

Allelopathy: A detrimental effects of plant species

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Abstract

Allelopathy refers to the detrimental effects of secondary metabolites or chemical exudates (allelochemicals) released by one plant species on the germination, growth, physiology, or development of other plant species sharing the same habitat. Unlike crop-weed competition, which is largely resource-driven, allelopathy involves biochemical interference in the form of phenolic acids, terpenoids, flavonoids, alkaloids, and cyanogenic compounds. These allelochemicals are released through root exudates, leaf leachates, volatile emissions, and decaying residues. The allelopathic effects of weeds such as *Parthenium*, *Cyperus*, *Argemone mexicana*, *Datura*, and wild oat on crops like maize, wheat, sorghum, and sunflower significantly hinder germination, seedling establishment, photosynthesis, respiration, nutrient uptake, and enzymatic activity. Similarly, crop plants like maize, wheat, sunflower, and rye also exert allelopathic effects on weeds, which can be utilized as biological control strategies. The mode of action of allelochemicals involves oxidative stress, ROS generation, alteration in lignin composition, inhibition of water uptake, and disruption of protein and nucleic acid metabolism. Factors such as plant density, life cycle, soil properties, climatic conditions, and stress environment strongly influence allelopathic activity. While allelopathy reduces crop productivity in certain intercropping systems, it also offers eco-friendly opportunities for weed management through cover crops, residue incorporation, and the development of bio-herbicides. Hence, allelopathy is a double-edged ecological interaction, demanding careful exploration for sustainable agriculture and integrated weed management.

Keywords: Allelopathy, allelochemicals, crop-weed interaction, germination inhibition, oxidative stress, bio-herbicides, sustainable agriculture.

Introduction

Allelopathy is the detrimental effects of chemicals or exudates produced by one (living) plant species on the germination, growth or development of another plant species (or even microorganisms) sharing the same habitat. Allelopathy does not form any aspect of crop-weed competition, rather, it causes Crop Weed interference, it includes competition as well as possible allelopathy. Allelochemicals are produced by plants as end products, by-products and metabolites liberalised from the plants; they belong to phenolic acids, flavanoides, and other aromatic compounds viz., terpenoids, steroids, alkaloids and organic cyanides.

Allelopathic Effect of Weeds on Crops

1. Maize

- Leaves & inflorescence of *Parthenium sp.* affect the germination and seedling growth
- Tubers of *Cyperus esculentus* affect the dry matter production

2. Sorghum

- Stem of *Solanum* affects germination and seedling growth
- Leaves and inflorescence of *Parthenium* affect germination and seedling growth

3. Wheat

- Seeds of wild oat affect germination and early seedling growth
- Leaves of *Parthenium* affects general growth
- Tubers of *C. rotundus* affect dry matter production
- Green and dried leaves of *Argemone mexicana* affect germination & seedling growth

4. Sunflower

- Seeds of *Datura* affect germination & growth

Allelopathic Effect of crop plants on weeds

- Root exudation of maize inhibits the growth of *Chenopodium album*
- The cold water extracts of wheat straw when applied to weeds reduce germination and growth of *Abutilon sp.*

Allelopathic Plants	Impact
Intercropping of black walnut with corn	Reduced corn yield by production of Juglone allelochemical from black walnut
Intercropping of <i>Leucaena</i> with other crops	Reduced yield - wheat & turmeric Increase - Maize & Rice
Rye, Fescue & Wheat	Suppressed weed when use as cover crop
Broccoli	Residue interfere in growth of other cruciferous crops
Sunflower & Buckwheat	Reduced weed pressure when use as cover crop in Fava bean
Tifton burclover	Inhibit growth in wheat
Sunn hemp	Inhibition of vegetable seed germination
Wild oat	Affect germination & early seedling growth in wheat
Datura	Affect germination & growth in sunflower

Allelopathic effect of weeds on weeds

Extract of leaf leachate of decaying leaves of *Polygonum* contains flavonoides which are toxic to germination, root and hypocotyls growth of weeds like *Amaranthus spinosus*. Inhibitor secreted by decaying rhizomes of *Sorghum halepense* affect the growth of *Digitaria sanguinalis* and *Amaranthus sp.*

