

## Weed Allelochemicals and Possibility for Pest Management

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**Abstract.** *Purpose:* Weed interference is a constraint in agricultural practice. The crop-weed interaction has been extensively described in literature, but the weed-weed interaction and their potential usage in crop production have not much been understood. In this paper, the interactions of allelochemicals of the weeds which cause troublesome in crop production and ecosystem against weeds, crops, and pathogens are described.

*Principal results:* Weed allelochemicals are classified into many chemical classes, and the majority is consisting of phenolics acids, alkaloids, terpenes, flavonoids, long chain fatty acids, lactones, and other volatile compounds. Type of weed allelochemicals and their doses are varied among weed species. Some allelochemicals such as catechin (+/-) have been reported to be responsible for weed invasiveness. Some crops exude germination stimulants to parasitic weeds such as *Striga* spp. and *Orobancha* spp. In contrast to their negative impacts on crop production, many weeds can be exploited as promising sources to control harmful insects, fungi, bacteria, and weeds. For instance, *Ageratum conyzoides* is a destructive weed in crop production, but it exerted excellent insecticidal, antifungal, and herbicidal capacity and promoted citrus productivity in *A. conyzoides* intercropped citrus orchards.

*Major conclusions:* In general, weeds compete with crops by chemical pathway by releasing plant growth inhibitors to reduce crop growth. Weed allelochemicals may be successfully exploited for pest and weed controls in an integrated sustainable crop production. Some weed allelochemicals are potent for development of natural pesticides.

### Introduction

Weed interference includes both competition and allelopathy. The competition consists of water, light, nutrients, spaces, and under certain conditions, carbon dioxide for photosynthesis. However, weeds also interact with crops and other plants including themselves by chemical pathway (allelopathy). To date, some hundreds weed species worldwide possessed allelopathic potential have been listed, of which 240 weed species are reported to exhibit inhibitory activity against crop plants [1]. A number of weed phytotoxins have been found in root exudates, leachates, leaf volatile, decomposition of weed plants, and weed soil. Weed allelochemicals belong to various chemical classes such as phenolic acids, flavonoids, lactones, ketones, coumarins, alcohols, polyphenols, glycosides, alkaloids, aldehydes, and terpenes. To understand the interactions of weeds-crops, weeds-weeds, weeds-plant pathogens, weeds-parasitic weeds, and weed autotoxicity is

indispensable for weed management. In addition, weed allelochemicals and the syntheses of their derivatives may be potential for the development of bioactive pesticides.

The interaction by chemical pathway (allelopathy) between weeds and crops has been extensively studied, but little is known about how weed allelochemicals interact in environment and agricultural practice, with the involvements of crops, weeds, and pathogens. This study overviews the interference of allelochemicals among weeds, crops, and pathogens and discusses potential uses of weed allelochemicals in pest management to establish a sustainable agricultural production.

### Weed interactions

The weed-crop interaction may result in either positive or negative influence. A great loss of crop yield has caused by weed-crop competition, together with the transference of harmful insects and pathogens to crops. However, legume weeds may be useful for soil improvement which could enhance crop yields. Chemicals released by weeds also play a role by either inhibiting (via growth inhibitors) or stimulating (via growth stimulators such as agrostemmin) crop growth [2,3]. Out of 30,000 plant species identified as weeds, 80 species are reported to reduce crop yield [4]. Qasem and Foy [1] demonstrated 240 weed species of different growth habits and life forms exhibited harmful effects on a wide range of crop species through different mechanisms. These weeds include both aggressive annual or perennial weeds and many world's worst weeds. The interaction among weeds is interesting and allelochemicals released from weeds to inhibit growth of other weeds are expected to be exploited as natural chemicals that may be useful in the development of natural herbicides. Qasem and Foy [1] also described the interactions of 64 weed species as donors on emergence of a number of receiver weeds

