well as protein formation and breakdown. Among these genes, two up-regulated genes that encode PAL and cytochrome P450 were selected for further investigation. Real-time quantitative polymerase chain reaction (qRT-PCR) was used to compare the transcript abundance of these two genes between the allelopathic rice and its counterpart. The results showed that the transcription levels of the two genes increased in both rice accessions when exposed to low nitrogen supply, but PI312777 exhibited a higher magnitude of up-regulation than Lemont. The relative expression levels of PAL were 11.38, 4.83 and 3.57-fold higher in PI312777 root at 1, 3, and 7 days of treatment, while for Lemont, the corresponding fold increases were 1.15, 2.74, and 2.94 compared to the control plants. A similar expression pattern was noted for cytochrome P450. These results indicate that the enhanced weed-suppressing capacity of PI312777, particularly in nitrogen-deficient environments, may be attributed to the heightened activation of genes responsible for the de novo production of allelochemicals [34].Rice variety and origin may regulate allelopathic behavior, for example, japonica rice is moreallelopathic than indica and japonica-indica hybrids [20b].It was found that the rice variety Sathi possesses the DEG-1 gene, which is a homologue of S-adenosylmethionine synthetase, another rice variety Zhonghua 11 having OsCPS4 gene (homologue of Copalyl diphosphate synthase 4)and the segenesare responsible for the allelopathic potential of the both rice variety [35],[36]. A recent study has characterized the MYB transcription factor, OsMYB57, to investigate its role in regulating allelopathy in rice. By increasing the expression of OsMYB57 in rice using the transcription activator VP64, inhibitory ratios against barnyardgrass were found to increase. This was accompanied by up-regulation of gene expression levels in the phenylpropanoid pathway, including OsPAL, OsC4H, OsOMT, and OsCAD, and an increase in L-phenylalanine content. Chromatin immunoprecipitation combined with HiSeq sequencing demonstrated that OsMYB57 controls the transcription of a mitogen-activated protein kinase, OsMAPK11, which interacts with OsPAL2;3. Notably, the expression of OsPAL2;3 was significantly elevated in the allelopathic rice variety PI312777 compared to the non-allelopathic cultivar Lemont. Additionally, this gene was found to be negatively influenced by Whirly transcription factors. Furthermore, microbes such as *Penicillium* spp. and *Bacillus* spp. with weed-suppression potential were found in the rhizosphere of rice accession Kitaake, which had increased expression of OsMYB57, and were responsible for inducing phenolic acid. These findings suggest that OsMYB57 plays a positive role in regulating rice allelopathy, providing a potential avenue for improving rice allelopathic traits through genetic modification[37]. Wang et al. (2016) discovered that a transgenic line with a VP64-activated R2R3 MYB transcription factor, OsMYB57, showed an enhanced ability to suppress weeds. These transgenic lines were further utilized to explore the transcription factor responsible for increasing rice grain yield, and it was found that the OsMYB1R1-VP64 transformed line showed a 35% increase in grain yield [38].Fang et al. (2015) employed proteomic techniques to investigate the molecular mechanism underlying crop allelopathy. The research revealed four key proteins associated with allelochemical synthesis: peroxidase precursor thioredoxin M-type, 3-hydroxy-3-methylglutaryl-coenzyme A reductase 3, phenylalanine ammonia-lyase (P.A.L.), and cinnamate 4-hydroxylase (CA4H). Among these, P.A.L. and CA4H play pivotal roles as core enzymes in the biosynthetic pathway of phenolic acids.

It was reported that specific genes related to phenolic biosynthesis play a crucial role in the allelopathy potential of rice [39]. They compared two different cultivars of rice (Lemont and PI312777) and found that PAL, C4H, F5H, COMT, CCR, and CAD genes were upregulated in the root and shoot tissues of PI312777, indicating an increase in phenolic compound metabolic processes and, hence, higher allelopathic potential[19].The biosynthesis of momilactones, a type of allelochemicals in rice, involves several genes that have been extensively studied. Among them, OsCPS4, OsKSL4, CYP99A2, CYP99A3, and OsMAS are co-regulated genes in the momilactones biosynthetic pathway and are located on chromosome 4 in a gene cluster. In a reverse genetic approach, two rice cultivars from Japonica subspecies were used to insert genes knock-out of OsCPS4 and OsKSL4. The results showed that the insertional mutant lines lacking OsCPS4 or OsKSL4 exhibited a significant reduction in inhibition potential, indicating that momilactones production was greatly reduced due to the absence of these genes [40].

