Allelopathy in Crop Production – A Review

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Abstract

One of the most significant biological barriers to agricultural production systems is weeds. They compete with crops for nutrients, sunshine, space, and water, which has a negative impact on crop development and output. Allelopathy is the ability of plants to either promote or inhibit the growth of other plants in their surroundings by the release of compounds into the surroundings. The compounds that are so released are primarily secondary metabolites, known as allelochemicals. Allelopathy based weed management has the potential to increase productivity without harming the environment, which proves essential for scientists trying to ensure that there will be food for future generations. The main objective of this review article is to focus the effect of different allelopathic measures in weeds, pests and diseases management. These include the use of allelopathic cultivars, intercropping with plants that suppress weeds, using residues, mulches, cover crops and crop water extracts that are allelopathic.

Keywords: Weeds, Allelopathy, Allelochemicals, weed management.

1. Introduction

The term allelopathy, which refers to the harmful effects of one organism on another, is derived from the Greek words allelon, which means "of each other," and pathos, which means "to suffer." Czech-Austrian botanist Hans Molisch coined the word "allelopathy" for the first time in 1937[1]. Allelopathy is a phenomena in which plants, fungi, viruses, and microbes generate secondary compounds that have an inhibitory or stimulatory effect on biological and agricultural systems [2]. The plant components release biochemicals that can act as stimulants (positive allelopathy) or inhibitors (negative allelopathy) against one another. Research on the enhancement of growth by allelochemicals has been done in relatively small numbers. Different crops are stimulated to germinate and develop when water extracts containing allelopathic substances are applied at lower quantities[3]. Most of the allelochemicals are secondary metabolites that are created as byproducts of several physiological processes in plants[4]. Alkaloids, flavonoids, phenolics, hydroxamic acids, brassinosteroids, jasmonates, salicylates, glucosinolates, polysaccharides, and amino acids are significant secondary metabolites that have been discovered as allelochemicals[5]. For instance, genes and enzymes involved in the synthesis of momilactone B, an allelochemical, are found in rice (*Oryza sativa* L.). It is a diterpene compound that is naturally produced by diterpene synthase enzymes from geranylgeranyl pyrophosphate precursor. Two genes, 4-copalyl-diphosphate synthetase and kaurene synthase-like 4, encode diterpene synthases,are responsible for its synthesis[6]. Since visible effects on target plants (such as reduced growth of seedlings or inhibition of seed germination) are frequently secondary indicators of primary changes (such as inhibition of cell division and elongation, interference with cell membrane permeability, enzymatic activities, respiration and photosynthesis, etc.), allelochemicals have the widest range of mechanisms of action [7]. The most significant biotic barrier to crop productivity is weeds, which can cause yield losses of 45–95%, depending on the environment and agronomic techniques used [8]. It is essential to diversify the present weed management methods due to the difficulties posed by traditional approaches (such as hand weeding, mechanical control, herbicides, etc.). The development of varied weed management techniques would open up a range of alternatives for site-specific weed control. Using the allelopathic phenomena to suppress weeds is one of the key novel weed control techniques[9]. The usefulness of allelopathy in agricultural systems for weed management, pests and disease management were covered in this review article. We have also addressed possible allelopathic crops, the issues associated with managing weeds, and the application of allelopathy in weed management.

2. Allelochemicals

Allelochemicals are divided into 14 categories based on their molecular structure. These include simple unsaturated lactones, water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes and ketones, long-chain fatty acids, and polyacetylenes; anthraquinone, benzoquinone, and complex quines; coumarin, terpenoids and steroids, tannins, alkaloids and cyanohydrins, amino acids and peptides, purines and nucleosides sulphide and glucosinolates [10].

These allelochemicals can significantly reduce plant growth when applied at high concentrations because theyinterfere with stomatal oscillations, respiration, protein metabolism, hormone biosynthesis, mineral uptake and transport, membrane permeability, photosynthesis, and plant-water relations. Weed growth inhibition is caused by the phytotoxic activity of allelochemicals. The germination and growth of several plants were inhibited by flavonoids and phenolics[11]. Allelochemicals cause slow maturation, delay or prevent reproduction, restrict the amount of water and nutrients that roots take up, and inhibit photosynthesis, respiration, protein synthesis, cell division, and thickness of seminal roots[12]. The following list of methods describes how allelochemicals can be released under favourable conditions into the rhizosphere or atmosphere.

- Leaching and volatilization [13]
- Root exudation [13]
- Decomposition of residues [14]
- Exposure to stress conditions, extreme temperature, drought, and UV exposure [15]

3. Management of weeds and allelopathy

Allelopathic species are known to control weeds in fields when they are used together with crop rotation, intercropping, mulching, cover or smother crops, crop residue incorporation and allelopathic crop water extracts[16], [17].The details of several allelopathic weed management techniques are provided below.