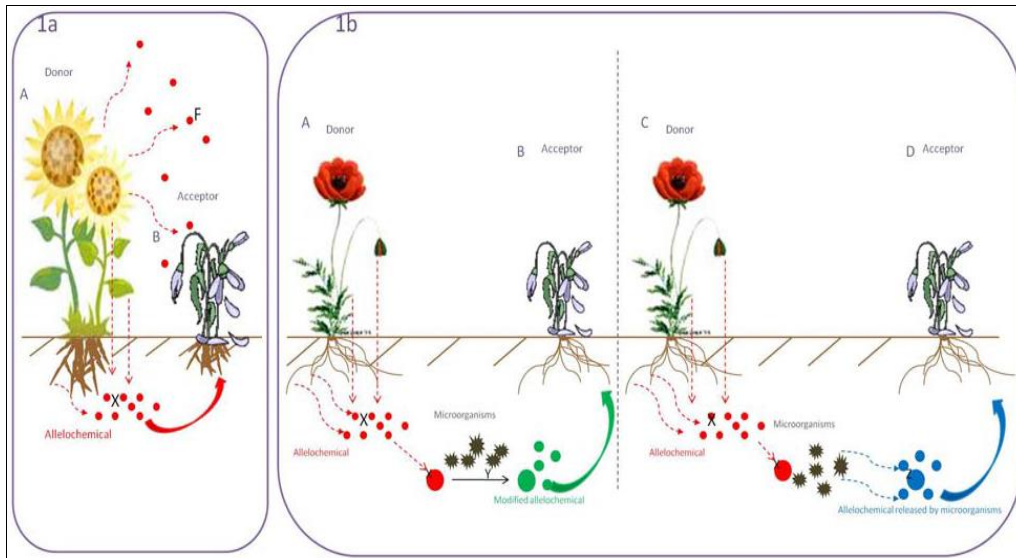


Fig 1: Allelopathic effect of sunflower and Rose on weed

Mode of action of Allelochemicals

Allelochemicals affect the plant physiology through multiple functions. They inhibit weed growth, cause stomatal closure, disturb mineral uptake, influence photosynthesis, affect respiration, induce water stress and damage the enzyme activity. In some studies, explore the mechanism of allelochemicals in legume crops (Baziramakenga *et al.*, 1995; Hussain *et al.*, 2010) [4, 13]. Another study explained the decrease in enzyme activity in hypocotyl cuttings of *P. aureus* under the allelochemical action of caffeic acid (Batish *et al.*, 2008) [5]. *Croton ciliatoglanduliferus* Ort. contains highly toxic flavonoids named retusin which targets the water splitting enzymes in PSII that affects the photosynthetic electron transport chain. Quercetin (flavonoids) inhibits the germination and growth of plants *Physalis ixocarpa*, *Lolium perenne* and *Trifolium alexandrinum* (Morales-Flores *et al.*, 2015) [17].

Effects of allelochemicals

1. Soil properties

Weeds were commonly known by growth retardants through preventive the approach of crops to foods and nutrients from the soil. Along with this hindrance, some weeds also inhibit the growth of neighboring crop plants by releasing the toxic chemicals. In a study, three allelotoxins, maltol, veratric acid and (-)-loliolide from the root exudates of crabgrass were identified (Zhou *et al.*, 2013) [28]. All these roots exudates reduced the soil biomass carbon consequential inhibit the growth of maize, wheat and soybean. *Lanzhou lily* is blemish weeds in the crops that inhibit the crop yield. Wu found a principle autotoxin in this weed that causes the soil sickness and crop yield. In his investigations, phthalic acid was found that damage the soil fertility by inducing the auto toxicity (Wu *et al.*, 2015) [25].

2. Oxidation stress

Oxidative suppress and reactive oxygen species (ROS) generations causes transformations in physiological and biochemical process. A number of studies have been conducted on the alteration of biochemical process by the application of allelochemicals that is due to generation of ROS in the weeds. Artemisinin isolated from leaves of *Artemisia annua* inhibits the growth of lettuce by arresting

the cell division by overproduction of reactive oxygen species (ROS) that leads to lipid peroxidation, proline peroxidation and reduction in chlorophyll contents (Yan *et al.*, 2015) [26]. Eugenol from the essential oil of summer savory and cinnamo induced the generation of ROS that causes oxidative stress and membrane damage of roots along with damage of electrolyte regulating membrane resulting in electrolyte leakage and cell death that detached the leaves of dandelion (Tworkoski, 2009) [24]. This resulted in an increase in the malondialdehyde contents, ascorbate peroxidases and guaiacol peroxidases that ultimately retard the growth of weeds (Ahuja *et al.*, 2015) [2].

