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WEED AND DISEASE MANAGEMENT BY ALLELOCHEMICALS IN GREEN AGRICULTURE : A REVIEW

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ABSTRACT

Weeds and diseases cause a considerably greater loss in agricultural productivity than any other type of agronomic loss. Weeds cause serious reduction in yield, though herbicides being effective in increasing yield, but its undiscerning use have resulted in serious ecological consequences. Allelopathy is the phenomenon of chemical interactions between plants through the release of secondary metabolites into the environment, which determines the dynamics of plant species in different environment and help to develop applications in agricultural systems. The release of allelochemicals from plant parts and decomposing plant materials can affect weeds and disease-causing microorganisms. Plants use allelochemicals to protect themselves from herbivore predation, microbial attack, and plant competition. This review summarizes the understanding of sustainable weed and disease management by allelochemicals and the mechanisms of action of these compounds.

***Keywords*:** Allelopathy, allelochemicals, agronomy, herbicides, pesticide, sustainable.

Introduction

Increasing human population has made a challenge to achieve targeted food security. In crop production, weeds compete for light, water, nutrients, harbour diseases and insects. Weed causes harm to crops in many ways due to their unusual adaptation and regeneration ability. Globally, weeds caused the highest potential loss, as compared to pests and pathogen. *Cyperus rotundus* inhibit the germination and seedling growth of many economically important crops as bajra, cowpea, sorghum, maize, black gram, rice, sesame, sunnhemp, groundnut, corn, tomato, cucumber, onion etc., *Alternanthera sessilis* inhibits germination and seedling growth of rice. Herbicides usage induces numerous changes in plant growth as growth inhibition, chlorosis, necrosis etc. Allelopathy has gained attention for sustainable weed management. Allelopathy is an ecologically significant biochemical phenomena which involves any direct or indirect (negative or positive) impact of donor plant on target plant through the release of chemical compounds into the environment (Rice, 1984a). In this process the allelochemicals released from any part of the plant can inhibit the growth of a neighbouring plants. Allelochemicals have potential for selective biological weed management, pest management etc. (Mo Shadab *et al.*, 2024). These compounds may be triketones, terpenes, benzoquinones, coumarins, flavonoids, terpenoids (mono-, di- and triterpenes, sesquiterpenes and steroids), strigolactones, phenolic acids (simple phenols, flavonoids, quinones, coumarins, etc.), tannins lignin, fatty acids, and non-protein amino acids etc. Allelochemicals of various crops as rice, buck wheat, clovers, oat, and cereals are phenolic compounds, fatty acids, bioflavonoids, phenolic acids, and hydroxamic acids respectively, which can be used in intercropping with other crops. The allelopathic potential can be extracted as cover crops, intercrop, or as mulch. Sorghum is one of the important allelopathic crop, the allelochemicals of which are hydrophobic sorgoleone (root exudate), phenolics and cyanogenic glycoside. Sorgoleone is a highly lipophilic allelochemical that binds firmly to soil colloids. The allelopathic potential is not expressed in some soils due to the chemical adsorption to soil colloids (Trezzi *et al.*, 2006). The Brassicaceae family has a strong allelopathic potential against other crop and weed plants. They produce the allelopathic compound (glucosinolate) throughout their plant parts. Several weed species have also been reported to be suppressed by sunflower allelopathy (phenolic compounds). Corn and *Urochloa sp.* intercropping enhance soil quality, decreases weed infestation, and increases crop and pasture yield (Borges *et al.*, 2015). A rice allelochemical (diterpene molecule), diterpene synthase enzymes biosynthesize momilactone B from geranylgeranyl pyrophosphate, using the methylerythritol phosphate (MEP) pathway has the highest levels of anti-weed activity (Dudareva *et al.*, 2013). The greater weed control efficiency (WCE) of 67.1, 68.2, and 81.5 percent at 20, 40, and 60 DAS was recorded by the cotton-sorghum intercropping system followed by the cotton-sesame intercropping method while the solitary cotton's WCE was significantly lower (Sathishkumar *et al.*, 2017). Maize intercropped with cowpea helped to reduce weed *Echinochloa colona*, *Portulaca oleracea*, *Corchorus olitorius* and *Dactyloctenium aegyptium* etc., by approx. 50 percent. Allelopathic plant residues in the field shows weed suppressing activity as maize residues were found to lower weed biomass in broccoli, oat and hairy vetch residue mulch reduced weed (*Amaranthus retroflexus*, *Polygonum aviculare*, *P. oleracea* and *Chenopodium album*) density in black pepper. In terms of density and biomass, the mulches were more successful in suppressing weeds. The mechanisms of action of allelochemicals on target plants (seed germination inhibition, reduction of seedling growth) are often secondary signs of primary changes (inhibition of cell division and elongation, interference with cell membrane permeability, enzymatic activities, respiration, and photosynthesis, etc.). Allelochemical herbicides primarily work by blocking the electron transport of photosystem II, stopping respiration and adenosine triphosphate production, using reactive oxygen species (ROS) as a mediator, alternative mechanisms, primarily effect on the plant growth regulators (auxins and gibberellins) and amino acid synthesis, indirect effects of allelopathy, are action on RNA polymerase, inhibition of photosystem I (Weir *et al.*, 2004) and inhibition of tubulin polymerization among other things (Duke *et al.*, 2002). Agrochemicals for crop disease and pest control can be replaced by allelopathy, which can be used in agriculture increase disease-resistant biotypes, contaminate the environment, and reduce the quality of food (Kumar *et al.*, 2023). Adsorption and leaching are the main biotic and abiotic degradation and transferring mechanisms that determine allelochemical bioavailability in soil (Kobayashi, 2004). Some of the factors that can affect the bioavailability of allelochemicals in the soil include the quantity of clay and organic matter present, pH of the soil, availability of water, and biological activity.

