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Allelopathy: A Natural Way towards Weed Management

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Review Article

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ABSTRACT

To meet the food requirement of the ever-growing population of the world the introduction of pesticides in agriculture was a welcome move to control obnoxious weeds below the threshold limit and thereby reduce the yield loss. But continuous use of synthetic herbicides in heavy doses creates environment pollution and increases the number of herbicide resistant weeds. Hence, researches should be done to find out some natural way for minimizing the dependency on synthetic herbicides. The objective of this article is to review the possibilities for using allelopathy to improve overall potentiality of weeds and crops in natural weed management. Allelopathy is the favorable or adverse effect of one plant on another due to direct or indirect release of chemicals from live or dead plants (including microorganisms). Although we cannot discard use of synthetic herbicides completely at the present situation but their use can be reduced up to a certain extent by utilizing allelopathic potentiality as an alternative weed management strategy for crop production as well as environmental benefits.

Keywords: Allelopathy, Allelochemicals, Weeds, Crops.

1. INTRODUCTION

With the burgeoning population of the world, achieving the food security has become a challenge to mankind; as a result only yield maximization is becoming the last word of modern agriculture. Although this approach is satisfying the food demand to almost a desirable extent, but is directly and indirectly causing negative impact on quality of the produce, environment and overall human health. This system is mostly based on the use of heavy doses of chemicals like fertilizers or pesticides to satisfy nutrient deficiency and to control pest attack respectively. Successful breeding for disease and insect resistant cultivars in combination with development of integrated pest management systems have led to a reduction in the demand for fungicides and insecticides, while herbicide use is still increasing worldwide. Continuous use of heavy doses of chemicals is encouraging resistance development in different pests and endangering the ecosystem. In this context, the resistance development among weeds to herbicides is of great concern. According to Stephenson (2000), most agricultural systems collectively use three million tones of herbicides per year. The use of herbicides causes another problem, that of the selective growth of weeds (Caamal et al., 1996). Resistance to specific synthetic herbicides is increasing dramatically in the last two decades leading to lowering the land values resulting farmers to run out of

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weed-controlling chemicals. It has become a worldwide problem. Now it is imperative to concentrate on research to find out some natural extract to control this menace, thereby minimizing or avoiding the frequent use of herbicides in future. In this regard allelopathic effect of different plants is drawing attention of many researchers in the recent past.

2. ALLELOPATHY AND ALLELOCHEMICALS

The term allelopathy, originated from the Greek word `allelon' meaning `each other' and `pathos' meaning `suffering' and was coined by plant physiologist, Hans Molisch, University of Vienna, Austria. `Pathos' also means `feeling', or `sensitive' and could therefore be used to describe both positive (sympathetic) and negative (pathetic) interactions (Gross, 1999). The concept of allelopathy received new attention in 1974, after the publication of the first book in English on allelopathy by Elroy L. Rice. He defined allelopathy as the effect(s) of one plant on other plants through the release of chemical compounds in the environment (Rice, 1984a). This definition is largely accepted and includes both positive (growth promoting) and negative (growth inhibiting) effects. Many ecologists, however, favor definitions including only negative effects in allelopathy. Lambers et al. (1998) for example, defined allelopathy as the growth suppression of one plant species by another due to the release of toxic compounds. Kohli et al. (1998) and Singh et al. (2001) opined that allelopathy refers to any direct or indirect effect of plants on other plants through the release of chemicals and plays an important role in many agro-ecosystems.

Chemicals that impose allelopathic influences are called allelochemicals or allelochemics. In a review of the potential use of allelochemicals as herbicides, Putnam (1988) listed 6 classes of allelochemicals namely alkaloids, benzoxazinones, cinnamic acid derivatives, cyanogenic compounds, ethylene and other seed germination stimulants, and flavonoids which had been isolated from over 30 families of terrestrial and aquatic plants. All these chemicals possess actual or potential phytotoxicity. According to Rice (1984b) tens of thousands of secondary substances out of several hundreds of low molecular weight compounds of primary metabolism are known today, but only a limited number has been recognized as allelochemicals. Rainfall causes the leaching of allelopathic substances from leaves which fall to the ground during period of stress; leading to inhibition of growth and germination of crop plants (Rice, 1974; Mann, 1987). Biodegradable natural plant products rarely contain halogenated atoms and possess structural diversity and complexity, constituting one such class of chemicals and these can act directly as herbicides or may provide lead structures for herbicidal discovery (Duke et al., 2000). Selection of allelopathic plants is a good and commonly used approach for identification of plants with biologically active natural products (Duke et al., 2000).

The readily visible effects of allelochemicals on the growth and development of plants include inhibited or retarded germination rate; seeds darkened and swollen; reduced root or radicle and shoot or coleoptile extension; swelling or necrosis of root tips; curling of the root axis; discoloration, lack of root hairs; increased number of seminal roots; reduced dry weight accumulation; and lowered reproductive capacity. These gross morphological effects may be secondary manifestations of primary events, caused by a variety of more specific effects acting at the cellular or molecular level in the receiver plants (Rice, 1974).