3.1. Crop rotation

The successive sowing of different crops in a specific field over a predetermined amount of time is known as crop rotation. In crop rotation, allelopathic or smothering crops control weeds, disease pathogens, and insect pests by releasing allelochemicals secreted by roots and released by the breakdown of previous crop residues[18],[19]. For instance, growing wheat in rotation with sorghum inhibited its germination[20]. In a sunflower-wheat rotation, there was likely less weed infestation in the wheat crop that was planted following the sunflower [21]. The subsequent crop in the rotation had about 40% decrease in weed density when rapeseed was added to the rotation [22].

3.2. Intercropping with allelopathic potential crops

Growing crops in the same field at the same time is known as intercropping. It is a crucial strategy for improving agricultural yield and financial returns as well as the efficiency with inputs *viz.* land, fertiliser, and water [23]. When planted together with other crops, crops having allelopathic potential in particular aid in lowering weed intensity and enhance crop output. The intercropping of sesame (*Sesamum indicum* L.), soybean, and sorghum on alternate rows greatly reduced the infestation of purple nutsedge (*Cyperus rotundus* L.) in cotton crops [24]. The invasion of giant witchweed (*Striga hermonthica*) was reduced by intercropping fodder legumes with maize than by growing only maize[25]. Several narrow- and broad-leaved weed species were effectively controlled by intercropping diverse allelopathic crop species in maize [26]. For example, intercropping cowpea and maize on alternate ridges improved land use efficiency and reduced weed intensity of *Echinochloa colona* (L.), *Portulaca oleracea* L., *Chorchorus olitorius* L., and *Dactyloctenium aegyptium* (L.) by about 50 percent[27].

3.3. Allelopathic Cover crops

The use of allelopathic cover crops as an economical and environmentally beneficial method of controlling weeds has grown in popularity recently [28]. Numerous studies and reviews on the utilisation of cover crops as weed control tool provided by their mulches have been published [29]. Allelopathic cover crops provide several advantages, such as preventing soil erosion, fixing nitrogen, and improving soil health. They can also effectively suppress weeds. The selection of strong allelopathic crops as cover crops can further boost the weed suppression potentials of cover crops, including physical suppression, shadow effect, temperature lowering, and competition with weeds for inputs [30]. Moreover, the weed seed bank will deteriorate due to the release of allelochemicals from cover crops through root exudates, leaf shading, and rain-induced washing. Strong allelopathic crops that are left in the field for an extended period of time will provide more effective weed control. The allelopathic potential and duration of cover crops determine how effective they are in controlling weeds [31]. The effectiveness of cover crops in controlling weeds is also dependent on the kind of weed. For example, sorghum, when grown as a cover crop, effectively suppresses broad-leaved weeds, but not narrow-leaved weeds [32].

3.4. Crop residue incorporation and mulching

Allelopathic plant residues that have been accidentally left in the field or deliberately applied have the ability to reduce the severity of weeds. Many allelochemicals, primarily phenolics, are released by the breaking of plant waste and they inhibit the growth of weeds. For instance, *Echinochloa crusgalli* and *Setaria verticillata* (L.) were reported to have an allelopathic effect on barley, rye and triticale crop residues kept in a maize field in Greece , where the growth of *Setaria verticillata* and *Echinochloa crusgalli* was reduced in comparison to non-mulched treatment. Furthermore, maize showed no adverse effects from applied mulches[33]. The rhizosphere releases allelochemicals that physically block and deprive weed seeds of light, thereby mulching with residues from crops or weeds that are allelopathic suppresses weed germination and growth. Mulching not only helps suppress weeds but also improves organic matter, promotes soil fertility, and acts as a buffer to keep the temperature of the soil constant [34].

3.5. Allelopathic water extracts

Many studies have examined the advantages of employing crop allelopathic water extracts due to their high efficacy in controlling various weed species. These water-soluble allelochemicals are used to control weeds after being extracted in water [35]. Allelopathic water extracts applied in combination may be a more effective weed-controlling method than these extracts applied alone. For instance, combining the application of water extracts from sunflower, sorghum, and eucalyptus (*Eucalyptus camaldulensis*) proved more successful in suppressing weeds in wheat than applying them alone [36].

3.6. Allelopathic water extracts and herbicides

Allelopathic water extracts are an affordable and environmentally beneficial method of controlling weeds, although the reduction in weed biomass is not as great as desired. However, for efficient weed control, these allelopathic water extracts can be used in combination with lower herbicide dosages [37]. When combined with allelopathic substances, herbicides may have a supportive effect on one or more weed species. When used in conjunction with an allelopathic compounds, a lower dosage of herbicide may be able to control weeds[38].