Allelopathic plant variety:

Table 2: Allelopathic variety of rice plant

Rice Variety	Weed Species	Allelopathic Effect	Reference
BR17	*Echinochloa crus-galli*	Inhibited development by more than 40–41%	[41]
Pusa Punjab Basmati-1509, Punjab Basmati-3, Basmati-386, PR 115, PR 124& PR 118	*Echinochloa crus-galli, E. colona and P. minor*	Suppressed germination	[42]
Jaya, Ratna, Pusa-1121, Pant Dhan-1, Basmati 1121& Swarna IR-64, Kalinga Sona, Pusa Basmati-11	*Echinochloacolona*	Reduced germination and seedling growth	[43]
PI 312777	*Echinochloa crus-galli*	Suppressed germination	[16]
Koshihikari	*Cyperus iria., Oryza sativa* (weedy rice).	Reduced germination and seedling growth	[44]

Currentscenario of rice allelopathy:

Rice allelopathy has garnered considerable attention in recent years, with numerous studies investigating various aspects of this phenomenon. A wealth of research has contributed to our understanding of rice allelopathy, and in this article, ithighlights some significant findings.One important part of rice allelopathy is the role of allelochemicals in suppressing the growth of other plants. Studies have identified a wide range of allelochemicals produced by rice plants, including phenolic acids, flavonoids, terpenoids, and alkaloids [45]. These compounds can have a range of effects on other plants, including inhibiting seed germination, root growth, and photosynthesis.One of the most well-known allelochemicals produced by rice plants is the compound momilactone A. This compound has been shown to inhibit the growth of a variety of plant species, including rice weeds and other crops such as wheat and maize[46]. Other compounds, such as benzoxazinones and tricin, have also been shown to have allelopathic effects on other plants[47].In addition to their effects on other plants, allelochemicals produced by rice plants can also have important implications for soil health and microbial communities. Overall, the study of rice allelopathy is an important area of research that has the potential to improve the sustainability and productivity of agriculture. By better understanding the mechanisms behind this phenomenon, researchers can develop new approaches to crop management that are both environmentally friendly and economically viable.The allelopathic effects of rice straw on weed control and soil microbial communities: Tarek et al., 2012, investigated the allelopathic effects of rice straw on wheat and its impact on soil microbial community structure. The study found that the application of rice straw had a significant effect on weed control and soil microbial communities, suggesting that allelopathy could be used as a sustainable approach for weed management.Identification of allelopathic compounds in rice [48].Ho et al. 2020, used a combination of high-performance liquid chromatography (HPLC) and mass spectrometry (MS) to identify allelopathic compounds produced by rice. The study identified several compounds, including ferulic acid, vanillic acid, and 2,4-dihydroxybenzoic acid, that had significant allelopathic effects on other plant species.The effects of rice allelopathy on soil microbial activity, it was investigated the impact of allelopathy on soil microbial activity in rice fields[28]. The study found that allelopathic compounds produced by rice plants had a significant impact on soil microbial activity, including a decrease in the activity of certain enzymes involved in nutrient cycling.A meta-analysis was carried out to examine the effects of allelopathy on rice cultivation, and the results revealed that allelopathic rice varieties showed a significant increase in yield and a decrease in weed infestation when compared to non-allelopathic varieties.These studies underscore the crucial role of rice allelopathy in modern agriculture, particularly in maintaining soil fertility and enhancing crop yield. Gaining deeper insight into the biochemical and ecological processes underlying this phenomenon can lead to the development of innovative, sustainable, and cost-effective crop management practices. It should be noted, however, that the allelopathic influence of rice is not uniform—it can shift according to factors such as the type of weed species present, the developmental stage of the rice plant, and surrounding environmental conditions.Hence, advancing research is essential to gain deeper insights into the allelopathic capabilities of different rice varieties and to formulate effective strategies for their utilization [49],[47].