In order to have any effect on the target plant the allelochemicals have to be released from the donor plant. This can happen in different ways:

1. Runoff and leachate from leaves and stem of plants. As for example, the allelochemicals in the leaves of black walnut, *Juglans nigra*, which are washed off with rain can inhibit the growth of the vegetation under the walnut tree (Bode, 1958).
2. Volatile phytotoxic compounds from the green parts of a plant, e.g. *Salvia leucophylla* and *Artemisia californica* (Halligan, 1973).
3. Phytotoxic compounds from decomposing plant material, such as rye (*Secale cereale)* when used as a mulching material. Apart from shading and keeping the soil moist, rye mulch also inhibits both germination and growth of weeds through release of phytotoxins (Barnes and Putnam, 1986).
4. Phytotoxic compounds released from the plant roots. Rice is an example, where living rice plants are able to suppress weed growth selectively (Navarez and Olofsdotter, 1996; Olofsdotter et al., 1997).

3. ALLELOPATHIC POTENTIALITY OF CROP PLANTS

Different crops such as beet (*Beta vulgaris* L.), lupin (*Lupinus lutens* L.), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) are known to have allelopathic effect on other crops (Rice, 1984b). Different allelopathic compounds of some crops, important in weed management are presented in Table 1.

Table 1: Allelochemicals of some important crops

Crops	Scientific name	Allelochemicals	Referrences
Rice	*Oryza sativa* L.	Phenolic acids	Rimando et al., 2001
Wheat	*Triticum aestivum* L.	Hydroxamic acids	Niemeyer, 1988
Cucumber	*Cucumis sativus* L.	Benzoic and Cinnamic acids	Yu and Matsui, 1994
Black mustard	*Brassica nigra* L.	Allyl isothiocyanate	Weston, 1996
Buck wheat	*Fagopyrium esculentum* L.	Fatty acids	Weston, 1996
Clovers and Sweet clover	*Trifolium spp.* *Melilotus spp*.	Isoflavonoids and Phenolics	Weston, 1996
Oat	*Avena sativa* L	Phenolic acids & Scopoletin	Weston, 1996
Cereals	-	Hydroxamic acids	Weston, 1996
Sudangrass		Phenolic acids and Dhurrin	Weston, 1996
Sorghum	*Sorghum bicolor* L.	Sorgoleone	Netzley and Butler (1986)

3.1 RICE (*Oryza sativa* L.)

Chung et al. (2003) described the effect of allelopathic potential of rice (*Oryza sativa* L.) residues against *Echinochloa crusgalli* P. Beauv. var. *oryzi-cola* Ohwi (barnyardgrass), an associated weed of paddy. It was found that average inhibition by the variety Duchungjong on *Echinochloa crusgalli* was 77.7% higher than other 113 tested varieties. Early and late maturing varieties showed less inhibitory effect of 50.2% and 56.1% respectively and intermediate rice varieties with 59.3% inhibition, although the difference between the intermediate and late-maturing groups was not significant. Both laboratory screening and field experiments reveal that rice allelopathy is active against both monocot and dicot weeds (Olofsdotter and Navarez, 1996). A rice cultivar (Taichung Native 1) has also shown activity against most of the weeds including barnyardgrass, desert horsepurslane (*Trianthema portulacastrum* L.), ducksalad, and toothcup (*Ammannia coccinea* Rottb.) (Dilday et al., 1998; Olofsdotter and Navarez, 1996), and is therefore considered to be a suitable choice for both identifying allelochemicals and studying allelopathy genetics (Olofsdotter, 2001). Phenolic acids have been identified in allelopathic rice germplasm (Rimando et al., 2001). According to Mattice et al. (1998) several purported allelochemicals has been identified from soil where allelopathic rice lines have been growing and also from soils containing decomposing rice residues (Chou and Lin, 1976).

In Philippines, 111 rice cultivars have been evaluated for weed suppression capability against barnyardgrass under field conditions over three seasons (Olofsdotter et al., 1999). They correlated screening results from the laboratory with a range of competition components, measured in the field, and claimed that allelopathy can give 34% of the reduction in total weed dry weight after 8 wks of seeding. Table 2 represents the selected data from this study including total dry weight of weeds, root length of the barnyard grass (*Echinochloa crusgalli* (L.) P. Beauv.) in laboratory screening, and a cultivar ranking. There appears to be a higher frequency of allelopathic varieties among tropical Japonicas within *Oryza sativa* and among *O. glaberrima* accessions than in other varietal groups (Courtois and Olofsdotter, 1998). Microscope studies revealed that allelopathic rice cultivars seem to inhibit secondary growth in barnyard grass roots besides reducing root elongation (Fig. 1) (Olofsdotter et al., 2002).

