Allelopathic Effects of Cereal, Pulse and Oilseed Crops in Weed Management

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Introduction

Allelopathy involves the release of biochemicals from one plant that can influence the growth and development of neighbouring plants, including weeds. This natural phenomenon is being increasingly explored as a sustainable and environmentally friendly approach to weed management in agricultural systems. By integrating allelopathy into farming practices, the reliance on synthetic herbicides can be reduced, addressing concerns about environmental pollution and the development of herbicide-resistant weeds.

Allelopathic Effects of Cereal Crops on Weed

Several cereal crops have demonstrated significant allelopathic potential for weed suppression. This can be attributed to the release of various allelochemicals from their roots, shoots and decaying residues into the environment. Allelopathic effects of cereal crops on weed suppression are presented in Table 1.

- **Rye (*Secale cereale* L.)**

Rye is widely recognized for its allelopathic effects and its effectiveness as a cover crop for weed suppression. Extracts from field and greenhouse-grown rye have been shown to significantly inhibit the germination of weeds like redroot pigweed (*Amaranthus retroflexus*) and green foxtail (*Setaria viridis*). However, the allelopathic effect of rye on succeeding crops, such as alfalfa, may lead to a reduction in stand count and forage yield, especially in the establishment year, though this effect might not persist beyond that season. Studies aim to breed rye with enhanced weed suppression capabilities by leveraging the natural variability in its allelopathic activity. Rye cover crops can suppress weeds during emergence and through competitive activity during vegetative growth.

- **Wheat (*Triticum aestivum* L.)**

Wheat is a major cereal crop globally and its allelopathic potential has been extensively studied for weed control. Wheat plants and their decomposing residues release allelochemicals such as gallic acid, p-hydroxybenzoic acid, syringic acid, ferulic acid, vanillic acid, protocatechuic acid, p-coumaric acid and benzoic acid. These compounds can suppress the emergence and establishment of important grassy and broad-leaved weed species. For example, studies have shown significant reductions in total weed dry biomass in plots sown with wheat compared to fallow plots. Different wheat cultivars and growth stages can influence the concentration of these allelochemicals. While some weeds like wild barley (*Hordeum spontaneum*) and oat (*Avena ludoviciana*) can show stimulatory effects on wheat root length, other weed species are inhibited.

Table 1. Allelopathic effects of cereal crops on weed suppression

Crop (Cereal)	Key Allelochemicals	Target Weeds Suppressed	Mode of Action	Reference/Notes
Wheat (*Triticum aestivum*)	Phenolic acids (ferulic, vanillic, p-coumaric)	*Phalaris minor*, *Avena fatua*	Inhibit seed germination & radicle growth	Residue incorporation enhances the effect
Rice (*Oryza sativa*)	Momilactones A & B	*Echinochloa crus-galli* (barnyard grass)	Root exudation suppresses germination	Notable in direct-seeded rice systems
Barley (*Hordeum vulgare*)	Phenolic acids, hordenine	*Chenopodium album*, *Amaranthus spp.*	Affects photosynthesis & root elongation	Barley mulch effective
Sorghum (*Sorghum bicolor*)	Sorgholeone, dhurrin	Wide spectrum: *Cyperus*, *Amaranthus*, *Digitaria* spp.	Root exudate inhibits cell division	Used in cover cropping

- **Maize (*Zea mays* L.)**

Maize is another important cereal crop that exhibits allelopathic properties. Grassy crops like maize release benzoxazinoid compounds which can impact plants, animals and microbes. Benzoxazinoids (BXs), such as DIBOA and DIMBOA, are a family of allelochemicals found in maize, rye and wheat, with DIMBOA being the main BX in maize. The synthesis of these compounds in maize has been fully elucidated and variations in BX content among cultivars correlate with their allelopathic potential, suggesting that this is a heritable trait. While maize seedlings are generally less sensitive to weed residues compared to wheat and paddy with smaller seeds, studies show that weed residues can still inhibit germination and shoot length of maize seedlings.

- **Sorghum (*Sorghum bicolor* L.)**

Sorghum is considered one of the most allelopathic crop species, producing potent phytotoxins like sorgoleone and its analogs. Sorgoleone is a predominant constituent of sorghum root exudates and accounts for much of its allelopathic properties. Sorghum allelopathy has been exploited in practices like green manure, crop rotations, cover crops, intercropping and mulching, as well as through aqueous extracts or powders for weed control. The biosynthetic pathway for sorgoleone primarily occurs in root hair cells. Sorghum extracts and powders have been shown to cause substantial suppression of germination and seedling growth in other crops like cotton, with shoot powder exhibiting higher inhibitory effects than root extracts.