Allelopathy and Weed Management

One of the biggest obstacles to agricultural productivity is weed invasion. According to Oerke (2006), weeds reduce agricultural output by 5% in most wealthy nations, 10% in emerging nations, and 25% in least developed nations. The main management strategy in conventional agriculture is chemical weed control. Supplementary approaches to herbicides are becoming more crucial to lessen reliance on chemical control and the harm caused to the environment. Understanding allelopathy could be a valuable tool to boost agricultural products acceptance in today's selective consumer markets (Trezzi *et al.*, 2016). Allelopathic chemicals have been widely employed as herbicides for biological control of weeds because they are safe, effective, and less expensive (Hussein and Abbas, 2021). Allelochemicals released by living and decomposing plant parts as leaves, flowers, seeds, stems, and roots can affect the density and growth of weeds (Kamala Bai *et al.*, 2022) (Fig. 1). Weed management can be achieved by various ways as intercropping, mulching etc. Velvet beans and other legume crops can cut weed biomass by 68% (Caamal-Maldonado *et al.*, 2001). Cell cycle disruption in wheat was caused by allelochemicals released from the root hairs of *Chenopodium murale* L. Barley growth and photosynthetic activity were inhibited by allelopathic water extracts from *Malva parviflora* L. and *C. murale* (Al-Johani *et al.*, 2012). When grown as intercrops with cotton, sesame, pearl millet, and sunnhemp effectively suppressed weeds. The weed flora of cotton-based agrosystems was poisoned by the combined effects of allelochemicals such as fatty acids, fatty acid methyl esters, terpenoids, and phenolics emitted by the intercrops (Verma *et al.*, 2021). In comparison to cotton grown solely with interculturing twice or the herbicide Dual Gold, the results showed that intercropping sorghum or sunflower with cotton significantly reduced weed density and growth and produced higher total crop productivity, LER (Land

Equivalent Ratio), PER (Price Equivalent Ratio), and net benefits. Thus, intercropping methods turned out to be more cost-effective than herbicides and interculturing (Kandhro *et al.*, 2014). Water extracts of tubers of *Cyperus rotundus* L. have inhibitory effects on the germination and seedlings growth of bajra, cowpea, sorghum, maize, black gram, rice, sesame, sunnhemp, and groundnut (Singh, 1968), extract and residues containing alkaloids, flavonoids, tannins, starch, glycosides, furochromones, and many novel sesquiterpenoids of *C. rotundus* have inhibitory effects on the germination and seedling growth of rice cultivators (Geethambigai and Prabhakaran, 2014; Abbas, 2014) and water extracts of tubers of *Cyperus philoxeroides* have inhibitory effects on wheat germination and seedling growth (Mehmood, 2014). Sorghum mulch controls weed by 26-37% in maize (Cheema *et al.*, 2004), 23-65% in cotton (Cheema and Khaliq, 2000), and 50% in aerobic rice (Ikeh *et al.*, 2019). Dar *et al.*, (2024) observed the impacts of *Pseudomonas fulva* T19 and sunflower extract on suppressing the weed canary grass (*Phalaris minor* Retz.) in wheat, a potential eco-friendly herbicide. Chen *et al.*, (2024) observed that the sedge species of *Arenaria polytrichoides* dominate the low-elevation community and exhibit negative allelopathic potentials on cushion plants, it is plausible to hypothesize that these sedge plants are primarily responsible for releasing effective allelochemicals.