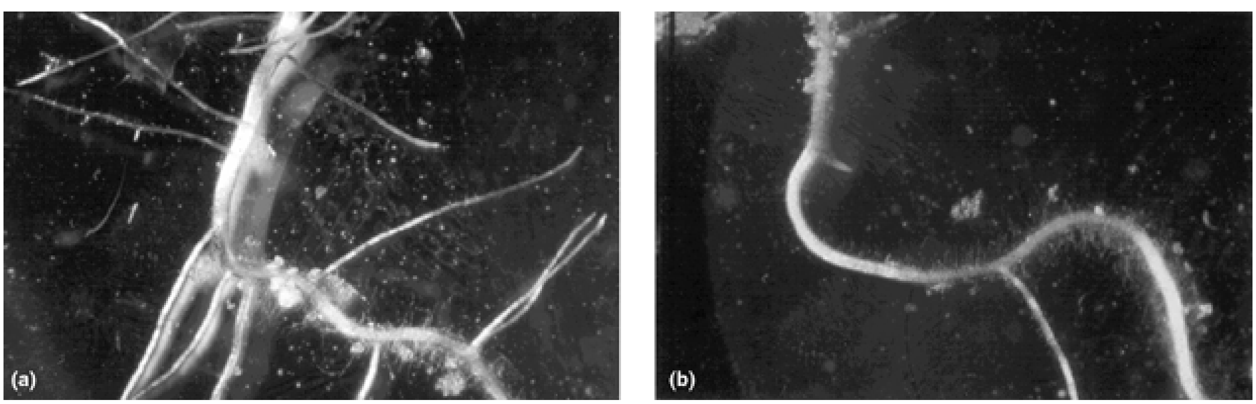
Numerous phytotoxins such as cytokinins, diterpenoids, fatty acids, flavones, glucopyranosides, indoles, momilactones (A and B), oryzalexins, phenols, phenolic acids, resorcinols and stigmastanols have been identified as growth inhibitors in rice. However, the actual modes of action of these compounds as well as other potential rice phytotoxins in nature are not well understood (Khanh et al., 2007).

Table 2: Weed suppressive ability of different rice cultivars with screening for allelopathy under field and laboratory condition

Rice cultivars	Field Experiments	*Laboratory Screening*		
	Total Weed Dry Weight: Three seasons (g)	Barnyard-grass root length (mm)	SE	Rank of whole data set
Lubang Red	500 (54.21)	35.8	2.4	1
YH1	543 (50.27)	37.1	2.4	3
Musashikogane	442 (59.52)	38.4	2.4	4
Taichung Native 1	588 (46.15)	42.6	2.4	5
Kouketsumuchi	407 (62.73)	42.8	2.4	6
Takanenishiki	425 (61.08)	46.6	2.4	14
AC 1423	477 (56.32)	46.8	0.9	15
Tan Gang	347 (68.22)	47.0	2.6	17
IR38 (control)	797 (27.01)	63.8	2.4	54
No-rice control	1092 (0.00)	97.0	0.8	111
Mean for all cultivars	706 (35.35)	58.9	–	–
SE	–	–	–	–
CV	–	26	–	–

Figures in parentheses indicate percentage of weed suppression over control.
Source: Olofsdotter et al., (1999)

Fig. 1: Photomicrographs of *Echinochloa crus-galli* roots grown together with (a) non-allelopathic rice `Aus 196' or (b) allelopathic rice `IR 64'. Secondary root growth is inhibited by the allelopathic rice cultivar (Source: Olofsdotter et al., 2002)



3.2 WHEAT (*Triticum aestivum* L.)

Oueslati (2003) examined the allelopathic effect of diluted extracts of roots, leaves and stems of two durum wheat varieties viz., Karim and Om rabii on barley (variety Manel) and bread wheat (variety Ariana). Guenzi and McCalla (1966) found phytotoxicity of phenolic acids, particularly *p*-coumaric acid, from residues of wheat and other cereals. Niemeyer (1988) reported that production of hydroxamic acids in wheat (*Triticum aestivum* L.) increased until the plant was 40 days old, which proves that allelopathic strength could vary with age of the plant. Allelopathic effect of wheat straw to corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) (Hicks et al., 1989) was also reported by Opoku et al. (1997). Steinsiek et al. (1982) stated that allelopathic interference of wheat to selected weed species was dependent on the extract, species, and temperature. They also inferred that ivyleaf, morning-glory (*Ipomoea hederacea* Jacq.) was most affected and barnyardgrass (*Echinochloa crusgalli* L. Beauv.) was least affected.