- **Rice (*Oryza sativa* L.)**

Rice is a staple food crop and its allelopathic potential against weeds has been well documented, offering an integrated weed management strategy to reduce herbicide usage. Research has focused on screening germplasm for elite allelopathic rice cultivars and identifying the allelochemicals involved. The incorporation of rice residues with high allelopathic activity can help suppress weed germination in rice-wheat cropping systems.

- **Barley (*Hordeum vulgare* L.)**

Barley possesses allelopathic potential, with alkaloids like gramine and hordenine playing a significant role in its defense against weeds, insects and pathogens. Barley allelopathic extracts can reduce the emergence and growth of serious weeds such as winter wild oat, hood canary grass, black grass, great brome and wild mustard. However, some weeds like wild barley can have a stimulatory effect on barley seedling growth.

Allelopathic Effects of Pulse Crops on Weed

Pulse crops, including legumes, also exhibit allelopathic effects that can be utilized in weed management. Their integration into cropping systems can provide benefits such as improving soil fertility and managing pests in addition to controlling weeds. Allelopathic potential of pulse crops are depicted in Table 2.

- **Lupine (*Lupinus albus* L.) and Medic (*Medicago truncatula Gaertn.*)**

Lupine and medic have shown phytotoxic activity in both controlled laboratory conditions and field settings, confirming their potential for weed suppression when used as living or terminated mulches. Medic, for instance, has been observed to suppress ryegrass weed types, while lupines can suppress grass weeds. Crop mixtures incorporating legumes can lead to weed suppression, thereby reducing the dependency on herbicides.

- **Sunnhemp (*Crotalaria juncea* L.)**

Sunnhemp, a tropical legume, has potential as a summer cover crop with allelopathic effects on both crops and weeds. Studies have indicated that sunnhemp residues, particularly from leaves, can reduce the germination of various weed species like smooth pigweed and also affect certain vegetable crops such as lettuce. The allelochemical activity remains potent even after harvest under dry conditions.

Table 2. Allelopathic potential of pulse crops

Crop (Pulse)	Key Allelochemicals	Target Weeds Suppressed	Mode of Action	Reference/Notes
Chickpea (*Cicer arietinum*)	Phenolic compounds	*Parthenium hysterophorus*, *Chenopodium album*	Leaf leachates inhibit seedling growth	Strong in post-harvest residues
Mung bean (*Vigna radiata*)	Flavonoids, phenolic acids	*Echinochloa crus-galli*, *Digitaria sanguinalis*	Interference with root/shoot growth	Works well in rotation
Cowpea (*Vigna unguiculata*)	Caffeic & p-coumaric acids	*Amaranthus spp.*, *Cyperus rotundus*	Suppresses germination & vigor	Residue incorporation important
Lentil (*Lens culinaris*)	Phenolic acids	*Phalaris minor*	Reduces germination energy	Effective as green manure

Allelopathic Effects of Oilseed Crops on Weed

- **Brassica Species**

Brassicas, including canola, rapeseed (*Brassica napus* L.) and mustards (e.g., *Sinapis alba* L., *Brassica nigra* L.), are cultivated as oilseed crops and have been studied for their weed-suppressive qualities. These plants contain glucosinolates (GSL), which decompose into isothiocyanate compounds with strong antibiotic properties that inhibit the growth of soil-borne fungi, bacteria, or nematodes. Indian mustard and, to a lesser extent, oilseed rape, exhibit powerful allelopathic action, while white mustard tends to have a weaker effect. The allelopathic effects also depend on crop residues, with green manure showing higher activity than residues after grain harvest. Oilseed rape also synthesizes phenolic compounds that contribute to its allelopathic effects. Allelopathic effects of oilseed crops are shown in Table 3.

- **Sesame (*Sesamum indicum* L.)**

Sesame is an ancient oilseed crop with pharmaceutical and cosmetic properties, known to contain various allelochemicals that can affect weeds and other crops. Research on sesame's allelopathic potential could lead to the development of bio-herbicides and assist in selecting compatible rotation crops.

- **Sunflower (*Helianthus annuus* L.)**

Sunflower is an important allelopathic crop, with its main allelochemicals being sesquiterpenes, including sesquiterpene lactones, triterpenes and flavonoids. These effects have been observed in both field conditions and in vitro bioassays.