Rice allelopathy serves as a natural and environmentally friendly means of weed control in agroecology. It relies on the intricate regulation of various genes, including those encoding transcription factors, to exhibit its allelopathic potential. Research reveals extensively characterized a specific MYB transcription factor called OsMYB57, aiming to unveil its role in governing rice allelopathy. By enhancing the expression of OsMYB57 in rice using the transcription activator VP64, we observed a notable increase in inhibitory ratios against barnyardgrass. Furthermore, we noticed an upregulation in the gene expression levels of OsPAL, OsC4H, OsOMT, and OsCAD, which are essential enzymes in the phenylpropanoid pathway. This upregulation was accompanied by an elevation in l-phenylalanine content.Through the integration of chromatin immunoprecipitation with HiSeq, we discovered that OsMYB57 transcriptionally regulates a mitogen-activated protein kinase known as OsMAPK11. Interestingly, we also found that OsMAPK11 interacts with OsPAL2;3. Comparing the expression levels of OsPAL2;3 in the allelopathic rice PI312777 and the non-allelopathic rice Lemont, we observed higher expression in the former. Additionally, we determined that Whirly transcription factors negatively regulate OsPAL2;3.

Furthermore, we identified the presence of weed-suppressive microbes, including Penicillium spp. and *Bacillus* spp., in the rhizosphere of the rice variety Kitaake, which exhibited increased expression of OsMYB57. These microbes were found to be responsible for inducing phenolic acid production. In this study OsMYB57 plays a positive regulatory role in rice allelopathy, thereby offering a potential avenue for improving rice allelopathic traits through genetic modification [37].

The fate of allelochemicals that are released by rice plants:

Allelochemicals released from rice plants can have different fates depending on various factors such as soil properties, environmental conditions, and microbial activity[50a],[50b]. Allelochemicals can be adsorbed onto soil particles, which can reduce their mobility and bioavailability. The adsorption capacity of soil depends on various factors such as soil type, organic matter content, and pH[51].Allelochemicals can be degraded by soil microorganisms, which can convert them into less toxic or non-toxic compounds. Microbial degradation can be influenced by environmental factors such as temperature, moisture, and nutrient availability[52]. Allelochemicals can move downward in the soil profile and potentially contaminate groundwater if they are not adsorbed onto soil particles. The extent of leaching depends on soil properties, rainfall, and irrigation practices.Some allelochemicals can be released into the air as volatile compounds, which can have an impact on atmospheric chemistry and air quality. Volatilization can be influenced by temperature, wind speed, and humidity. Allelochemicals can be taken up by other plants growing in the vicinity of rice plants, which can affect their growth and development. The extent of plant uptake depends on the concentration of allelochemicals in the soil and the sensitivity of the target plant species[53],[33]. Overall, the fate of allelochemicals released from rice plants is complex and influenced by various factors. Understanding the fate of allelochemicals is important for developing strategies to manage their potential impacts on crop productivity and soil health.

Prospect of rice allelopathy in agriculture and crop protection:

Rice allelopathy has great potential in agriculture and crop protection, as it offers a sustainable and eco-friendly approach to weed management and disease control[54].Rice allelopathy offers an eco-friendly strategy for weed management by inhibiting their seed germination, growth, and reproduction. This natural mechanism can help minimize dependence on chemical herbicides, thereby lowering potential risks to both the environment and human health[55].This can also be used to control plant diseases caused by soil-borne pathogens. Allelochemicals released by rice plants can inhibit the growth and activity of pathogenic fungi, bacteria, and viruses, thus reducing the incidence and severity of plant diseases[56].Rice allelopathy can contribute to sustainable agriculture by reducing the use of synthetic inputs such as herbicides, pesticides, and fertilizers. This approach can help to preserve soil health and biodiversity, reduce greenhouse gas emissions, and improve the quality of agricultural products. It can be used as a component of crop rotation systems, where rice is grown in one season and followed by other crops that are less sensitive to allelopathic effects. This approach can improve soil fertility and reduce weed and disease pressure in subsequent crops.Breeding for allelopathic traits: Rice allelopathy can be enhanced through breeding programs that select for allelopathic traits. This approach can lead to the development of rice varieties that have higher allelopathic potential, which can improve weed and disease management in rice-based cropping systems[49].Rice allelopathy presents a valuable opportunity for advancing sustainable farming and crop defense strategies. Integrating allelopathic traits with traditional agricultural practices can create innovative and environmentally friendly production systems. Utilizing naturally occurring plant chemicals allows for reduced dependence on synthetic inputs while supporting ecological harmony within farming ecosystems [25].