3.3 SORGHUM (*Sorghum bicolor* L.)

Netzley and Butler (1986) isolated sorgoleone {2- hydroxy- 5- methoxy- 3- [(8'Z, ll'Z)- 8' ,1l' ,14' -pentadecatriene]- p- benzoquinon} from hydrophobic root exudates of sorghum. Sorgoleone, the major p-benzoquinone, and three other structurally related minor p-benzoquinones together constitute 90% or more of the root exudates (Netzly et al., 1988). According to Cheema (1988) nine water soluble allelochemicals of sorghum (*Sorghum bicolor* L.) are phytotoxic to the growth of certain weeds like *Phalaris minor* Retz., *Chenopodium album* L., *Rumex dentatus* L. and *Convolvulus arvensis* L. He also found that incorporation of sorghum roots into soil suppressed the weed biomass by 25–50% and increased wheat yields by 7–8%. A single spray of 5% sorgaab (water extract of mature stalk of *Sorghum bicolor* L. Moench plants obtained after soaking in water for 24 h and sprayed as a natural herbicide) solution applied 30 days after sowing increased wheat yields by 14% and suppressed weed biomass by 20–40% (Cheema et al., 1997). Cheema and Khaliq (2000) tested the allelopathic effect of sorghum to control weeds of irrigated wheat under semiarid region of Punjab. These authors found that soil incorporation of sorghum stalks at 2, 4 and 6 Mg ha^{-1} reduced weed dry weight by 42, 48 and 56%, respectively. Sorgaab spray reduced weed dry weight by 35–38%. They also studied the effect of concentration and frequency of sorgaab application. They found that one, two or three sorgaab spray at 1:10 gave the same result as three sprays at 1:20 ratio at 90 DAS, although one or two sprays showed less weed suppression (Table 3).

Table 3: Effect of various weed control methods on density and dry weight of weeds

Treatment	Weed density (Number of plants per m^{-2})		Weed dry weight (g m^{-2})	
Control	63.7 aa	–	19.6 a	–
Sorghum stalks (soil incorp.) @ 2Mg ha^{-1}	50.9 b	(20.2) b	11.3 bcd	(42.0)
Sorghum stalks (soil incorp.) @ 4Mg ha^{-1}	45.0 c	(29.2)	10.0 cde	(48.0)
Sorghum stalks (soil incorp.) @ 6Mg ha^{-1}	37.7 d	(40.8)	8.6 e	(56.0)
Sorgaab spray (1 : 20) 30 DAS	50.0 b	(21.6)	12.6 b	(35.4)
Sorgaab spray (1 : 20) 30 and 60 DAS	49.0 bc	(23.1)	12.0 bc	(38.7)
Chlorotoluron CMCPA and 2.50 kg ha^{-1}	11.6e	(81.8)	2.3 f	(88.0)
Hand weeding	32.6 d	(48.9)	6.6 dc	(51.0)
L.S.D (0.05)	4.9		2.12	

a Means with different letters in a column differed significantly (5% level).
b In parenthesis % decrease compared with control, DAS: days after sowing, soil incorp.: soil incorporated, major weed flora of experimental field: *Fumaria indica* Hauskn., *Phalaris minor* Retz., *Rumex dentatus* L. and *Chenopodium album* L.
Source: Cheema and Khaliq (2000)

3.4 BLACK MUSTARD (*Brassica nigra* L.)

Brassica spp. contains high amounts of glucosinolates (Fenwick et al., 1983). According to Petersen *et al.* (2001) Isothiocyanates were strong suppressants of germination on tested species—spiny sowthistle (*Sonchus asper* L. Hill), scentless mayweed (*Matricaria inodora* L.), smooth pigweed (*Amaranthus hybridus* L.), barnyardgrass (*Echinochloa crusgalli* L. Beauv.), blackgrass (*Alopecurus myosuroides* Huds.) and wheat (*Triticum aestivum* L.). Turk and Tawaha (2003) studied the allelopathic effect of black mustard (*Brassica nigra* L.) on germination and seedling growth of wild oat (*Avena fatua* L.). Allelopathic effect of extracts of different plant parts like leaf, stem, flower and root of black mustard was experimented. These authors found that germination and radicle length were affected by extract solutions and the inhibitory effect on germination increased with increasing concentration of extract solution of the fresh plant parts (Table 4). They also observed that the protease enzyme activity was suppressed causing reduced water uptake, which led to poor seed germination of wild oat. They found that residue incorporation affected the germination, plant height and dry matter accumulation per plant and the effect was greater for both root and shoot incorporation than only root incorporation.