Allelopathy and Disease Management

Plant diseases damage vegetable crops and agronomic crops like grains, pulses, oilseeds etc. Allelopathy can be used as a part of integrated disease control mechanism with various types of gaseous compounds which prevent plant pathogens from spreading (Gomez-Rodriguezao *et al.*, 2003). Root exudation (secondary metabolites) into the rhizosphere, affect plants and pathogen interaction (Broeckling *et al.*, 2008, Wang *et al.*, 2009). Members of the families Magnoliaceae, Amaranthaceae, Brassicaceae, Acanthaceae, and Chenopodiaceae are known for their antifungal activities. Essential oils of *Callistemon lanceolatus, Eucalyptus tereticornis, Ageratum conyzoides*, and *Ocimum kelmandescherium* inhibited the growth of the phytopathogenic fungi *Aspergillus flavus, A. niger, A. fumigatus, A. terreus, A. parasiticus, Alternaria alternata, Fusarium oxysporum, Colletotrichum truncatum, Trichoderma viride*, and *Helminthosporium tericum* (Singh *et al.*, 1992; Javaid and Shoaib, 2013). Early blight disease caused by *Alternaria solani* in marigold is reduced by 90%, when planted in vicinity of tomatoes. Bacterial wilt of tomato plant caused by *Pseudomonas solanacearum* is reduced by planting tomato and cowpea together. Allelochemicals of *Oryza sativa* inhibits sporulation in *Fusarium oxysporum* (Hao *et al.*, 2010), *Azadirachta indica* reduces mycelial growth of *Macrophomina phaseolina* (Javaid and Rehman, 2011) and suppresses the pest *Corcyra cephalonica* by 26% by the production of allelochemicals azadirachtin, salannin and nimbin (Batish *et al.*, 2007; Farooq *et al.*, 2011), watermelon suppresses conidial growth in *F. oxysporum* (Ling *et al.*, 2013), *Datura metel* causes radial growth inhibition in *Trichoderma harzianum* and *T. viride* (Rinez *et al.*, 2013), *Solanum lycopersicum* inhibits *Ralstonia solanacearum* activity (Hasegawa *et al.*, 2019), *Pheum palmatum* causes growth suppression of *Pyricularia oryzae*, *Colletotrichum coccodes*, *Rhizoctonia solani*, *Phytophthora capsici* (Jang and Kuk, 2018), *Reynoutria japonica* reduces *Septoria glycines* viability (Borovaya *et al.*, 2020), *Syzygium aromaticum* and *Vatica diospyroides* reduces conidial germination and disease infection in *Aspergillus flavus* (Boukaew *et al.*, 2017). Leaf water extract of neem prevents *Fusarium solani* growth by 53% (Joseph *et al.*, 2008). *Capsicum unnuum* allelochemicals suppresses *Heliothis armigera* by 54% (Batish *et al.*, 2007). Crop rotation can be a mechanism of disease control by allelopathy as barley and potato, turnip and potato, mustard and potato when grown in rotation reduces inoculum intensity of *Rhizoctonia solani* by 55%, 56% and 46% respectively (Larkin and Griffin, 2007).