Critical analysis on rice as allelopathic plant:

Rice is well-known for its allelopathic characteristics, producing allelochemicals that influence the germination, growth, and development of surrounding plants. Numerous studies have documented that rice root exudates and plant residues can suppress the growth of a variety of plant species, including weeds, crops, and soil-borne pathogens. However, the use of rice allelopathy in agriculture and crop protection presents some limitations and challenges.

Firstly, the effectiveness of rice allelopathy in weed and pest management can be inconsistent across different agroecosystems and cropping systems due to variations in environmental conditions such as soil type, temperature, and moisture.Secondly, the use of allelopathic crops like rice may have unintended ecological consequences, such as changes in soil microbial communities and soil nutrient dynamics. This is because the secretion of allelochemicals can inhibit the growth of beneficial soil microbes, impacting soil health and nutrient cycling. Additionally, the allelopathic effects of rice can also impact non-target organisms like beneficial insects and soil fauna, which can have cascading effects on ecosystem functioning.Thirdly, the allelopathic effects of rice can vary depending on the target plant species. Although rice allelopathy has been shown to have inhibitory effects on weeds such as barnyardgrass and goosegrass, the effects on other weed species may be less pronounced or nonexistent. Thus, the use of rice allelopathy in weed management may be limited to specific weed species or cropping systems.

Despite these obstacles, rice allelopathy presents a valuable opportunity for creating sustainable and environmentally friendly approaches to weed and pest management. Leveraging the natural allelopathic properties of rice can help farmers minimize the use of synthetic herbicides and pesticides, reducing potential risks to human health and the environment. However, additional research is needed to fully understand the underlying mechanisms and ecological impacts of rice allelopathy, as well as to develop effective, site-specific management strategies.

Conclusion

In conclusion, while rice allelopathy has the potential to provide a sustainable and eco-friendly solution for weed management, there are also limitations and challenges associated with this approach. Therefore, a holistic and integrated approach that combines allelopathy with other weed management strategies may be necessary to achieve sustainable and resilient cropping systems.

Acknowledgement:

The author sincerely thanks Web Archive for providing access to digital copies of numerous research articles that contributed to this review.

Competing Interests:

The author confirms that there are no conflicts of interest to disclose.