Weed allelochemicals could suppress growth of other weeds but showed less effective to itself or other weeds in similar families. We observed that phytotoxins released by barnyardgrass (*Echinochloa crus-galli*) were much inhibitory against dicot weeds than monocot weeds [5]. Similarly, mimosine, an allelochemical in *Leucaena* plants and *Mimosa* spp. species, exerted strong inhibition against growth of several upland and lowland weeds, but it was not suppressive against growth of *Mimosa* species, as this species is the mimosine producer [6]. For invasive weeds, it was noted that the invasive species inhibited growth of the native species by releasing toxins into the environment such as (+) catechin [7]. Duke et al., in contrast, claimed that (-) catechin is more phytotoxic than (+) catechin [8].

Allelochemicals from weeds also obtain antibacterial and antifungal activities. These compounds were found in plant extracts, residues, leachates, volatiles, and essential oils. Qasem and Foy [1] listed 51 weed species have antimicrobial and antifungal properties. Sources of toxins were from residues, extracts, tuber oils, leachates, and volatiles with different allelochemicals such as phenolics [9], sesquiterpenes [10], phloroglucinol, acetophenone [11], and diterpenes [12].

The interaction between weeds and parasitic weeds was also concerned as the parasitic weeds represent a major threat to agricultural production. It was found that different cultivated species producing ethylene or strigoles that stimulate seed germination of certain parasitic weeds, including different species of *Orobancha* and *Striga*. Sorghum, barley, and *Vicia dasycarpa* spp. *villosa* stimulated emergence of *Orobancha crenata* [13,14], whilst bean, sorghum, maize, and cucumber promoted growth of *O. ramosa* [15]. The use of a variety of mixtures of plant species is possible to reduce *Orobancha*-host interaction by combining certain host species with different degrees of susceptibility [16]. *Striga* seed germination can be suppressed by root exudates of some non-host plants, including cotton root exudates that stimulate *S. asiatica* seed germination. The use of wild species to control parasitic weeds is possible but preliminary screening should be elaborated [1].

## Weed allelochemicals

It has been found that any plant part of weeds can possess allelochemicals, despite the quantity may be differed from each part, such as stems, leaves, flowers, buds, bark, pollen grains, seeds, fruits, roots, and rhizomes [17,18]. The mechanisms of allelochemical release in weeds include volatilization from stems and leaves [19], roots [20], shoots [21], pollen [22], fruits [23], flowers [24], and residue decay [25]. Allelochemicals must reach sufficient doses to receiver plants through soil, but they are often modified, accumulated, leached, or taken up by the target plants [1].

Allelochemicals produced by weeds may differ by weed species and environmental factors such as light, ultraviolet, ionizing radiation, red and far-red light, minerals, drought stress, fungi, pathogens, and insects [1]. Some fungi and insects exploited allelochemicals as energies by using their allelochemical degrading enzymes [5]. However, allelopathic agents are usually chemicals derived from secondary metabolites or waste products from the primary metabolic pathways in plants [26]. Allelochemicals do not play a role in the primary metabolism essential for plant growth and development, but are produced when they are under biotic and abiotic stresses [17,27]. There may have over 10,000 known secondary metabolites in higher plant and fungi [27], but the possible number of secondary chemicals in nature may reach 400,000 [1]. The interaction of weed allelochemicals in the environment is rather complicated because their transformation to the receiver plants depending on certain environmental conditions and soil factors. Allelochemicals from weeds, similar to other secondary metabolites, are commonly phenolics, terpenoids, alkaloids, coumarins, tannins, flavonoids, steroids, and quinones [28]. However, only certain compounds have been reported to be allelopathic in plant tissues, such as juglone, scopoletin, hydroxamic acid, and sorgoleone [18].

The utilization of weed allelochemicals for weed and pest management is potent. However, the direct use of these compounds is not possible, because of their fast degradation and the isolation of these allelochemicals is complicated and costly. Therefore, the appropriate use of weeds in the crop-weed system, especially legume weeds, in an ecological and sustainable agriculture production, should be a key topic for weed researchers and agronomists. On the other hand, the syntheses of weed allelochemicals' derivatives are helpful to reduce cost, and may find compounds with novel modes of action for the development of bioactive pesticides.