Table 1. Allelopathic water extracts in combination with herbicides in management of weeds

Allelopathic water extracts in combination with herbicides	Crops	Weeds suppressed	Percent of weeds managed over control	Reference
Ryelan @ 15 ml /ha + Sorghum water extract @ 7.5 lit / ha	Rice	*Echinochloa crusgalli* *Cyperus iria* *Cyperus rotundus*	34.7	[39]
Atrazine @ 120-125 g a.i./ ha + Sorghum + Sunflower + Mulberry water extracts @ 20 lit / ha each	Maize	*Trianthema portulacastrum*	74.6	[40]
S-Metolachlor @ 700-1000g a.i./ha + Sorghum water extract @ 12-15 lit/ha	Cotton	*Cyperus rotundus*	81.2	[41]
Pendimethalin @ 413 ml a.i./ha + Sorghum @ 15-18 lit/ ha	Sunflower	*Chenopodium album*	72	[42]

4. Crops with Allelopathic potential

Numerous plant species, including weeds and crop plants, have been shown to have significant allelopathic potential. But when it came to assessing their allelopathic potential in field and greenhouse bioassays, only crop plants were given priority. The potential for chemical-free weed control and other pest suppression was assessed in relation to the allelopathic potential of numerous field crops [5].

4.1. Rice

Using allelopathic qualities of rice to reduce weed infestation has been a long-standing determination among agronomists and might constitute the main objective of rice allelopathy research. To improve weed suppression, the most practical approach would involve using rice residues directly and using breeding strategies to control rice allelopathy genetically. The growth of rice flatsedge (*Cyperus iria* L.) was reduced to a similar extent by incorporating rice residues with high allelopathic activity as was achieved by applying bentazon and propanil herbicides [43].

4.2. Sorghum

A significant cereal crop farmed all over the world is sorghum (*Sorghum bicolor* (L.) Moench). Since it grows quickly and suppresses weeds, it is frequently used as a summer cover crop. The allelopathic potential of sorghum and its consequences in various cropping systems have been adequately addressed in literature. Sorghum has varying degrees of allelopathic activity relating to the cultivar, growth stage, and environmental factors. The phyto-inhibitors released by roots, leaves, and stems, as well as their germinating seeds of sorghum plants can impede the growth of broadleaf and grass species, including velvetleaf (*Abutilon theophrasti*), smooth pigweed(*Amaranthus hybridus*), and green foxtail (*Setaria viridis*) [44],[45]. Gallic acid, protocateuic acid, syringic acid, vanillic acid, p-hydroxybenzoic acid, p-coumaric acid, benzoic acid, ferulic acid, m-coumaric acid, caffeic acids, p-hydroxybenzaldehyde, and sorgoleone are among the phytotoxins found in sorghum, which limit weed growth [46]. Approximately 90% of the root exudates are made up of sorgoleone, the primary p-benzoquinone, and three other structurally similar minor p benzoquinones. The main way that sorgoleone inhibits plant growth is by preventing photosynthesis and respiration [47]. Sorghum water extract was applied to rice to suppress *Echinocloa colona*, *Cyperus rotundus*, and *Cyperus iria*. It also reduced the dry weight of the weeds (40.4%) and enhanced the yield (12.5%) in comparison to the control. Moreover, it has proven effective in controlling weeds of cotton, sunflower, and mungbean[48]. The productivity of these crops was enhanced by 3-59 percent, reliant on the crop type, frequency, and timing of application[3].

4.3. Sunflower

Sunflower is a rich source of plant metabolites, including sesquiterpenoids, which have a variety of biological functions and are allelopathic to weeds. Certain broadleaf weeds can be controlled naturally by using sunflower. Allelopathic chemicals, including diterpenes, triterpenes, and phenolic compounds, have been identified and chemically described [49]. Allelopathic compounds derived from sunflower may impact the antioxidant system of target plants, leading to cellular damage and cell-membrane permeability. This would decrease the target plant's capacity to germinate and gradually diminish the vigour of their seeds [50].

5. Allelopathic potential by trees

Trees are able to control the germination, growth, and development of weeds through allelopathy. It was shown that ethanolic extracts from the seeds of *Annona squamosa*, *Carica papaya*, *Coffea arabica*, and *Tamarindus indica* inhibited *Amaranthus spinosus* germination by 13, 58, 100, and 36%, respectively [51]. Both eucalyptus leaf leachate and oil had different effects on the growth of weeds: the leaf leachate at a concentration of 20% suppressed the biomass production of *Cynodon dactylon* by approximately 50%, while the application of 1.0 percent oil reduced it by 68%. The application of 1.0 percent oil significantly inhibited the production of shoot and root length, leaf chlorophyll, and total biomass of *Cyperus rotundus*. Old mango leaf aqueous extracts decreased the dry weight, shoot length, root length, and germination of *Amaranthus retroflexus* by 95, 96, 93, and 95 percent, respectively.