Allelochemicals in Plants

Two types of metabolites are produced in plants as primary metabolites, found in all plants which have role in plant metabolism and secondary metabolites which are produced in plants as defense mechanism under different stresses (herbivore and pathogen attack) (Joshi *et al.*, 2020; Khare *et al.*, 2020). More than two million secondary metabolites have been reported till now (Willis, 2017), which are restricted to certain parts in the plant body. Besides their medicinal uses these compounds are also used as pesticides, insecticides, and growth-promoting activity to improve crop productivity (Mikail *et al.*, 2022). These metabolites mostly act as allelochemicals, deterrents or toxins that protect plants from stresses. Allelochemicals comprise a group of various plant secondary metabolites produced as some specific biochemical compounds, which represents a group of compounds released by plant which affects the physiological activities including growth and development of other plants eventually leading to their loss. In last few decades, several new allelochemicals have been reported to be detected and identified from diverse plant species (Table 1). Li *et al.*, (2010) classified allelochemicals into following ten categories according to their structures and properties including (1) water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes, and ketones, (2) simple lactones, (3) long-chain fatty acids and polyacetylenes, (4) quinines (benzoquinone, anthraquinone, and complex quinines), (5) phenolics, (6) cinnamic acid and its derivatives, (7) coumarins, (8) flavonoids, (9) tannins, and (10) steroids and terpenoids (sesquiterpene lactones, diterpenes, and triterpenoids). Upadhyay *et al.*, (2024) grouped these chemicals into four classes - terpenes, polyphenols, N-containing secondary metabolites (alkaloids, benzoxazinoids, cyanogenic glucosides, and non-protein amino acids) sulphur-containing compounds (glucosinolates, glutathione, allinins, phytoalexins etc).

(i) Phenolics

Phenolics are one of the allelochemicals produced in the plants during several biotic and abiotic stresses. Flavonoids, phenols, coumarins, lignans, stilbenes, and, tannins comprise the phenolic compounds. Phenols accumulate at the site of infection to inhibit the growth of pathogens (Bhonwong *et al.*, 2009). Phenolic compounds are made of aromatic ring with a hydroxyl group attached to it and possibly other substituents, including phenols, quinones, coumarins and flavonoids (Xu *et al.*, 2023). More than 8000 phenolic compounds have been reported from plants (Shahidi and Yeo, 2018). Flavonoids are polyphenolic structures having C6-C3-C6 carbon framework. Most of the flavonoids found in fruits, vegetables, and specific beverages. Defense mechanism employed by plants involves flavonoids accumulation at the infection site and which cause a hypersensitivity reaction and ultimately causing cell death. Flavonoids are reported to modulate the auxin transport in plants during pathogen stresses (Potters *et al.*, 2007; 2009). Flavonoids protect the plants against fungal pathogens through cell wall disruption, membrane damage, inhibition of enzyme activity, inducing cell death and inhibition of the efflux pump (Al Aboody and Micky Maray, 2020). Flavonoids moderate the pathogenic enzymes by metal ion chelation required for their enzyme catalysis. Kaempferol-3-O-β-D-glucoside, is a flavonoid allelochemical of *Solidago canadensis* (Li *et al.*, 2011). Catechin is a controversial flavonoid allelochemical secreted by spotted knapweed, accumulate in high concentrations in soils (Perry *et al.*, 2005; Weir *et al.*, 2006), contributes to growth limitation of the native plants (Bais *et al.*, 2003). Juglone is an allelochemical of Juglandaceae family is one of the best-known quinone (Willis, 2000), is found in the form of non-toxic naphthol O-glycoside in the leaves, barks, roots and are hydrolyzed into naphthol and oxidized into phytotoxic juglone. Juglone has high stability in soil as its toxicity can maintain for up to a year after the removal of the walnut trees (Strugstad and Despotovski, 2012). Thujone from *Thuja occidentalis* shows the allelopathic activities against seed germination and seedling growth of *Taraxacum mongolicum* and *Arabidopsis thaliana* (Bai *et al.*, 2020). The litter of *Pinus halepensis* contain a sesquiterpene called β-caryophyllene shows a toxic effect on the germination and growth of some herbaceous plants (Santonja *et al.*, 2019). Another sesquiterpene allelochemical dihydromikanolide from *Mikania micrantha* has been reported to reduce fungal growth (Yu *et al.*, 2023). Coumarin extracted from the leaf of *Gliricidia sepium,* reported to inhibit the growth of other plants (Kamo *et al.*, 2013). Two coumarins, umbelliferone and daphnoretin are identified as allelochemicals from *Stellera chamaejasme* (Guo *et al.*, 2015).