References

1. Farooq, M., Jabran, K., Cheema, Z. A., Wahid, A., & Siddique, K. H. M. (2011). The role of allelopathy in agricultural pest management. *Pest Management Science, 67,* 493–506.
2. Pan, L., Li, X. Z., Yan, Z. Q., Guo, H. R., & Qin, B. (2015). Phytotoxicity of umbelliferone and its analogs: Structure-activity relationships. *Plant Physiology and Biochemistry, 97,* 272-277.
3. Zeng, R. S. (2014). Allelopathy—the solution is indirect. *Journal of Chemical Ecology, 40,* 515–516. doi: 10.1007/s10886-014-0464-7.
4. Zeng, R. (2008). Allelopathy in Chinese ancient and modern agriculture. In *Allelopathy in Sustainable Agriculture and Forestry* (pp. 39–59). New York: Springer. doi: 10.1007/978-0-387-77337-7_3.
5. Boydston, R. A., Morra, M. J., Borek, V., Clayton, L., & Vaughn, S. F. (2011). Onion and weed response to mustard (*Sinapis alba*) seed meal. *Weed Science, 59,* 546–552.
6. Awan, F. K., Rasheed, M., Ashraf, M., & Khurshid, M. Y. (2012). Efficacy of brassica sorghum and sunflower aqueous extracts to control wheat weeds under rainfed conditions of pothwar, Pakistan. *Journal of Animal and Plant Sciences, 22(3),* 715–721.
7. Bajwa, A. A., Mahajan, G., & Chauhan, B. S. (2015). Nonconventional weed management strategies for modern agriculture. *Weed Science, 63(4),* 723-747.
8. Macias, F. A., Marin, D., Oliveros-Bastidas, A., Varela, R. M., Simonet, A. M., Carrera, C., ... & Molinillo, J. M. (2003). Allelopathy as a new strategy for sustainable ecosystems development. *Biological Sciences in Space, 17,* 18–23. doi: 10.2187/bss.17.18.
9. Das, C., Dey, A., & Bandyopadhyay, A. (2021). Allelochemicals: An Emerging Tool for Weed Management. In S. C. Mandal, R. Chakraborty, & S. Sen (Eds.), *Evidence Based Validation of Traditional Medicines* (pp. 249–259). Singapore: Springer. doi: 10.1007/978-981-15-8127-4_12.
10. Silva, R. M. G., Brigatti, J. G. F., Santos, V. H. M., Mecina, G. F., & Silva, L. P. (2013). Allelopathic effect of the peel of coffee fruit. *Scientia Horticulturae, 158,* 39–44. https://doi.org/10.1016/j.scienta.2013.04.028.
11. Haider, G., Cheema, Z. A., Farooq, M., & Wahid, A. (2015). Performance and nitrogen use of wheat cultivars in response to the application of allelopathic crop residues and 3,4-dimethylpyrazole phosphate. *International Journal of Agriculture and Biology, 17,* 261–270.
12. Cheng, F., & Cheng, Z. (2015). Research Progress on the use of Plant Allelopathy in Agriculture and the Physiological and Ecological Mechanisms of Allelopathy. *Frontiers in Plant Science, 6,* 1020. doi: 10.3389/fpls.2015.01020.
13. Amb, M. K., & Ahluwalia, A. S. (2016). Allelopathy: Potential Role to Achieve New Milestones in Rice Cultivation. *Rice Science, 23(4),* 165-183.
14. Khanh, T. D., Linh, L. H., Linh, T. H., Quan, N. T., Cuong, D. M., Hien, V. T. T., ... Xuan, T. D. (2013). Integration of Allelopathy to Control Weeds in Rice. In A. J. Price & J. K. Kirkland (Eds.), *Herbicides-Current Research and Case Studies in Use* (pp. 75–99). Intech Publishing, New York, USA. doi: 10.5772/56035.
15. Xiao, Z., Zou, T., Lu, S., & Xu, Z. (2020). Soil microorganisms interacting with residue-derived allelochemicals effects on seed germination. *Saudi Journal of Biological Sciences, 27(4),* 1057–1065. doi: 10.1016/j.sjbs.2020.01.013.
16. 16.Serra Serra, N., Shanmuganathan, R., & Becker, C. (2021). Allelopathy in rice: a story of momilactones, kin recognition, and weed management. *Journal of Experimental Botany, 72(11),* 4022–4037. doi: 10.1093/jxb/erab084.
17. Kong, C. H., Xuan, T. D., Khanh, T. D., Tran, H. D., & Trung, N. T. (2019). Allelochemicals and Signaling Chemicals in Plants. *Molecules, 24(15),* 2737. doi: 10.3390/molecules24152737.
18. Dos Santos, W. D., Ferrarese, M. M. L., & Ferrarese Filho, O. (2008). Ferulic acid: an allelochemical troublemaker. *Functional Plant Science and Biotechnology, 2(1),* 47-55.
19. Zhang, Q., Zhang, Q., Lin, S., Wang, P., Li, J., Wang, H., & He, H. (2020). Dynamic analysis on weed inhibition and phenolic acids of allelopathic rice in field test. *Archives of Agronomy and Soil Science, 67,* 1809–1821.

20a. Khanh, T. D., Elzaawely, A. A., Chung, I. M., Ahn, J. K., Tawata, S., & Xuan, T. D. (2007). Role of allelochemicals for weed management in rice. *Allelopathy Journal, 19,* 85-96.

20b. Khanh, T. D., Xuan, T. D., & Chung, I. M. (2007). Rice allelopathy and the possibility for weed management. *Annals of Applied Biology, 151(3),* 325–339. doi: 10.1111/J.1744-7348.2007.00183.X.