6. Employing allelopathy for pests and disease management

6.1. Pest management

Insect resistance is the most important side consequence of widespread synthetic pesticide use, which also typically has detrimental effects on the environment, human health, and animal welfare[53], [54]. [55] . Neem (*Azadirachta indica* L.) seed oil has antifeedant qualities against strawberry aphid nymphs and adults (*Chaetosiphon fragaefolii* (Cockerell)[57], while neem plant parts contain an allelochemical called azadrichtin that effectively inhibits a variety of insects, such as Whiteflies (*Ashbya gossypii*, *Bemisia tabaci*), green cicadellid (*Jacobiasca lybica* (Bergevin and Zanon))[58]. At a concentration of 8%, sorghum water extracts were the most effective (resulting in 62.5% aphid mortality), whereas sunflower water extracts (16% concentration) produced 52.5% aphid mortality. Aphid mortality was 45.7% when sorghum and mulberry combination water extracts (16%) were used, and 57.5% when sorghum and sunflower were combined [37].

Table 2. Allelopathic control of insects

Allelopathic source	Mode of application	Suppression of Insects	Reference
Eucalyptus	Oil volatiles	Decline in adult *Corcyra cephalonica* populations in both males (78%) and females (66.67%)	[59]
Neem	2% Seed kernel water extract	Reduction in the incidence of pod borer (*Heliothis armigera*.) (32%) and flower thrip (*Taeniothrips sjostedti*) (54%).	[60]
Tomato	4% Leaf water extract	Reduction in the incidence of pod borer (*Heliothis armigera*.) (12%) and flower thrip (*Taeniothrips sjostedti*) (32%).	[37]
Hot pepper	2% Fruit water extract	Reduction in the incidence of pod borer (*Heliothis armigera*.) (54%) and flower thrip (*Taeniothrips sjostedti*) (31%).	[37]

6.2. Disease management

Plant disease is a major problem that impacts a variety of crops, particularly vegetables but also oilseeds, grains, and other crops. Numerous diseases transmitted by soil disrupt the crop stand and reduce the quality of the harvest, which results in significant losses to crop productivity. Diseases still result in significant losses in agricultural production, despite the long-standing use of cultural methods like burning diseased plant debris and cultivating resistant varieties. Most diseases cannot be effectively controlled with chemicals, either because they are unavailable. Allelopathic crops can be used in a variety of ways to control plant diseases [37]. A microclimate produced by intercropping helps to lessen the severity of disease [61]. In the soil microenvironment, Brassica spp. create volatile sulphur compounds (glucosinolates), which are then transformed into isothiocyanates by biofumigation in order to inhibit soil organisms. These substances have the ability to lower nematodes and fungal pathogens in the soil [62]. The aerial portions of *Tagetes erecta* L. (marigold) emit some volatile allelochemicals. Marigold accomplished a 90% reduction of tomato early blight caused by *Alternaria solani* when intercropped with tomatoes[63].By intercropping tomatoes with cowpeas, tomato bacterial wilt has been effectively controlled [64].

Table 3. Allelopathic management of Diseases

Allelopathic source	Mode of application	Suppression of Insects	Reference
Rice	Root exudates	37% decrease in *Fusarium oxysporum* f. sp. Niveum spore germination	[65]
Barley + Potato	Grown in rotation	55.1% decrease in *Rhizoctonia solani* inoculum intensity	[66]
Neem	20% w/v Leaf water extract	53.2% decrease in *Fusarium solani* f. sp. melongenae growth	[67]
Tulsi	20% w/v Leaf water extract	43.9% decrease in *Fusarium solani* f. sp. melongenae growth	[67]

7. Conclusion

In farming systems, allelopathic weed management can offer an environmentally acceptable alternative to chemical herbicides, which pose several risks to human health, biodiversity, and the environment. In addition to providing environmentally friendly weed management, the use of allelopathic weed control techniques such as intercropping, crop rotation, cover cropping, mulches, residues, and water extract, either alone or in conjunction with synthetic herbicides, will also provide sustainable crop production because of their beneficial effects on soil fertility, organic matter contents, and ecosystem biodiversity. It is intended to increase allelopathic potential of crops through the application of both traditional and contemporary plant breeding methods.

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