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Allelopathy a Tool for Sustainable Weed Management

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Authors' contributions

This work was carried out in collaboration between both authors. Author KHS wrote the protocol and wrote the first draft of the manuscript. Author PG managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Phytochemicals released by plant species into the environment inhibit the emergence and growth of surrounding plants by changing their metabolic activity or impacting on their soil community mutualists referred as allelopathy. Allelochemicals are the compounds produced from the secondary metabolism of higher plants and microorganisms such as fungi, bacteria and viruses and affect on many processes in ecosystems and agro-ecosystems. In complex agro-ecosystem both crop and weed shows allelophathic effect. Allelochemicals from crop plant affect on other crop and weed while allelochemicals from weed effect on other weed and crop, beside this both weed and crop also shows autoallelopathy. Hence scientific and proper estimation of allelopathic plant, their allelochemical and susceptible weed species is necessary through advance research. This is helps to increase agricultural production, reduction in cost of pesticides, environment hazard, and way for the sustainable weed management and sustainable development of agricultural production as well as ecological systems.

Keywords: Allelopathy; allelochemicals; crop; weed.

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1. INTRODUCTION

The term allelopathy derives from two Greek words *i.e allelon* which means "of each other", and *pathos* means "to suffer". Term allelopathy was first defined by Molisch in 1937 to indicate effects resulted from biochemical substances transferred from plant to plant [1]. Allelopathy is a form of interaction both positive and negative in-between the organisms that is due to the action of chemical substance referred as allelochemicals [2]. Allelopathy, defined as the chemical interactions between plant and plant or plants and microorganisms, leading either positive or negative effects on the performance of neighbors [2]. Decomposed crop residues releases allelochemicals can suppress weed boom in farmlands, and decrease the prevalence of diseases and pests. However, residues mulch can increase the content of soil organic matter and improve soil fertility. Also it shows negative effect by soil sickness [2]. Allelopathy is a phenomenon in which one organism release biochemical's that influences the growth, survival, development and reproduction of other organisms. Released biochemicals are called as allelochemicals and which have good or lethal effects on targated organisms [3]. Phytochemicals produced by plant species into the surrounding environment reduced emergence and expansion of surrounding plants by altering their metabolism activity such as respiration, enzyme synthesis, photosynthesis, mineral ion uptake, protein and nucleic acid synthesis refers as allelopathy [4]. Allelopathy defined as one plant species effects on another plant species or organisms by releasing chemicals into the soil and air environment [5]. In soil environment allelopathy is very complex and depends on soil texture, structure, organic matter and soil moisture. Allelochemicals movement from soil to plant is occur through soil water absorption by plant and its effect depends on concentration of allelochemical in soil water [6]. Allelopathy has both competitive and defensive characteristics in many invasive plants [7].

2. ALLELOCHEMICALS

Allelochemicals are product of plants or microorganisms (fungi, bacteria and viruses) secondary metabolic activity and affects on many processes in agro-ecosystems or ecosystems [8]. Allelopathic effect is referred as mainly negative interaction, [9,10] but positive interactions also reported, depending on the allelochemicals, target plant species and allelochemicals concentration. Near about 300,000 species observed in the plant kingdom [11], they have potential to produce many secondary compounds and among them only limited proportion of these compounds has been explored [12]. Secondary metabolites produced by plant are helpful for the association of plants with the biological environment, to attract pollinators or seed dispersers, defense mechanism over natural enemies and as allelochemicals over possible competitors [13]. Through secondary metabolism plants produce a varied compounds, which is depends on the precursor compound and specific genes activation. For example, in rice (*Oryza sativa* L.) for synthesis of allelochemical momilactone B involved enzymes and genes. It is a diterpene molecule and synthesized biologically from geranylgeranyl pyrophosphate precursor by diterpene synthase enzymes. Its production is due to two genes encoding diterpene synthases *i.e.* 4-copalyl-diphosphate synthetase and kaurene synthase-like 4 [14]. The specialized genes activation for biosynthesis of allelochemicals is dependent on environmental stimulation [15]. In an agricultural ecosystem, allelochemicals is produced by crop and weed plant species. Allelochemicals classified into 14 categories depends on chemical composition [16]: they are straight- chain alcohols, water-soluble organic acids, simple unsaturated lactones; aliphatic aldehydes and ketones; long-chain fatty acids and polyacetylenes; anthraquinone, benzoquinone and complex quinones; cinnamic acid and its derivatives; benzoic acid and its derivatives; simple phenols, flavonoids; coumarin; terpenoids and steroids; tannins; alkaloids and cyanohydrins; amino acids and peptides; purines and nucleosides sulfide; and glucosinolates. Plant growth regulators also considered to be allelochemicals.