## Allelochemicals of some specific weeds

### *Bidens pilosa*

This is a noxious invasive weed, distributing widely in the tropics and subtropics, and becoming a problem in many countries. In Japan, this weed is strengthening its distribution and dominated strongly in uncultivated and abandoned land, and where native species is replaced by human purposes. Despite several pharmaceutical properties of this weed have been reported, but its invasive strength causes more problems than its benefits. We observed that the plant extracts of *B. pilosa* exerted strong suppression against growth of *Raphanus sativus* and *E. crus-galli*, and several phytopathogens [28]. Fifteen phenolics including pyrocatechin, salicylic acid, *p*-vinylguaiacol, dimethoxyphenol, eugenol, 4-ethyl-1,2-benzenediol, *iso*-vanillin, 2-hydroxy-6-methylbenzaldehyde, vanillin, vanillic acid, *p*-hydroxybenzoic acid, protocatechuic acid, *p*-coumaric acid, ferulic acid, and caffeic acid were identified in the leaves, stems, and roots of the weeds. Of them, caffeic acid accounted for a rather high quantity (117.4-350.3  $\mu\text{g/g}$ ) in all plant parts than other compounds (2.5-37.1  $\mu\text{g/g}$ ) [28]. However, the release rates of these compounds as well as their fates in the soil have not been clarified yet. In addition, phenylheptatriyne was also detected from this plant and demonstrated to act as an allelochemical [29].

*Echinochloa crus-galli*

This is one among the most noxious weeds worldwide and is causing troublesome in agricultural production. A number of allelochemicals were found in the root exudates at the germination stage. The extract of root exudates showed selective influence against monocot and dicot plants [5]. More recently, we found that this weed released a number of allelochemicals into paddy soil to suppress growth of rice and monochoria (*Monochoria vaginalis*), but showed much lower inhibition against growth of itself. Allelochemicals presented in barnyardgrass soil were phenols, terpenes, and fatty acids [5]. However, identification of growth inhibitors other than these substances, which involved in the inhibitory activities of barnyardgrass, has not been succeeded yet.

Yamamoto et al. [30] reported that barnyardgrass inhibited the growth of cockscomb (*Celosia cristata* L. var. *kunze*), timothy (*Phleumpratense* L.), cress (*Lepidium sativum*), amaranth (*Amaranthus viridis*), rice (*Oryza sativa*), lettuce (*Lactuca sativa*), and barnyardgrass itself. *p*-Hydroxymandelic acid, an allelochemical exuding from young barnyard grass roots, significantly reduced the growth of rice at 59.5-178.6 mM. It was also re-discovered the presence of *p*-hydroxymandelic acid in barnyardgrass infested soil [31].

*Imperata cylindrica*

This weed species is also one among the most problematic weeds worldwide, especially in upland. *I. cylindrica* (cogongrass) is very difficult to control as the weed extends by its strong rhizome. Many efforts have been attempted to minimize this weed distribution, but very sporadic successes have been approached. We identified and quantified from the rhizome of *I. cylindrica* possessed about 40 compounds belonging to phenols, phenolic acids, fatty acids, steroids, and lactones [32]. Chemicals in root leachates and those released by the weed rhizome to soil of cogongrass were also examined. It was found that even though the released amount and the quantity of growth inhibitors detected in the soil was in much lower levels than those observed in the rhizome, but their quantities are lethal enough to suppress growth of most upland weeds. Many allelochemicals derived from this weed exhibited strong plant growth inhibition at low concentration [32]. Several phenolic acids were identified in this weed including vanillic acid, *p*-coumaric acid, syringic acid, scopolin, scopoletin, chlorogenic acid, *iso*-chlorogenic acids [33,34,35].