(ii) Alkaloids

Alkaloids have also been recognized for their allelopathic effect. Due to their alkaline nature named as alkaloids, are found in plants as the salts of various organic acids (Robinson, 1963). Alkaloids are heterocyclic nitrogen-containing basic compounds of plant origin, are common in Asteraceae, Fabaceae, Boraginaceae, and Apocynaceae (Haig, 2008). They are one of the major groups of secondary metabolites and having significant structural biosynthetic diversity (Yang & Stockigt, 2010), are classified as indole alkaloids (from tryptophan), pyrrolizidine alkaloids (from ornithine or arginine), and quinolizidine alkaloids (from lysine) (Seigler, 1998; Latif *et al.*, 2017). They are thought to inhibit plant growth by several mechanisms including interference with DNA, enzyme activity, protein biosynthesis and membrane integrity in developing plants (Wink, 2004; Latif *et al.*, 2017). Hexadecahydro-1-azachrysen-8-yl ester was recognized as a latent alkaloid allelochemical from *Imperata cylindrical* which can suppress root growth and colonization in mycorrhiza (Hagan *et al.*, 2013). Meta-tyrosine from *Festuca rubra* also been reported to delay the root growth of some plants (Bertin *et al.*, 2007). Mimosine from *Leucaena leucocephala* can retard the plant growth by interfering the cell division of protoplasts by hampering the related enzyme activity (Kato-Noguchi and Kurniadie, 2022). Blackgram and chickpea germination, growth, and yield were allelopathically affected by *Melia azedarach L.* leaf litter and leaf aqueous extracts.

(iii) Terpenoids

The term "terpene" or "terpenoid" is derived from the German word "terpentin" (terpentine) because the first reported terpenoid was isolated from turpentine (Herz, 1963). Approximately 24,000 naturally occurring terpenoids have been reported. They are comprised of five carbon isoprene subunits that are usually linked together head-to-head or head-to-tail or by head-to-middle ring end. Basically, they are the hemiterpenes made of five-carbon isoprene unit and can be categorized as monoterpenes (having two isoprene units), sesquiterpenes (having three isoprene units), diterpenes (having four isoprene units), triterpenes (having six isoprene units), tetraterpenes (having eight isoprene units) and polyterpenes (with more than eight isoprene subunits), are volatile compounds produced by plants and contribute in several biological functions in plants as synthesis of hormones, photoprotection, bio-signalling of molecules etc. (Robinson, 1963; Latif *et al.*, 2017; Croteau *et al.*, 2000). They have been reported for their wide medicinal properties, large number of diverse terpenoids are produced by higher plants (Robinson, 1963), but only a few of them have been reported to be involved in allelopathy in plants. Their effects may occur as inhibition of ATP formation, disruption of hormonal activity, complexation with protein, inhibition of respiration, seed germination and plant growth. Generally, monoterpenoids are the main terpenoid which are responsible for inhibition of seed germination and growth of some bacteria (Sigmund, 1924; Robinson, 1963). Monoterpenoids and sesquiterpenoids are defensive compounds against fungus, insects and other nearby plants (Withers and Keasling, 2007; Ninkuu *et al.*, 2021). α-pinene, myrcene, α-terpinene, β-cymene, 1,8-cineole, camphene etc. are monoterpenoids from *Rosmarinus officinalis* have weedicidal effects on *Eleusine*, *Cynodon*, *Digitaria* sp. (Chen *et al.*, 2013). Sesquiterpenoids as 3,8-oxo-7-hydroxy- 5,11(12)-tetradehydrocadinanene), and -oxo- 10,11-dehydroageraphorone and murol-4-en-3,8- dione isolated from *Eupatorium adenophorum* showed antifeedant activity against *Helicoverpa armigera* and *Spodoptera exigua* (Shi *et al.*, 2012). Drimenin, drimenol, polygodial, isodriminol, valdiviolide, and drimendiol from *Drimys winteri* have been reported for their resistance against *Gaeumannomyces graminis* var. *tritici* (Paz *et al.*, 2020).

(iv) Glucosinolates and isothiocyanates

Glucosinolates are sulphur-rich compounds which are hydrolyzed by myrosinases into toxic metabolites (nitriles, thiocyanates, and isothiocyanates) (Fenwick *et al.*, 1983). Isothiocyanates play an important role in defense against attack by insects and microorganisms (Urbancsok *et al.*, 2017) and are deterrents to herbivores (Bennett and Wallsgrove, 1994). Glucosinolates are volatile in nature so they can also be used for soil fumigation (Bangarwa and Norsworthy, 2017). Glucosinolates generally belong to three categories- indole, aliphatic and benzenic. Glucosinolate producing plants synthesize indole glucosinolate in a large amount as compared to aliphatic and benzenic glucosinolates against insect herbivores (Textor and Gershenzon, 2009; Lei *et al.*, 2019).