2.1 Types of Allelopathy

2.1.1 True allelopathy

Allelochemicals are toxic to their original form in which it produced in environment.

2.1.2 Functional allelopathy

Allelochemicals are non-toxic to plant at initial form, when it released in to environment but after transformation by microorganisms in to another form it become toxic. Non-toxic naphthol O-glycoside observed in black walnut. It is synthesized in to living tissues may be released from barks, leaves and roots in to the soil or air environment. After releasing naphthol O-glycoside is very fast converted into less phytotoxic naphthol *i.e.* aglycone, through soil microbial action or, hydrolysis finally oxidized in to phytotoxic juglone.

2.1.3 Alloallelopathy

It is chemical coactions between the two different species. Allelochemicals which are released by one species harmful to other species and does not affecting on its source. Example: Maize (*Zea mays*) is show allelopathic affect on *Chenopodium* spp. and *Amaranthus* spp.

2.1.4 Autoallelopathy

It is chemical co-action within the same species. Allelochemicals released by one species harmful to itself. Example: Plant species such as rice (*Oryza sativa*), wheat (*Triticum aestivum*), cowpea (*Vigna unguiculata*), alfalfa (*Medicago sativa*) *etc.* shows allelopathic effect on itself. Root exudates of allelochemical Sorgoleone from sorghum reduce germination per cent and dry matter of next season sorghum under monoculture [17].

2.1.5 Concurrent/ direct allelopathy

Types of allelopathy in which released toxic from living species directly affect on surrounding species. It is also known as ‘living plant effect’. Example: Several weeds growing under sorghum (*Sorghum bicolor*) suppressed by sorghum effect. Four polyphenolic compound secreted by *Myriophyllum spicatum* inhabit the growth of (*Microcyctis aeruginosa*) blue-green algae [18].

2.1.6 Residual allelopathy

It is allelopathic effect due to the residues decomposition of previous crop or plant on succeeding crop or plant. Example: Decomposed residues of *kharif* sorghum show allelopathic effect to wheat and *Phalaris minor* in rabi season.

2.2 Importance in Agro-Ecosystem

In agro ecosystems, different practices like weed management, crop rotation, inter cropping, crop succession, plant reproduction, species association can be affected by allelopathy [19]. In addition of this, allelochemicals can be used for synthesis of herbicides, helps to invention of new mode of action. From a genetic point of view, biological science techniques (especially transgenic), or may be classical breeding, can boost the objective of promoting the assemblage of preferable allelochemicals by crops [12]. Genetic studies are widely helpful to grab better, real role of allelochemicals in plant to plant interactions also to determine their limitations and impact on the environment. However, the assemblage of allelopathic compounds needs energy supply by the plant, which could theoretically limit their biological production. Within the circumstance of genetic advancement, the equilibrium between allelopathy and yield capacity may be a recurring task [12]. Allelochemicals can even have asway to species populations which are potentially lethal to crop plants. Allelochemical released from the rice plant root *i.e.* p-coumaric acid with a high concentration, helps to reduce fusarium attack (*Fusarium oxysporum f. sp. niveum*) in melon under rotation with rice [20]. Rapeseed (*Brassica napus* L.), residues after incorporation into the soil, decreased the quantity of (*Xiphinema americanum*) nematodes in orchards due to production of thiocyanates, isothiocyanates and nitriles by hydrolysis of glucosinolate [21].