3. Alterations in Lignin composition

Lignin is the crucial component of cell wall of the plants. It is noteworthy that change in monomers of the lignin, hydroxyphenyl (H), syringyl (S) and guaiacyl (G), by any environmental stress alter the lignin contents consequently growth of the plants. (Parizotto *et al.*, 2015) [19] explored the inhibiting effect of Benzoxazolin-2(3H)-one (BOA) on the growth of soybean. In this study inhibiting effect of BOA was associated with the alteration of lignin contents that were accompanied by increase in H, S and G monomers. Application of allelochemicals increase the lignin contents 29, 44 and 40% respectively that damage the growth of plant. Germination and growth of weeds were also decreased with this growth retardant phenomenon and mode of action on the plants.

4. Photosynthesis disruption

Sorgoleone is well known allelochemicals which interferes the photosynthesis and inhibits the evolution of oxygen in potato (*Solanum tuberosum*) and groundsel (*Senecio vulgaris*) (Einhellig *et al.*, 1993) [9]. (Nimbal *et al.*, 1996) [18] found sorgoleone as an effective inhibitor of PS II at binding sites than atrazine, a herbicide. It inhibits the electron transfer at reducing site of photosystem (PS II) between Qa and Qb. Other studies have revealed that Sorgoleone has acted as analogue of plastoquinone (PQ) and competed the PQ-binding site on the D1protein of photosystem II (PS II) and has shown inhibitory effect for electron flow (Czamota *et al.*, 2001). It also inhibits hydroxyphenylpyruvate dioxygenase (HPPD), a target site

for herbicides. It is an efficient inhibitor as sulcotrione, famous synthetic herbicides. Inhibition of HPPD is actually depletion of PQ that decreases the availability of PQ at binding sites of PS II (Meazza *et al.*, 2002) [15].

5. Perturbation of water uptake

Proton ATPase is crucial to plants for electrochemical gradients in plasma membrane that drive the uptake of secondary metabolites and plant response to the environment. Uptake and translocation of these allelochemicals through roots is best explained through isotope trace studies (Duke, 2003) [8]. Allelochemicals disrupt the H⁺-ATPase activity in root microsomal membranes and inhibit the growth of targeted weeds due to presence of mitochondrial and tonoplast ATPases inhibitors. Proper functioning of H⁺-ATPase enzyme is essential to maintain proton concentration in the rhizosphere, external to root cell membrane. Inhibition of this enzyme retards the water uptake capacity of plant. This produces an electrochemical gradient to drive the water uptake (Michelet and Boutry, 1995; Steudle and Peterson, 1998) [16, 20]. In this way, phytotoxins disturb other fundamental functions of the plants without ever reaching there. In other studies, allelotoxins induce perturbation to plant water balance and ions uptake in roots that disturbs the normal active transport (Barkosky *et al.*, 2000) [3]. These allelochemicals also damage the cellular membrane increase the electrolyte leakage and lipid peroxidation that reduce the mitochondrial respiration and pigment synthesis. The presence of phytotoxin hydroquinone inhibits the enzyme activity that damages the water uptake phenomenon and leads to action of plant growth reduction (Einhellig, 1995; Hejl and Koster, 2004; Hull and Cobb, 1998; Tu *et al.*, 1995) [11, 12].

6. Proteomics of weeds

Various allelotoxins have been tested on the seeds and seedlings and their detrimental effect can produce abnormalities in the seed mechanism and inhibit the germination and growth of weeds. Light harvesting complex contains chlorophyll and binding proteins, variation in the binding proteins alter the concentration of chlorophyll pigments. This alteration in chlorophyll pigment disturbs the health of weed. Another study, described the variation in binding proteins in lettuce on the application of seed extract of cucumber significantly as compared to control (Lee *et al.*, 2015) [14]. By the variation of binding proteins total chlorophyll was reduced by 23% and chlorophyll a/b by 27%. Another protein that is very sensitive to environmental factors is oxygen evolving proteins (OEE) attached with PS-II in the chloroplast. Its vital role is to release Oxygen by splitting the water and protects the Magnesium cluster and ionic contents because Mg is the central component of chlorophyll that activates carbon fixation process in chloroplast hence regulates many biochemical reactions within the cell. Any environmental factors that damage the OEE protein actually affect the Mg concentration that reduces the chlorophyll contents. Castro evaluated the role of herbicidal 'flumioxazin' on the proteomic variation of Grapevine (*Vitis vinifera* L.) (Castro *et al.*, 2005) [6]. It mainly affected photosynthesis related proteins including OEE and LHCII that interfere with the photosynthesis process. The effect of paraquat was also explored on the mitochondrial proteins and found a clear oxidative modification change in proteomic level by the application of