*Parthenium hysterophorus*

*Parthenium* (*P. hysterophorus* L.), native to Mexico, US, and Argentina, has been an invasive weed in more than 30 countries worldwide [36]. In Asia, the weed is an emerging threat weed in India, Nepal, Bangladesh, Pakistan, Vietnam, China, and Sri Lanka [37]. It is a dominant weed in Australia, Southeast Asia, Western Africa, Caribbean countries, and Latin America [38,39]. *P. hysterophorus* showed strong inhibition on emergence of various crops and weeds [40]. Allelochemicals were found in every plant part of this invasive weed, and major components included sesquiterpene and lactones, parthenin, coronopilin, phenolic acids (caffeic, vanillic, ferulic, chlorogenic, *p*-hydroxybenzoic, *p*-coumaric acids), and anisic acid [41,42,43,44]. Other constituents are tannins, saponins, cardiac glycosides, seteroids [45], and volatile compounds [46]. In general, *Parthenium* weed contain toxins from chemical group of C<sub>15</sub> [47]. The lactones in *Parthenium* contain 35 lactones of the pseudoguaicinolide and xanthanolide skeletal types [47].

*Ageratum conyzoides*

This weed is originated from mid-America, now widely spreads in the subtropics and tropics [48]. It is a destructive weed of arable land, caused problems in crop production [49]. This weed is highly adaptable and spreads vegetatively through stolons [50]. *A. conyzoides* exhibited strong

inhibition against emergence of other weeds in fields [51]. Allelochemicals isolated from this weed consisted of essential oils [52], ageratochromene and its hydroxyl derivatives, and flavones [53,54], and the two dimmers [55], and phenolic acids included *p*-coumaric acid, sinapic acid, and benzoic acid [51].

#### *Ambrosia trifida*

This weed is native to North America and is an invasive species [56], and was reported invading throughout China by its strong production of plant biomass and suppressing all associated species [55]. *A. trifida* is among the most economically destructive weeds and its infestation interferes with the growth and establishment of crop plants. Particularly in wheat fields, *A. trifida* often caused significant reduction of growth and yield of wheat [57]. Since this weed invaded the fields, crop production was reduced, particularly wheat, corn, and soybean [57,58]. Carotene sesquiterpenes, thiarubrines, thiophenes [59,60], and essential oils [61,62] were identified from this noxious weed. Some among them were plant growth inhibitors [57,61]. In the *A. trifida* infested soil, two carotene-type sesquiterpenes were identified and acted as plant growth inhibitors [55]. These allelochemicals were attributed to the weed residues, not from root exudates [57]. The presence of other allelochemicals in this weed remains obscure.

#### *Lantana camara*

This is a perennial shrub, native to the tropical America and West Africa, and it was introduced into Asia as an ornamental garden plant, eventually escaped from cultivation, and became invasive [55]. This weed invades in natural forests or plantations, pastures, grasslands, along river banks and roadsides, and in agricultural fields [49]. In agricultural production, *L. camara* leads to a significant reduction in crop productivity. *L. camara* is ranked as one of the world's 10 worst weeds among the top 100 invasive species [63]. Lantadenes A and B were allelochemicals found in the decomposed plants of *L. camara*. Other chemicals from this invasive weed included monoterpenes and sesquiterpenes, triterpenes, irridoid glycosides, furanonaphtho-quinones, flavonoids, and phenyl ethanoid glycosides [64,65].