(v) Benzoxazinoids

Indole containing benzoxazinoids are well known specialized among the diverse biological plant metabolites (Florean *et al.*, 2023). Hydroxamic acids provide the fundamental structure of a larger family of benzoxazinoids. A few examples of benzoxazinoids are 2-benzoxazolinone, 6-methoxy-benzoxazolin-2-one and 2,4-dihydroxy-1,4-benzoxazin-3-one (Hazrati *et al.*, 2020). Benzoxazinoids have several functions like allelopathy (Teasdale *et al.*, 2012), anticancerous (Wu *et al.*, 2012), antioxidant (Gleńsk *et al.*, 2016) etc., are synthesized in Poaceae, Acanthaceae, Ranunculaceae, and Scrophulariaceae (Schulz *et al.*, 2013; Latif *et al.*, 2017, Handrick *et al.* 2016; Bhattarai *et al.* 2022; Gaikar *et al.*, 2021; Shavit *et al.*, 2022; Rice *et al.*, 2022; Choi *et al.*, 2019). These allelochemicals are reported to act as natural insecticides, fungicides, and herbicides (Zhou *et al.*, 2018). Rye, common wheat, durum wheat, sorghum, barley and oat are possibly the most studied allelopathic crops. 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA) and 2,4-dihydroxy-(2H)-1,4-benzoxazin-3(4H)-one (DIBOA) released by rye cause strong suppression of plant growth (Hashimoto and Shudo, 1996; Niemeyer, 2009; Kremer and Ben-Hammouda, 2009). The variety of benzoxazinoids (DIBOA, HMBOA, BOA, DIMBOA, MBOA) are mainly reported from members of Poaceae (*Secale cereale*, *Sorghum bicolor*, *Triticum aestivum*) (Chon and Kim, 2004; Stochmal *et al.*, 2006; Weston *et al.*, 2013).

(vi) Phytoalexins

Phytoalexins are low molecular weight compounds which are produced during stress (Ahuja *et al.*, 2012; Jeandet, 2015). These compounds are not produced in healthy plants or present only in very small quantities (Mert-Türk, 2002). The capacity of plants to metabolize phytoalexins determines the nature of the plant-pathogen relationship. Plant growth hormones such as auxins and abscisic acid have negative regulation of phytoalexins. Plant exposure to pathogens leads to hypersensitivity reactions (rapid necrosis of localized regions) and thereby phytoalexin accumulation. The accumulation of phytoalexin restricts the growth of invading pathogens. Studies revealed that several biotic and abiotic agents stimulate the synthesis of phytoalexins and confirm the role of phytoalexin in defense against pathogens. Five different diterpenoid phytoalexins, abietoryzins A-E, were isolated from rice cultivar ‘‘Jinguoyin’’ showed antifungal properties against *Bipolaris oryzae* and *Pyricularia oryzae* (Kariya *et al.*, 2023). some important phytoalexins camalexin, rapalexin A, wasalexins have been reported to be produced by *Arabidopsis* (Pedras *et al.*, 2008).

Mechanism of Action of Allelochemicals

Allelochemicals are released from plant parts in various ways, including volatilization, leaching, root exudation, and plant part breakdown. Volatilization only occurs in arid or semi-arid environments. Encircling plants may absorb allelochemicals as vapours, or the condensate may seep into the soil and be absorbed by the roots. Allelochemicals leak out of the aboveground portions of plants through precipitation, dew, or irrigation, where they are then deposited on other plants or in the soil. One of the main direct inputs into the rhizosphere soil is the exudation from plant roots. It is currently difficult to determine whether these toxic substances are contained in residues and released upon decay, or whether microorganisms transform the simple residues into these toxic products due to the presence of microbial enzymes. This is true regardless of whether these compounds are effectively oozed, spilled, or arise from dead cells sloughing off the roots (Rice 1984b; Putnam 1985; Mushtaq and Siddiqui, 2018). Biosynthetic allelochemicals are dispersed throughout various allelopathic species by using the above two mentioned techniques (Khalid *et al.*, 2002). Allelochemical’s physiological and biochemical effects on several crucial plant metabolic pathways are included in the diverse ways, as it inhibit mitosis in plant roots, and alter the rate at which ions are absorbed by plants (Celik and Aslanturk, 2010; Gulzar *et al.*, 2016; Mushtaq *et al.*, 2019), phenolic acids decrease the uptake of macro and micronutrients (Akemo *et al.*, 2000), ethylene and ABA (abscisic acid) production rises during allelopathy stress (Bogatek *et al.*, 2005), different organic compounds influence membrane permeability (Galindo *et al.*, 1999), benzoic and cinnamic acid decreases the amount of chlorophyll in soybeans, which inhibits photosynthesis (Baziramakenga *et al.*, 1994), can suppress respiration (Batish *et al.*, 2001), obstruct protein synthesis (Bertin *et al.*, 2007), and limit the specific enzyme activity in plants (Muscolo *et al.*, 2001). Allelochemicals from *Nicotiana plumbaginifolia* increased the activity of superoxide dismutase (SOD) and catalase (CAT) (Singh *et al.*, 2015). Repressed or hindered germination rate, swollen and obscured seeds, decreased root or radicle and shoot or coleoptile extension, rotting or swelling of root tips, twisting of the root axis, discoloration, lack of root hairs, increased number of seminal roots, decreased dry biomass accumulation, and decreased reproductive potential are some of the immediate visible effects of allelopathy (Wu *et al.*, 1998).