2.2.1 Crop allelopathy

Allelochemicals can improve or retard plant emergence, growth and allow the improvement of crops with less phytotoxic residue amounts in water and soil, thus leads to waste water treatment and recycling [22,23]. They are a appropriate substitute for artificial herbicides due to the fact that allelochemicals do no longer have residual or poisonous effects, even though the potency and specificity of several allelochemicals are limited [24]. The main aim of research on allelopathy consist efficiently utilize allelopathic effects for agricultural production, reduce use and cost of chemical pesticides and environmental pollution, and providing suitable methods for the sustainable enhancement of agricultural production and ecosystem [22]. Crop allelopathy can be efficiently used to control weeds inside the field, to reduce autoallelopathy and negative effect in-between the allelopathic crops [25]. Allelopathic applications, inclusive of straw mulching, offer precise weed management [26]. Using allelopathic flowers as ground cowl species affords an environmental pleasant option [27].

Allelochemicals are released from higher plants in the form of vapor through roots, stem and leaf or leaf leachate, root exudates, decomposition of plant residues, seed and plant part extract.

Momilactone A and B is allelochemical found in rice leaves, husks, straws, and root exudates that has highest activity levels against weeds inhibited shoot and root growth of *Echinochloa crusgalli* [28]. Aqueous leaf extracts of reputed allelopathic rice variety IAC165, treated with Methyl Jasmonate (0.05 mM) or Methyl Salicylate (5 mM), showed improve inhibitory effects (25 and 21%, respectively) on barnyard grass (*Echinochloa crusgalli* L.) root growth, while (18 and 23%, respectively) on shoot growth [29]. Aqueous extract of rice showed significantly increase IAA oxidase activity in barnyard grass and retard IAA levels, thus damage the growth regulatory system and inhibit seedling growth [30].

Sorgoleone an allelochemical produced in sorghum root epidermal cells, inhibit the photosynthesis in germinating seedlings shoot growth of weeds, with broadleaf species. After formulation as a WP sorgoleone, is more effective in inhibiting weed growth, and crop species are tolerant to it [31]. Activity of nitrosomonas the nitrifying bacterium reduced by the Sorgoleone and increased the ammonia percentage in the soil, enhancing its potency as a nitrogenous fertilizer [32].

Benzoxazolinone (BOA) is a benzoxazinone which is exuded from the roots cultivated grasses like rey, corn and wheat suppresses the emergence and expansion of several plants including crops and weeds [33]. Allelochemicals were isolated from the germinating maize (DIBOA) inhibited the roots growth of weed cress (*Lepidium sativum* L.) [34]. The seedlings growth of wild mustard, *Avena ludoviciana* and *Hordeum spontaneum* were found to be reduced by an aerial parts aqueous extract of barley by increasing level of lipid eroxidation [35]. Infestation of parasitic weed *Striga hermonthica* (Del.) reduced under intercropping system of maize and *Desmodium* spp. due to allelopathic effect [36]. Weed Ipomoea growth in maize (*Zea mays* L.) and soybean fields, inhibited by Wheat (*Triticum aestivum* L.) straw, thus minimize the use of herbicide application. Germination and expansion of many problematic grassy and dicots weed were efficiently reduced by the mulching of Rye [37]. Wheat (*Triticum aestivum* L.) is known to be allelopathic against crops and weeds [38]. Wheat straw reduced weed densities and biomass by an average of 90% compared with those plots without residues [39]. Narwal et al. [40] Reported that wheat straw caused 16.8% reduction of broad-leaved weeds but showed no effect on grassy weeds. Wheat living tissue prior to glyphosate desiccation significantly suppress emergence of ivy-leaf morning glory, *Ipomoea hercaea*, and redroot pigweed (*A. retroflexus*) [41]. Rye (*Secale cereale*) is a promising crop and gives large amounts of biomass [42]. Spring-planted rye suppressed emergence of crabgrass (*Digitaria* spp.), ragweed (*Ambrosia spp.*) and lambsquarter (*Chenopodium album* L.) by 42, 90, and 98%, respectively, compared to plots without rye.