#### *Parasitic weeds*

Parasitic weeds are serious problems in agriculture, causing large crop reduction in many parts of the world. The most common species are *Striga* spp., *Orobanch*e spp., and *Cuscuta* spp. The *Striga* spp. parasitize mainly tropical cereal crops, such as maize, sorghum, pearl millet, and upland rice [66,67]. Whereas *Orobanch*e spp. parasitize more-temperate climate crops, such as sunflower, tomato, tobacco, rape seed, and legumes [67]. Unlike *Striga* spp. and *Orobanch*e spp., that are selective on only several plant species, *Cuscuta* spp. can invade plants as diverse as green algae (*Chara* spp.), fern, gymnosperms, and a wide variety of angiosperms [68]. Chemical constituents from *Striga* were flavonoids, apigenin and derivatives, luteolin, chrysoeriol, acetin, caffeic acid sugar esters, verbascoside and derivatives, norsesquiterpene, and blumenol [69]. Interestingly, germination of *Striga* spp. and *Orobanch*e spp. are induced by strigolactones such as alectrol and orobanchol from red clover (*Trifolium pretense*) stimulated germination of *O. minor* [70]. In *Cuscuta hygrophilae*, terpenes, long-chain fatty acids, phenols, phenolic acids, and lactones were identified and reported to involve in the suppression on other weeds of the parasitic weed [71].

#### *Other weeds*

Mechanism of action of these allelochemicals against crops includes the interference with cell division and membrane permeability [72], hormone induced growth [73], reduction of photosynthesis, water conductance [74], soil microflora [75], stomata opening, and interference with protein and nucleic acid metabolism [76].

Important allelochemicals detected in different weed species are:

(i) Phenolic acids: *Antennaria microphylla* [77], *Avena fatua* [78], *Bromus japonicas* [79], *Camelina alyssum* [80], *Chenopodium album* [81], *Chromolaena odorata* [82], *Cirsium arvense* [83], *Cyperus esculentus* [84], *Digitaria sanguinalis* [85] [86], *Echinops echinatus* [87], *Erica* spp. [88,89,90], *Euphorbia corrollata* [91], *Galium mollugo* [92], *Lantana camara* [93], *Melilotus alba* [94], *Parthenium hysterophorus* [43,95], *Pteridium aquilinum* [96,97], *Plantago occidentalis* [98]; *Rorippa sylvestris* [99,100], *Rumex crispus* [101], *Salsola kali* [102], *Sasa cernua* [103], *Sporobolus pyramidatus* [104], *Sorghum halepense* [91,105], *Vulpia* spp. [106], *Xanthium strumarium* [107].

(ii) Long chain fatty acids: *Polygonum aviculare* [75].

(iii) Monoterpenes, triterpenes, terpenes, sesquiterpenes: *Ambrosia psilostachya* [91], *Artemisia absinthium* [108], *A. annua* [78], *A. herba-alba* [109], *Ambrosia trifida* [62], *Bidens pilosa* [28], *Chenopodium ambrosioides* [110], *Cherodendrum viscosum* [111], *Cyperus rotundus* [112], *Digitaria sanguinalis* [113], *Salvia apiana*, *S. leucophylla*, *S. millifera* [114,115], *Lantana camara* [64,65].

(iv) Alkaloids: *Datura stramonium* [116,117], *Delphinium ajacis* [118], *Chromolaena odorata* [82], *Lantana camara* [64,65].

(v) Lactones: *Ambrosia cumanensis* [119], *Centaurea maculosa* and *C. repens* [120,121], *Parthenium hysterophorus* [41,47,95].

(vi) Flavonoids: *Abutilon theophrasti* [122], *Galium mollugo* [92], *Pluchea laneolata* [123], *Ruta graveolens* [124].

(vii) Glycosides: *Phleum pretense* [125], *Polygonum orientalis* [126], *Lantana camara* [64,65].

(viii) Other compounds: free amino acids (*Abutilon theophrasti*) [122], agrostemin (*Agrostema githago*) [127], allyl isothiocyanate (*Brassica nigra*) [128], oxalic acid (*Chenopodium murale*) [110], abscisic acid and phaseic acid (*Croton bonphlandianum*) [129], arthaquinone (*Polygonum sachalinense*) [130], aromatic compounds (*Salvia reflexa*) [131], thiophenes and benzofurans (*Tagetes patula*) [132].