Conclusion

Allelopathy as a science is rapidly evolving, and the approach is one aspect of plant blockage in nature, despite the complex research procedures. Even though barriers to plant-plant interaction have proven to be a significant challenge to understanding how allelopathy functions, research on the subject has increased recently, but many groups of zones have not yet been explored. Agrochemicals that are derived from characteristic sources can be investigated and described using a variety of methodologies, including phenotypic characters, biotechnology, physiology, life structures, plant source-sink relationships, supplement accessibility, inadequacy, biology, ecological factors, soil physical and synthetic contracts, and analysis of allelochemicals produced. The effectiveness of allelopathic weed control will also be enhanced by initiatives to encourage industries to develop allelochemical-based herbicides, research into the allelopathy of uncharted areas, application of allelochemical hormesis, and understanding of allelochemical mode of action (Farooq *et al.*, 2019). Allelochemical's identification, mobility, absorption, interactions with other substances, half-lives in soil, biodegradability, etc. should be considered. Allelopathy will have a significant impact on environmentally safe and sustainable agriculture. It might make it easier to preserve the resources that are already accessible and assist in resolving issues brought on using chemicals. It can also be utilized economically and environmentally to save the crop.

Table 1: Allelopathic plants, their allelochemicals and effects on target plants.

S.No.	Allelopathic plants	Allelochemicals	Target plant	References
1.	*Artemisia argyi*	Phenolics (caffeic acid derivatives)	*Chrysanthemum morifolium*	Li *et al.*, 2021
2.	*Azadirachta indica*	Margocinolid, epoxyazadiradione, margosinona, iso-azadirolida	*Myracrodruon urundeuva*	da Silva *et al.*, 2021
3.	*Azadirachta indica*	Hexane-soluble, acetone-soluble and water-soluble allelochemicals extracts from *A. indica* shoots	*Amaranthus rotundus*, *Cirsium arvense*, lettuce, *Digitaria sanguinalis*, *Sinapis arvensis L.*, *Lolium ultiforum Lam.*	Ashrafi *et al.*, 2008
4.	*Callistemon viminalis*	Phenolic acids (gallic acid, ferulic acid, syringic acid, coumaric acid)	Inhibited growth of *Anagallis arvensis* and *Vicia sativa* without affecting main crop plant wheat chickpea	Vashishth et al, 2023
5.	*Cassia tora* and *Cassia uniflora*	Phenols, ketones, acids, and alcohols	*Parthenium hysterophorous*	Vitonde *et al.*, 2014
6.	*Dipteryx lacunifera*, *Ricinus communis*, *Piper tuberculatum*, *Jatropha gossypiifolia*	Phenolics and terpenoids,	*Bidens bipinnata*	Lopes *et al.*, 2022
7.	*Eucalyptus globulus*	Polyphenolic compounds	Herbicidal properties against *Portulaca oleracea*	Pinto *et al.*, 2021
8.	*Helianthus annuus*	-	Inhibits the germination and growth of *Parthenium hysterophorus*	Rawat *et al.*, 2011
9.	*Hordeum vulgare*	Phenolics, alkaloids	Suppress the growth of different weeds on barley field i.e. *Portulaca oleracea*, *Euphorbia tinctoria*, *Chenopodium album*, *Convolvulus arvensis*, *Echinochloa colonum*, *Sorghum halepense*, *Cyperus rotundus*	Albehadili, 2019
10.	*Miscanthus sacchariflorus*	Orientin, luteolin, veratric acid, chlorogenic acid, protocatechuic acid, *p*-coumaric acid, ferulic acid.	*Bidens frondosa*, *Echinochloa crusgalli*, and *Erigeron canadensis*	Ghimire *et al.*, 2020
11.	*Ocimum basilicum*	Eugenol, phenol, 2-methoxy-3-(2-propenyl), 1,3,6,10-cyclotetra decate traene, 1,4-isopropyl-3,7,11-trimethyl (+), genranyl, camphorene.	Allelopathic effect on weeds and increasing the growth and yield of tested peanut and cowpea plants	Kamel *et al.*, 2022
12.	*Oryza sativa*	Phenolics, fatty acids, benzoxazinoids, terpenoids	Weedicidal effects	Rahaman *et al.*, 2022
13.	*Pisum sativum*	Phenolic and flavonoid contents	in controlling weeds (chard and canary grass) associated with wheat	El-Rokiek *et al.*, 2023
14.	*Ricinus communis*, *Artemisia santolinifolia*, *Triticum aestivum*, *Sorghum bicolor*	Derivates of phenolic acids, flavonoids, and alkaloids,	Suppress the growth of major weeds, i.e. wild mustard (*Sinapis arvensis*), Italian ryegrass (*Lolium multiflorum*), carrot grass (*Parthenium hysterophorus*).	Anwar *et al.*, 2021
15.	*Sorghum bicolor*, *Helianthus annuus*, *Morus alba*	-	Weedicidal effect against *Avena fatua*, *Phalaris minor*, *Chenopodium album*, *Coronopus didymus* in rice crop field	Naeem *et al.*, 2018