21. Aliotta, G., Cafiero, G., & Otero, A. M. (2006). Weed germination, seedling growth and their lesson from allelopathy in agriculture. In M. J. Reigosa, N. Redrol, & L. Gonzales (Eds.), *Allelopathy: A Physiological Process with Ecological Implications* (pp. 285–299). Dordrecht: Springer.
22. Heap, I. M. (1997). The occurrence of herbicide-resistant weeds worldwide. *Pesticide Science, 51,* 235-243.
23. Alam, M. A., Hakim, M. A., Juraimi, A. S., Rafii, M. Y., Hasan, M. M., & Aslani, F. (2018). Potential allelopathic effects of rice plant aqueous extracts on germination and seedling growth of some rice field common weeds. *Italian Journal of Agronomy, 13(2),* 134-140.
24. Masum, S. M., Hossain, M. A., Akamine, H., Sakagami, J. I., Ishii, T., Gima, S., &Bowmik, P. C. (2018). Isolation and characterization of allelopathic compounds from the indigenous rice variety 'Boterswar' and their biological activity against *Echinochloacrusgalli* L. *Allelopathy Journal, 43,* 31-42.
25. Li, Y., Jian, X., Li, Y., Zeng, X., Xu, L., Khan, M. U., ... Lin, W. (2020). Ospal2-1 mediates allelopathic interactions between rice and specific microorganisms in the rhizosphere ecosystem. *Frontiers in Microbiology, 11,* 1411.
26. Iqbal, A., Shah, F., Hamayun, M., Khan, Z. H., Islam, B., Rehman, G., ... Jamal, Y. (2019). Plants are the possible source of allelochemicals that can be useful in promoting sustainable agriculture. *Fresenius Environmental Bulletin, 28,* 1040-1049.
27. Chung, I. M., Kim, K. H., Ahn, J. K., Chun, S. C., Kim, C. S., Kim, J. T., & Kim, S. H. (2002). Screening of allelochemicals on barnyardgrass (*Echinochloa crus-galli*) and identification of potentially allelopathic compounds from rice (*Oryza sativa*) variety Hull extracts. *Crop Protection, 21(10),* 913–920. doi: 10.1016/S0261-2194(02)00063-7.
28. Ho, T. L., Nguyen, T. T. C., Vu, D. C., Nguyen, N. Y., Nguyen, T. T. T., Phong, T. N. H., ... Sumner, L. W. (2020). Allelopathic Potential of Rice and Identification of Published Allelochemicals by Cloud-Based Metabolomics Platform. *Metabolites, 10(6),* 244. https://doi.org/10.3390/metabo10060244.
29. Song, Z. Y., McClain, C. J., & Chen, T. (2004). S-adenosylmethionine protects against acetaminophen-induced hepatotoxicity in mice. *Pharmacology, 71(4),* 199–208.
30. Kong, C. H., Li, H. B., Hu, F., Xu, X. H., & Wang, P. (2006). Allelochemicals released by rice roots and residues in soil. *Plant and Soil, 288,* 47–56. https://doi.org/10.1007/s11104-006-9033-3.