Sarmentine from *Piper* species inhabit wild mustard, velvetleaf, redroot pigweed and crabgrass by complete inhibition of photosynthetic electron transport [31]. Leptospermone exudates from bottle brush plant (*Callistemon citrinus*) causes bleaching of grass weeds [31]. Compound L-DOPA is secreted by the roots of faba bean (*Vicia faba* L.) shown herbicidal effects on many weed species such as creeping thistle (*Cirsium arvense*), wild mustard, henbit (*Lamium amplexicaule*) and field poppy (*Papaver rhoeas*) [43]. Mucuna species (*Mucuna* spp.) root exudates L-DOPA are very useful to scale back the invasion of most worst weed of the world's, *i.e.* (*Cyperus rotundus* L.) purple nut-sedge and (*Imperata cylindrica*) quick grass [44]. In the south eastern part of Brazil, peels of coffee (*Coffea arabica*) fruit, containing flavonoids, phenols and caffeine as allelochemical, are used as natural amendment in agriculture to control weeds [45]. Soybeans is used as trap crop to reduce severity of (*Orobanche spp.*), by suicidal germination of sunflower broomrape [46]. Poonpaiboonpipat et al. [47] Found that barnyard grass (*Echinochloa crusgalli* L.) membrane system weaken by lemon grass (*Cymbopogon citratus*), through electrolyte leakage and lipid peroxidation. Decomposed alfalfa roots and their associated soil produced a 51–56% reduction in blady grass seed germination [48]. Velvet bean increases the yield of its companion graminaceous crops and that it smothers the growth of harmful weeds such as nutsedge (*Cyperus* spp.) and alang alang (*Imperata cylindrica*) [49].

Sunflower (*Helianthus annuus*) shows strong weed suppression. Anaya [50] Reported that soil incorporation of sunflower residues markedly inhibited density of dicot weeds by 66%. Sunflower straw stunned plant height of wild oat, *Agropyron repens*, *E. crus-galli*, *Ambrosia*

Table 1. Allelopathic effect of weeds on crop

Weeds	Affected crop	Source	Effect	Reference
Parthenium (*Parthenium hysterophorus*)	Blackgram (*Vigna mungo*)	Leaf leachates	Lower germination and Seedling vigour	Babu et al. [60]
Lantana(*Lantana camera*)	Greengram (*Vigna radiata*)	Decayed residue	Reduce seed Germination	Vaidya et al. [61]
Rough cockleb (Xanthium strumarium)	Mungbean (*Vigna radiata*)	Root exudates	Growth inhibition	Kumbhar and Patel [62]
Spiny amranthus (*Amaranthus spinosus*)	Wheat (*Triticum Aestivum*)	Leaf extract	Shoot and root length Germination and chlorophyll per cent	Shinde and Salve [63]
Barnyard grass *Echinochloa colona* L.	Rice (*Oryza sativa*) Soybean (*Glycine max*)	Root and leaf exudates	Suppress germination and seedling growth	Chopra et al. [64]
Johnson grass (*Sorghum halepense*)	Chick Pea (*Cicer arientinum*)	Decayed residues	Seed germination	Kadioglu et al. [65]

artemisiifolia and lambsquarter. Biomass of *E. crusgalli, A. artemisiifolia* and lambsquarter was suppressed [51]. Aqueous extracts made from two sunflower cultivars reduced emergence of several noxious weeds such as velvetleaf (*Abutilon theophrasti*), Jimsonweed (*Datura stramonium*), morning glory (*Ipomoea purpurea*) and wild mustard (*Brassica kaber*) [52].