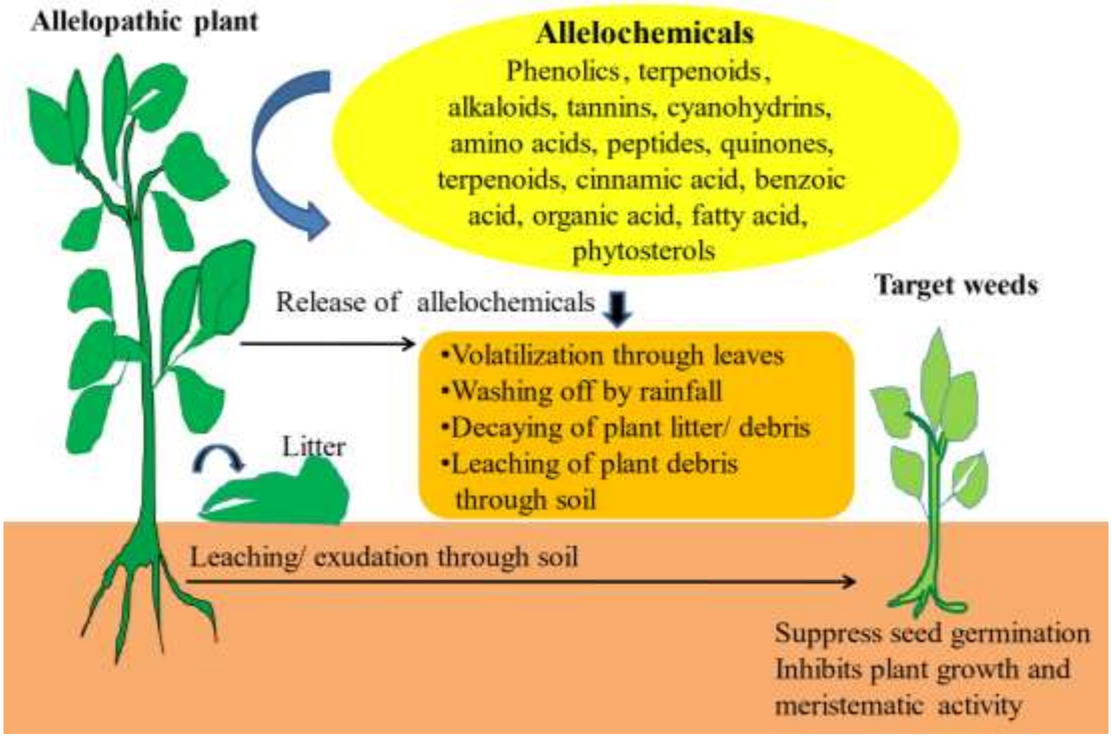

Fig. 1: Role of allelochemicals released by allelopathic plants towards management of weeds.

Conflict of Interest

The authors confirm that this article's content has no conflict of interest.

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