Table 4: Influence of various concentrations of different aqueous extracts made from *Brassica nigra* L. plant parts on the germination of *Avena fatua* L. seeds

Extracting Plant part	Germination, by extract conc. (g kg-^{1})					LSD (0.05)
	4	8	12	16	20	
Leaf	73	70	62	55	43	3.0
Stem	90	86	82	77	71	4.0
Flower	80	75	69	65	61	4.0
Root	85	80	75	69	65	3.2
Mixture	76	71	65	59	48	2.3
Control=98						
LSD (0.05)	3.0	3.0	2.8	4.0	3.0	

Leaf, stem, and root extracts, obtained from vegetative plants; flower extract obtained from reproductive plants. The mixing equal parts from leaf, stem, flower, and root extracts prepared the mixture.
Source: Turk and Tawaha (2003)

3.5 WHITE MUSTARD (*Sinapis alba* L.)

Phytotoxic effect of a breakdown product of white mustard (Benz yl-ITC) on, *Abutilon theophrast* (velvetleaf), *Senna obtusifolia* L. formerly *Cassia obtusifolia* L. (sicklepod), and sorghum (*Sorghum bicolor* L. Moench) was reported by Tollsten and Bergstrom (1988).

3.6 LEGUMES

Allelopathic effect of aqueous extracts of perennial legume *Pueraria thunbergiana* leaves on the germination and growth of lettuce was reported by Fujii (1994). Noguchi (2002) reported that xanthoxins may be responsible for the allelopathic effect of this plant. Kato-Noguchi (2003) isolated pisatin (32.7 nmol g^{-1} fresh weight) from methanol extract of pea shoots and showed its inhibitory effect on the root and hypocotyl growth of cress at concentrations greater than 10 mM, and those of lettuce at concentrations greater than 30 mM. Akemo *et al*. (2000) used mulch of dead pea plants to control weeds with an aim to utilize its allelopathic potentiality in place of man-made chemicals. They found that growth of several weeds was affected.

Caamal-Maldonado et al. (2001) examined the toxic effect of four legumes velvetbean (*Mucuna deeringiana* (Bort) Merr.), jackbean (*Canavalia ensiformis* (L.) DC.), jumbiebean (*Leucaena leucocephala* (Lam.) de Wit), and wild tamarind (*Lysiloma latisiliquum* (L.) Benth.) on growth of three weeds viz., barnyardgrass (*Echinochloa crusgalli* L. P. Beauv.), alegría and amaranth (*Amaranthus hypochondriacus* L.). The aqueous leachates (1%) of all four legumes exhibited strong phytotoxic effect on the radicle growth of the weeds.

3.7 CUCUMBER (*Cucumis sativus* L.)

One of the first studies on varietal differences in allelopathic strength was made in cucumber, *Cucumis sativus*. A screening of 526 cucumber accessions, originating from 41 countries, revealed several accessions showing strong growth inhibition of *Panicum miliaceum* and *Brassica hirta*. In the experiment, 26 accessions caused 50-87% growth inhibition of the species tested (Putnam and Duke, 1974).

4. ALLELOPATHIC POTENTIALITY OF WEEDS

Many weeds are now achieving importance as an agent of weed control for having special types of allelochemicals. These allelochemicals are capable of suppressing germination and growth of several other weeds, some of which are herbicide resistant.

4.1 CONGRESS GRASS (*Parthenium hysterophorus* L.)

Parthenium hysterophorus L. is an obnoxious weed of present day, which is creating problem by its huge proliferation in any place. It exerts negative effects on agriculture, animal husbandry, ecology and the environment (Kohli and Rani, 1994). The allelopathic effect of this weed is mainly due to the presence of parthenin, a sesquiterpene lactone of pseudoguanolide nature in various parts of the plant (Kanchan and Jayachandra, 1980b; Kohli et al., 1993; de la Fuente et al., 2000), having greatest concentration in the leaves followed by inflorescence, fruits, roots and stems (Kanchan, 1975). Parthenin is known to have specific inhibitory effects on root and shoot growth of *Crotalaria mucronata* L., *Cassia tora* L., *Oscimum basilicum* L., *Oscimum americanum* L. and barley (*Hordeum vulgare* L.) (Khosla and Sobti. 1979, 1981). Various phenolic compounds identified in *Parthenium* (caffeic, vanillic, ferulic, chlorogenic and anisic acid) (Kanchan, 1975; Kanchan and Jayachandra, 1980a, b) may be responsible for growth reduction of test crops in amended soils. There was a 30-40% reduction in yield of crop plants when grown on soil containing dried root and leaf material of *Parthenium*. Parthenin enters the soil through the decomposing leaf litter (Kanchan and Jayachandra, 1976).