herbicide on Pea (Taylor *et al.*, 2005) [22]. It also interacts with photosynthetic machinery and causes extensive production of hydrogen peroxide that disturbs the growth of plant. Allelochemicals also affect the proteomic profile of the plants. These allelochemicals may be applied exogenously or approach the plant as volatile organic compounds or scent naturally. Similarly, the effect of floral scent that contains majority of volatile organic compounds including esters, terpenes and aroma alcohol was also studied (Yu *et al.*, 2015) [27]. These allelochemicals change the proteomic profile of tobacco leaves. This change in proteomic profile also influenced the photosynthesis, defense response, electron movement and stomata movement regulation.

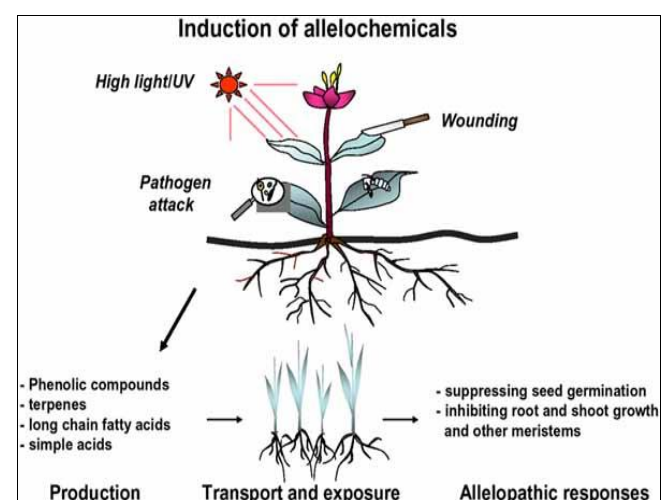
Factors influencing allelopathy

a. Plant factors

- 1. Plant density:** Higher the crop density the lesser will be the allelochemicals it encounters
- 2. Life cycle:** If weed emerges later there will be less problem of allelochemicals
- 3. Plant age:** The release of allelochemicals occurs only at critical stage. For eg. in case of *Parthenium*, allelopathy occurs during its rosette & flowering stage.
- 4. Plant habit:** The allelopathic interference is higher in perennial weeds.
- 5. Plant habitat:** Cultivated soil has higher values of allelopathy than uncultivated soil.
- 6. Climatic factors:** The soil & air temperature as well as soil moisture influence the allelochemicals potential
- 7. Soil factors:** Physico-chemical and biological properties influence the presence of allelochemicals.
- 8. Stress factors:** Abiotic and Biotic stresses may also influence the activity of allelochemicals

Mechanism of action of allelochemicals

- ☒ Interfere with cell elongation
- ☒ Interfere with photosynthesis
- ☒ Interfere with respiration
- ☒ Interfere with mineral ion uptake
- ☒ Interfere with protein and nucleic acid metabolism



Use of Allelopathy in biological control of weeds:

1. Use of cover crop for biological control
2. Use of allelopathic chemicals as bio-herbicides

Conclusion and Future Prospects

Allelopathy plays a crucial role in crop-weed interactions by

releasing secondary metabolites that influence germination, growth, physiology, and biochemical pathways of neighboring plants. These allelochemicals disrupt photosynthesis, respiration, nutrient uptake, and water balance, ultimately reducing crop productivity or suppressing competing weeds. Understanding these complex interactions provides opportunities for sustainable weed management and reduced dependence on synthetic herbicides. Integrating allelopathic crops, residues, and cover crops into agricultural systems can enhance soil health, biodiversity, and ecological balance while minimizing environmental risks. However, variability in allelopathic effects due to plant species, environmental conditions, and soil properties highlights the need for precise field validation. Future prospects lie in molecular-level characterization of allelochemicals, genetic engineering of crops for enhanced allelopathic traits, and development of bioherbicides as eco-friendly alternatives. With advanced research and careful application, allelopathy offers a promising, sustainable approach to weed suppression and resilient agricultural production systems.

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