31. Kato-Noguchi, H. (2008). Allelochemicals released from rice plants. *Japanese Journal of Plant Science, 2(1),* 18–25.
32. Rimando, A. M., Olofsdotter, M., Dayan, F. E., & Duke, S. O. (2001). Searching for rice allelochemicals: An example of bioassay-guided isolation. *Agronomy Journal, 93,* 16–20.
33. Singh, A., Rajeswari, G., Nirmal, L., & Jacob, S. (2021). Synthesis and extraction routes of allelochemicals from plants and microbes: A review. *Reviews in Analytical Chemistry, 40(1),* 293–311. https://doi.org/10.1515/revac-2021-0139.
34. Song, B., Xiong, J., Fang, C., Qiu, L., Lin, R., Liang, Y., & Lin, W. (2008). Allelopathic enhancement and differential gene expression in rice under low nitrogen treatment. *Journal of Chemical Ecology, 34(5),* 688–695. doi: 10.1007/s10886-008-9455-x.
35. Junaedi, A., Jung, W. S., Chung, I. M., & Kim, K. H. (2008). Differentially expressed genes of potentially allelopathic rice in response against barnyardgrass. *Journal of Crop Science and Biotechnology, 10(4),* 231–235.
36. Xu, M. M., Galhano, R., Wiemann, P., et al. (2012). Genetic evidence for natural product-mediated plant-plant allelopathy in rice (*Oryza sativa*). *New Phytologist, 193,* 570–576.
37. Fang, C., Yang, L., Chen, W., Li, L., Zhang, P., Li, Y., ... Zhang, P. (2020). MYB57 transcriptionally regulates MAPK11 to interact with PAL2;3 and modulate rice allelopathy. *Journal of Experimental Botany, 71(6),* 2127-2141. https://doi.org/10.1093/jxb/erz540.
38. Wang, J., Wu, F., Zhu, S., et al. (2016). Overexpression of OsMYB1R1-VP64 fusion protein increases grain yield in rice by delaying flowering time. *FEBS Letters, 590,* 3385–3396.
39. Fang, C., Li, Y., Li, C., Li, B., Ren, Y., Zheng, H., ... Lin, W. (2015). Identification and comparative analysis of microRNAs in barnyardgrass (*Echinochloa crus-galli*) in response to rice allelopathy. *Plant, Cell & Environment, 38(7),* 1368–1381. doi: 10.1111/pce.12492.
40. Estiati, A. (2019). Rice momilactones, potential allelochemical for weeds suppression. *Asian Journal of Agriculture, 3,* 6-15.
41. Khan, M. A., & Siddiqui, M. A. (2017). Allelopathic potential of rice varieties against major weeds of rice and wheat. *Indian Journal of Weed Science, 49(2),* 179–181.
42. Kaur, H., Kaur, N., & Sethi, R. (2017). Allelopathic potential of rice varieties against major weeds of rice and wheat. *Indian Society of Weed Science, 2017.*
43. Kumar, S., & Singh, S. P. (2009). Allelopathic potential of some rice varieties against barnyard grass (*Echinochloa crus-galli*). *Journal of Agricultural Sciences, 47(3),* 369–372.
44. Jabran, K. (2017). Rice allelopathy for weed control. In *Manipulation of Allelopathic Crops for Weed Control* (pp. 35-47). SpringerBriefs in Plant Science. Springer.
45. Kong, C. (2007). Allelochemicals involved in rice allelopathy. In *Allelopathy: New Concepts and Methodology* (pp. 267–281).
46. Hickman, D. T., Rasmussen, A., Ritz, K., Birkett, M. A., & Neve, P. (2021). Allelochemicals as multi-kingdom plant defense compounds: towards an integrated approach. *Pest Management Science, 77(3),* 1121-1131. doi: 10.1002/ps.6076.
47. Khamare, Y., Chen, J., & Marble, S. C. (2022). Allelopathy and its application as a weed management tool: A review. *Frontiers in Plant Science, 13,* 1034649. doi: 10.3389/fpls.2022.1034649.
48. Tarek, A. E. S., Moataza, M. S., & Ibrahim, M. E. M. (2012). Soil Microorganisms and Their Impact on Rice Straw Allelopathic Potential. *Australian Journal of Basic and Applied Sciences, 6(10),* 675–680.
49. Rahaman, F., Shukor Juraimi, A., Rafii, M. Y., Uddin, K., Hassan, L., Chowdhury, A. K., ... & Hossain, A. (2022). Allelopathic potential in rice - a biochemical tool for plant defense against weeds. *Frontiers in Plant Science, 13,* 1072723. doi: 10.3389/fpls.2022.1072723.
50a. Kong, C. H., Wang, P., Gu, Y., Xu, X. H., & Wang, M. L. (2008). Fate and impact on microorganisms of rice allelochemicals in paddy soil. *Journal of Agricultural and Food Chemistry, 56(13),* 5043–5049. doi: 10.1021/jf8004096.
50b. Kong, C. H., Wang, P., Zhao, H., Xu, X. H., & Zhu, Y. D. (2008). Impact of allelochemical exuded from allelopathic rice on soil microbial community. *Soil Biology and Biochemistry, 40,* 1862–1869.
51. Kobayashi, K. (2004). Factors affecting phytotoxic activity of allelochemicals in soil. *Weed Biology and Management, 4,* 1–7. https://doi.org/10.1111/j.1445-6664.2003.00112.x.
52. Jilani, G., Mahmood, S., Chaudhry, A. N., Hassan, I., & Muhammad, A. (2008). Allelochemicals: sources, toxicity and microbial transformation in soil - a review. *Annals of Microbiology, 58,* 351–357. https://doi.org/10.1007/BF03175528.
53. Zhou, S., Richter, A., & Jander, G. (2018). Beyond defense: multiple functions of benzoxazinoids in maize metabolism. *Plant and Cell Physiology, 59(8),* 1528–1537. doi: 10.1093/pcp/pcy064.
54. 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. https://doi.org/10.3390/agronomy11112104.
55. Bhadoria, P. B. S. (2011). Allelopathy: A Natural Way towards Weed Management. *American Journal of Experimental Agriculture, 1(1),* 7-20.
56. Saraf, M., Pandya, U., & Thakkar, A. (2014). Role of allelochemicals in plant growth promoting rhizobacteria for biocontrol of phytopathogens. *Microbiological Research, 169,* 18-29. https://doi.org/10.1016/j.micres.2013.08.009.