4.2 CHENOPODIACEA SPECIES

Jefferson and Pennacchio (2003) tested the allelopathic potentiality of the aqueous and methanol extracts of the leaves of four Chenopodiacea species viz., *Atriplex bunburyana* F. Muell., *Atriplex codonocarpa* Paul G. Wilson., *Maireana georgei* (Diels) Paul G. Wilson and *Enchylaena tomentosa* R. Br. at 0.006, 0.06, 0.63, 1.55, 3.12, 6.25 g l^{-1} and 0.025, 0.25, 2.5, 6.25, 12.5, 25 g l^{-1} respectively, for allelopathy on lettuce seeds as well as on the chenopod species themselves. They found that germination of lettuce seed was inhibited at concentrations ranging from 3.12 and 6.26 g l^{-1}. The root and shoot growth of lettuce was also inhibited. These authors also observed the inhibitory effect of the extracts of the leaves of *Atriplex bunburyana* and *Atriplex codonocarpa* on the seed of the chenopods, *Enchylaena tomentosa* and *Maireana georgei*. However, *A. codonocarpa* was not, in contrast, affected by extracts derived from the leaves of *E. tomentosa* and *M. georgei*. At the same time all four species were susceptible to allelopathy by extracts isolated from leaves of their own respective species. These results indicated that allelopathy could be considered as a possible mechanism controlling the timing of chenopod germination and seedling establishment.

4.3 CANARY GRASS (*Phalaris minor* Retz.)

Om et al. (2002) listed the allelopathic effect of different weeds on *Phalaris minor* (Table 5). It is clear from the data that the allelopathic potentiality is in the following order: C*henopodium album* L.< *Medicago denticulate* L.< *Melilotus indica* L.< *Convolvulus arvensis* L. (inhibiting 100% germination over control) < *Vicia hirsute* L. (inhibited 86.33% germination) < *Cirsium arvense* L. (47.85% inhibition) < *Lathyrus aphaca* L. (37.98%) < *Rumex acetosella* L. (9.36%). Two weeds, i.e. one grassy (*Cynodon dactylon* L.) and one broad leaf (*Coronopus* didymus L.) had stimulating effect by 7.85 and 3.30 per cent increase in germination. The length of radicle and plumule was affected in the similar order as that of germination. Higher concentration of weed extract (1:4) had more inhibiting effect by about 20 to that of lower concentration (1:8).

4.4 RUSSIAN KNAPWEED (*Acroptilon repens* L.)

A. *repens* is a widely distributed and problematic weed of the western US (Maddox et al., 1985). Stevens (1986) found that the roots of *A. repens* inhibited the root growth of many plants including some weed species also such as *Lactuca sativa*, *Medicago sativa*, *Echinochloa crusgalli* and *Panicum miliaceum* by 30% at concentrations comparable to those found in the soil surrounding *A*. *repens* plants. The germination of *Agropyron smithii* and *Bromus marginatus* was inhibited by aqueous leaf extracts of *A*. *repens* at high levels, however, according to Beck and Hanson (1989), germination was induced by lower concentrations.

Table 5: Allelopathic effect of different weeds on germination and growth of *Phalaris minor*

Treatment	Germination of *P. minor* (%)	% Inhibition over control	Length of plumul (cm)	Length of radicle (cm)
(A) Weeds				
1. *C. arvense*	34.33 (34.66)	47.85	2.25 (1.78)	2.75 (2.03)
2. *A. arvensis*	59.16 (50.53)	10.13	3.78 (2.17)	4.03 (2.25)
3. *C. album* L.	00.00 (00.57)	100.00	0.00 (1.00)	0.00 (1.00)
4. *R. acetosella* L.	59.67 (50.69)	9.36	3.58 (2.12)	3.82 (2.18)
5. *L. aphaca* L.	40.83 (39.22)	37.98	3.95 (2.22)	4.11 (2.25)
6. *M. denticulata*	00.00 (00.57)	100.00	0.00 (1.00)	0.00 (1.00)
7. *M. indica* L.	00.00 (00.57)	100.00	0.00 (1.00)	0.00 (1.00)
8. *V. hirsuta*	09.00 (12.87)	86.33	0.80 (1.28)	1.27 (1.43)
9. *C. arvensis*	00.00 (00.57)	100.00	0.00 (1.00)	0.00 (1.00)
10. *C. didymus*	68.00 (55.73)	-3.30	4.12 (2.23)	4.90 (2.72)
11. *C. dactylon*	71.00 (57.76)	-7.85	3.90 (2.20)	4.60 (2.37)
12. Control	65.83 (54.38)	—	3.73 (2.17)	4.97 (2.40)
CD at 5%	(4.59)	—	(0.13)	(0.12)
(**B) Extract concentration**				
1:4	30.19 (26.94)	—	2.17 (1.67)	2.48 (1.76)
1:8	37.78 (32.74)	—	2.18 (1.69)	2.60 (1.79)
CD at 5%	(1.87)	—	(NS)	(NS)

Data in parenthesis is the arc sine transformed data.
Source: Om et al. (2002)

4.5 MORNING GLORY (*Ipomoea tricolor* Cav.)

Similarly, some species of *Ipomoea* are used as green manures and as a weed controller in some tropical regions of Mexico. In sugarcane (*Saccharum officinarum* L.) fields of the state of Morelos, Mexico, farmers promote *Ipomoea tricolor* (Cav.) growth before sugarcane cultivation. The allelopathic potential of *Ipomoea* was described by Anaya et al. (1990). Pereda-Miranda et al. (1993) identified Tricolorin A as the major phytogrowth inhibitor from the resin glycoside mixture of the plants.