### Implications in development of natural pesticides

Allelochemicals from plants, including weeds, have been referred as future natural pesticides or nature's herbicides in action. Allelochemicals are natural origin and they can be degraded fast after incorporating into environment, are acknowledged to be safer than synthetic pesticides. However, allelochemicals with strong biological activities often have complicated chemical structures, resulted in complicated extraction and the synthesis of their derivatives for the development of novel pesticides is costly. Allelochemicals are selective at low doses and they have no long-term environmental effects as they can be degraded by natural decomposing microorganisms [1]. However, to date, no synthetic herbicide from allelopathic background has been made [133]. Various broadleaf crops and weed species were found to susceptible to AAL-toxins, a natural metabolites produced by *Alternaria alternate* f. sp. *lycopersici*, the pathogen that cause stem canker of tomato [1]. Monocots are generally ineffective to AAL-toxin and Abbas et al. [134] proposed that they could be exploited for selective weed control. Parthenin, a sesquiterpene lactone from *Parthnium hysterophorus* strongly reduced germination and seedling growth of billy goat weed but no effect was found on wheat [135]. Despite present developed pesticides are of microbial (fungi or bacteria origin) derivatives or products [18], but allelochemicals from weeds are still promising and needs elaboration toward development of natural pesticides.

## Potential in pest management

Many weeds have been reported to inhibit emergence of other weeds, such as dodder [71], *A. conyzoides* [51,52,54], *P. hysterophorus* [40,42,46,49], *I. cylindrica* [5], *B. pilosa* [28], *Chenopodium murale* [136], and barnyardgrass [5,31]. The incorporation of weed biomass, for instance *A. conyzoides* and *B. pilosa*, to paddy fields reduced paddy weed emergence to 70% and promoted rice yield up to 20% [137]. The allelopathic property of *L. camaran* can be exploited to control water hyacinth. The highly inhibitory compounds that are responsible for the mortality of water hyacinth were subsequently identified as pentacyclic triterpenoids, lantadenes A and B [55].

Some weeds can be promising sources to control parasitic nematodes. The presence of *A. trifida* contributed to lower number of the parasitic nematodes, such as *Aphelenchoides*, *Filenchus*, and *Tylenchus* [138]. The intercropping of *A. conyzoides* enhanced the amount of predator mites (*Amblyseius* spp.) in the citrus orchard [139]. These predatory mites are effective natural enemies of the pest, citrus red mite (*Panonychus citri*) [52]. The volatile chemicals from *A. conyzoides* were described to promote infestation of *Amblyseius* spp. [52]. *P. hysterophorus* showed strong inhibition on growth of some pathogens like *Fusarium oxysporum*, *Aspergillus niter*, and *Drechslera hawaiiensis*. The antifungal property of this weed was attributed to parthenin, a major phytoalexin of this weed [47]. *A. conyzoides* also stunted the spore germination of soil pathogenic fungi including *Phytophthora cirophthora*, *Pythium aphanidermatum*, and *Fusarium solani*, and flavonones A, B, C, and ageratochrome and its two dimers A, B exhibited strong inhibition against growth of weeds and plant fungi [54]. *B. pilosa* also exhibited excellent antifungal capacity and the essential oils of the weed played a critical role [28]. The bactericidal and fungicidal activity of *A. trifida* against six bacterial strains and two fungal strains were reported [62].

## Conclusions

Interaction of weed allelochemicals is an interesting topic which may help to extend knowledge on the allelopathic mechanism of weeds. The use weeds for weed and pest management strategy in the establishment of a sustainable agriculture production is promising. To separate a single allelochemical from weeds is a laborious work, but it can clarify how allelochemicals play a role in the weed-weed, and weed-crop interactions. For instance, some allelochemicals may play as a plant growth inhibitors, but in contrast, the others may act as plant growth promoters. Therefore, understanding the role of allelochemicals in the interactions among crops, weeds, bacteria, fungi, and insects therefore enhance the efficacy of pest management in crop production. In addition, allelopathic effects of weeds against certain crops should be further studied to exploit effectively weed allelochemicals. In addition, further searches for novel and potent allelochemicals with stronger bioactivities should also been conducted to utilize the allelopathic potential of weeds in greater extents.

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