Table 3. Allelopathic effects of oilseed crops

Crop (Oilseed)	Key Allelochemicals	Target Weeds Suppressed	Mode of Action	Reference/Notes
Mustard (*Brassica juncea*)	Glucosinolates → isothiocyanates	*Phalaris minor*, *Rumex dentatus*	Cell membrane disruption, enzyme inhibition	Brassica residues act as biofumigants
Sunflower (*Helianthus annuus*)	Sesquiterpene lactones, phenolic acids	*Amaranthus spp.*, *Chenopodium album*	Root exudates suppress germination	Effective in intercrops
Groundnut (*Arachis hypogaea*)	Phenolic acids	*Echinochloa colona*, *Cyperus rotundus*	Retards seed germination	Moderate effect
Rapeseed (*Brassica napus*)	Allyl isothiocyanates	Grassy and broadleaf weeds	Volatile compounds suppress germination	Useful in rotations

- **Soybean (*Glycine max*)**

Soybean also exhibits allelopathic potential, with studies showing its extracts can inhibit germination and plant height of subsequent crops like lettuce.

- **Camelina (*Camelina sativa* L.)**

Also known as false flax, Camelina is a low-input, high-yield oilseed crop that belongs to the Brassicaceae family. While tolerant to abiotic stresses, it is susceptible to highly competitive weeds. Essential oils from plants like Greek Oregano, Lavandin and common sage have shown inhibitory effects on *Camelina sativa* L. seeds.

- **Oat (*Avena spp.*)**

Certain oat cultivars have demonstrated allelopathic effects on oilseed plants such as sunflower, safflower, rapeseed and soybean, particularly at higher solution doses. Oat stem extracts, especially those from the Checota and Kahraman cultivars, decreased root and shoot length in these oilseed crops.

- **Rapeseed (*Brassica napus* L.)**

As an important green manure crop, rape can increase soil fertility but may also have allelopathic effects on subsequent crops. Rape extracts have been shown to control a total of weed plants in experimental areas, including those with recognized allelopathic potential.

Allelochemicals and their mechanisms

Allelopathy involves the active synthesis and release of secondary metabolites, known as allelochemicals, by one plant that negatively impacts its neighbour's growth. These compounds are present in all plant tissues and are released into the rhizosphere through various mechanisms, including root exudation, volatilization and the decomposition of residues. Allelochemicals affect key physiological and biochemical processes in target plants. For instance, benzoxazinoids in sweet grasses and sorgoleone in sorghum are well-known examples of such compounds. Phenoxazinones, which are degradation products of benzoxazinoids in soil, can have increased phytotoxicity and antimicrobial activity, acting as intercalating agents that inhibit growth.

Application Strategies in Weed Management

Allelopathy can be practically applied in agricultural systems through various cultural practices.

- **Cover Cropping and Mulching**

Allelopathic crops can be used as cover crops or mulches to reduce weed pressure in fields. Cover crops like rye, vetch, or Brassicaceae plants can suppress weeds in crop rotations, including vegetable crops. However, potential negative allelopathic effects of cover crop residues on the main crop should be considered.

- **Intercropping and Crop Rotation**

Intercropping allelopathic plants with other crops, or rotating routine crops with allelopathic ones, are effective methods for weed control. Leguminous cover crops in cereal production, for example, can control weeds and enhance soil fertility.

- **Breeding Allelopathic Cultivars**

Plant breeding efforts can enhance the allelopathic potential of crop cultivars, leading to the development of weed-suppressive varieties. Identifying suitable allelochemicals also aids in developing natural herbicides.

- **Aqueous Extracts**

Water extracts from allelopathic crops can be sprayed over crops and weeds as a natural herbicide. However, the concentration is crucial, as low concentrations may promote plant growth, while high concentrations can suppress it.

Challenges and Future Directions

While allelopathy offers a promising avenue for sustainable weed management, its applicability in agricultural settings depends on the stability and chemical fate of allelochemicals upon environmental release and their presence in biologically active concentrations. Soil-dwelling microorganisms can accelerate the conversion and modification of allelochemicals, which can alter their properties. Further research is needed to understand these complex plant-interkingdom interactions and to develop integrated weed management approaches that combine allelopathic strategies with other methods. Such an integrated approach is crucial for optimizing weed suppression while minimizing adverse effects on the main crops.

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