4.6 CROTON BONPLANDIANUM

Sisodia & Siddique (2010) conducted a study to investigate the allelopathic effects of *Croton bonplandianum* weed on seed germination and seedling growth of crop plants (*Triticum aestivum* L., *Brassica oleracea* var. botrytis L. and *Brassica rapa* L.) and weed plants (*Melilotus alba* Medik., *Vicia sativa* L. and *Medicago hispida* Gaertn). Aqueous extracts of root, stem and leaf of Croton at 0.5, 1.0, 2.0 and 4.0% concentrations were applied to find out their effect on seed germination and seedling growth of test plants under laboratory conditions. The root, stem and leaf extracts had no effect on seed germination. The stem extracts had a stimulatory effect on the shoot length at all concentration levels, as against an inhibitory effect of leaf extracts. Among the different parts, leaves were the most allelopathic and stems were least allelopathic. The inhibition effect was found to increase with increasing concentrations of different aqueous extracts (Sisodia and Siddiqui, 2008, 2009). Stem extracts at low concentration generally promoted root length but leaf and root extracts inhibited root length and dry weight. Root length, shoot length of weed species decreased progressively when plants were exposed to increasing concentration (0.5, 1, 2 and 4%). It was also found that with increasing concentrations of aqueous extracts of different parts of *C. bonplandianum,* the osmotic potential and phenolic content increased while pH does not have any major change.

5. LIMITATION OF USING ALLELOPATHIC EFFECT

There are many limitations in using allelopathic potentiality as a weed management tool. The limitations are both because of plant itself, producing allelochemicals and the environmental condition. Many abiotic and biotic soil factors have influences on phytotoxic levels of allelochemicals (Huang et al., 1999; Inderjit et al., 1999a). Various abiotic and biotic factors, such as plant age, temperature, light and soil conditions, microflora, nutritional status, and herbicide treatments influence the production and release of allelochemicals, although allelopathy is considered as a genetically influenced factor (Duke, 1985; Hoagland and Williams, 1985). While moving in the soil allelochemicals may undergo transformation as various factors regarding soil environment like physical, chemical, biological and physicochemical properties of soil may influence the activity of allelochemicals. So to study the allelopathic potentiality of a plant the role of soil should not be ignored. According to Inderjit and Dakshini (1995) many studies on allelopathy, however, do not involve soil rather involve an artificial soil substrate. After entry into soil allelochemicals may be toxified or detoxified by microbes. (Inderjit, 2001). Oleszek and Jurzysta (1987) mentioned the influence of soil texture on phytotoxic effects. Inderjit and Dakshini (1994) found that the amounts of water-soluble phenolics in *P. lanceolata* leaf leachate amended soil varied depending on the soil textural classes (clay, sandy-loam, sand, and silty-loam). Clay mineralogy also plays important role in activity of allelochemicals. The cation exhange capacity, moisture holding capacity, concentration of inorganic ion etc. are dependable on the type of clay minerals. Oxidative polymerizaton of organic compounds is influenced by the clay-size layer silicates as mentioned by Huang et al. (1999).

Many allelochemicals are very much expensive to synthesize inspite of having excellent herbicidal properties as for example, tentoxin (Duke et al., 2000). Some allelochemicals are toxic to human beings and are carcinogenic, e. g. AAL-toxin and fumonisin are toxic to mammalian cells (Duke et al., 2000). Sorgoleone, for example, is reported to cause dermatitis (Inderjit and Bhowmik, 2002). The meals remaining after oil extraction is fed to livestock, but in limited amounts for glucosinolates are degraded by an endogenous enzyme, myrosinase (E.C. 3.2.3.1) to form in particular, isothiocyanates and thiocyanate ion, nitriles and oxazolidinethiones and these species have been found to be harmful when consumed by humans and animals and can, for example, cause thyroid, liver and kidney diseases in monogastric animals (Tookey et al., 1980; Van Etten et al., 1983). Some allelopathic agents are active only under hot and dry climate as they work in vapor phase such as monoterpenes because the high vapour density of the essential oils may penetrate into soil, affecting adversely the undergrowing plants (Kohli and Singh, 1991; Vaughn and Spencer, 1993; Koitabashi et al., 1997).