Major allelopathic crops that function as cover crops in general are barley (*Hordeum vulgare*), sorghum (*Sorghum spp.*), corn (*Zea mays*), wheat (Triticum aestivum), rye, buckwheat (*Fagopyrum esculentum*), velvetbean (*Mucuna pruriens*), crimson clover (*Trifolium incarnatum*), subterranean clover (*T. subterraneum*), hairy vetch (*Vicia vilosa*) and *Ipomoea batatas* and *I. tricolor* [42]. These allelopathic plants showed strong weed suppression [53].

2.2.2 Weed allelopathy

The main cause of interference may include consumption and depletion of limited resources, production of toxic chemical compounds that are released into the environment, parasitism, and protection. However, negative interference includes competition and other deleterious effects of one plant on another, including allelopathy and parasitism. Many weed species reported allelopathic effect on crop species by various ways [54].

Straw of Rye grass (*Lolium multiflorum* Lam.) released allelochemicals reduce 34% maize root growth [55]. The secretion of catechin from the roots of the noxious weed, spotted knapweed *(Centaurea stoebe)* effect on many crops [56]. Crude powder and aqueous extract of *Medicago sativa* resulted lethal effects on germination, nutrient uptake and growth of tomato *Lycopersicon esculentum.* Diluted extracts of *Taraxacum officinale* and *Cirsium vulgare* strongly reduced emergence and growth of maize and beans [57]. *Taraxacum officinale and Cirsium vulgare* extract was shown to inhibit germination of *Phaseolus vulgaris*, independent of concentration, taking effect only as their metabolites and less quantity [57]. Allelochimicals soluble in *Chenopodium* species (*C. murale*) proved strong inhibitory to a number of species tested: *Trifolium alexandrimum, Triticum aestivum, Melilotus indicus, Lycopersicon esculentum, Cucumis sativus* [57]. Quack grass, *Agropyron repens* influence on species *Lycopersicon esculentum* and *Capsicum Annuum* [57]. Drost and Doll [58] Concluded that extracts and residues of *Cyprus esculentus* have an inhibitory effect on the growth of soybeans (*Glycine max*) and maize. Horowitz and Friedman [59] Dried *Cyprus esculentus* tubers and mixed with soil. The root and top growth of barley planted in that soil were significantly reduced.

3. LIMITATION

Allelochemical released from different plant also affect on the mycorrhizal fungi, nitrogen-fixing bacteria and pathogens in the soil. When allelochemical released into the soil also effect on spores germination, as well as the mutual relationship between mycorrhizal fungi and host plants [66]. Rice plants produced a phenolic compound had an inhabitary effect on three strains of Rhizobium spp. Similarly, it also reduced leghemoglobin percentage in the root nodules of two bean (*Phaseolus vulgaris* L.) varieties, thus it effect on atmospheric nitrogen fixation capacity of bean crop. An allelochemical released in the soil or air environment is usually in the complex form, and its quantity is varying as per condition. Hence, before determination allelochemicals potential its type and quantity of released should be considered. Evaluation of different type of interactions such as complementary, supplementary and competative between different allelochemicals necessary, because in a specific situation one allelochemical may not show allelopathic effect as a single factor, but may enhance allelopathic affect in relation with another allelochemicals [10]. Allelochemical effect might vary with varieties to varieties or genotypes to genotypes [67]. Genotypes of similar environment or with same taxonomy do not necessary to show same allelochemical, with same quality and quantity or same type of allelopathic response [68]. After released into the soil or aerial environment allelochemicals can be degenerated; with half life period is shortly hours to month [69] and it is mainly depends on concentration of allelochemical, type of soil, soil enzymes, type and population of microorganism and community structure [22].

4. CONCLUSION

The main aim behind allelopathy research is utilization of founded allelopathic effects to increase agricultural production, reduction in cost of pesticides, stop degradation of environment and furnish proper sustainable practices of weed management and sustainable development of agricultural production as well as ecological systems. Allelochemicals from crop plant effect on other crop and weed while allelochemicals from weed effect on other weed and crop, beside this both weed and crop also shows autoallelopathy. Hence scientific and proper estimation of allelopathic plant, their allelochemical and susceptible weed species is necessary through advance research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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