The amount of nutrient available to the plant and the efficiency of the plant to utilize the nutrient strongly influences the allelopathic potentiality of rice plant. Sometimes the deficiency of nutrients favors the production of secondary metabolites as mentioned by Hoagland and Williams (1985). As for example in aerobic P-deficient soil rice roots excrete organic anions particularly citrate to solubilize and enhance phosphorus uptake (Kirk et al., 1999a,b). The concentration of some inorganic ions affect the activity of allelochemicals. According to Cheng (1989) only the extent of Mn^{2+} and Fe^{2+} ions exposed to organic chemicals influence the oxidation of organic chemicals but the content of these ions do not play any direct role. Mn, Fe, Al, and Si oxides cause polymerization of phenolic compounds into humic acids; however, Mn oxide is the most powerful catalyst (Huang et al., 1999). Some allelochemicals affect the growth of the plant itself i. e., autotoxic effect which is another problem in the mechanism of allelopathy. As for example Yu and Matsui (1994) identified autotoxins, including some derivatives of benzoic and cinnamic acids from the root exudates of cucumber. Quan Yu (2003) showed the inhibitory effect of root exudates and aqueous root extracts of cucumber (*Cucumis sativus*) and allelochemicals on root antioxidant enzymes and leaf photosynthesis, transpiration and stomatal conductance in cucumber. Therefore while studying the role of alleloapthy in controlling weeds the autotoxicity of plats should not be ignored. There must be some strong interaction among autotoxic chemicals and soil environment. In some areas of the world the phytotoxic effect of decomposing rice residues in the soil caused problem on next years crop (Chou, 1998).

6. FUTURE SCOPE OF RESEARCH

Several areas of allelopathy have already been studied and some studies are in progress although some areas are needed to be studied extensively to implicate the mechanism of allelopathy successfully. For optimal use of allelopathy under field conditions, the influence of environmental factors needs to be investigated. In this concern soil environment is the most important factor. The interaction of allelochemicals with different soil properties plays a vital role. From agronomic point of view the allelopathy must be studied. Several agronomic practices such as method of sowing or transplanting (for rice wet-seeded or dry-seeded), spacing of crop, seed rate, timing and source (organic, inorganic or integrated) of nutrient application, method, time and frequency of irrigation etc will create different situation for establishment and growth of both crop plants and weeds, thereby influencing the mechanism of allelopathic activity. The intensity of competition between crops and weeds for space, light, moisture and nutrient will differ under various field conditions, which in turn will affect the allelopathic potentiality. Therefore, this area needs special attention to make allelopathic potentiality successful.

Use of heavy doses of herbicides creates the problem of resistance development in weed. Another problem is continuous use of one herbicide can change the weed community. In case of use of allelochemicals as natural herbicide these must be studied. There may be some residual effect of allelochemicals of crops or weeds. As for example, after the rice harvest residual effects by allelopathic rice cultivars on weed emergence has been reported by Dilday et al. (1998). This must be studied intensively to select crop management practices, crop rotation, cropping system etc. otherwise this may create new agronomic problems. For successful utilization of allelopathic properties the identification of allelochemicals is necessary. It may happen that more than one allelochemicals are involved in allelopathic mechanism. In case of rice the identification of allelochemicals are in progress (Rimando et al., 2001; Mattice et al., 2001). In addition to identification of allelochemicals its movement in the soil, transportation, absorption, mode of action, its interaction with other chemicals, half-lives in soil, biodegradability etc. should be taken under consideration. Finally identification of genes encoding for allelopathy in different plants is required. At IRRI, a research programme was started in 1996 to understand the genetic control of allelopathy, and locate the genes involved in allelopathy on the rice chromosomes and in this context, quantitative trait loci (QTL) analysis was chosen as the principle method for the genetic work (Courtois and Olofsdotter 1998). According to Olofsdotter et al. (2002) after establishment of the genotype of the lines the next steps will include: (1) phenotyping the RILs in a greenhouse, (2) genotyping the population using molecular markers; (3) QTL mapping; (4) analysing the relationship between allelopathic potential and other important agronomic traits; and (5) developing near-isogenic lines (NIL) for allelopathy through marker-assisted selection.

Even though many secondary metabolites having allelopathic activities have been isolated, numerous allelochemicals are undiscovered. The identification of allelochemicals is of prime importantance for the development of bioactive pesticides. Despite the fact that the direct use of allelochemicals as natural pesticides is difficult in the field because of their easy degradation in nature and high cost of delivery, the synthesis of compounds derived from various allelochemicals may help resolve these problems (Khanh et al., 2007).

7. CONCLUSION

So it is clear from the above discussion that there is immense prospect of allelopathic mechanism as a weed management tool. Allelochemicals from several plants have been identified and their activities have also been established. In spite of that some points we have to consider before implication of allelochemicals as natural herbicide: (i) Firstly, along with laboratory experiments field experiments are exclusively needed to study its interaction with various physical, chemical, biological and physico-chemical properties of soil. (ii) Secondly the movement of allelochemicals, mode of action, selectivity etc should be broadly studied and (iii) Finally the impact of use of allelochemicals from agronomic and environmental point of view needs special attention. Before use of any chemicals the security from environment point of view is to be taken into consideration. The dose, frequency and method of application determine the extent of toxicity of a chemical. The acceptance of allelochemicals is much depended on this context.

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