Review

Received: 18 September 2010 Revised: 13 November 2010 Accepted: 18 November 2010 Published online in Wiley Online Library: 19 January 2011

(wileyonlinelibrary.com) DOI 10.1002/ps.2091

The role of allelopathy in agricultural pest management

Muhammad Farooq,[a*] Khawar Jabran,[a] Zahid A Cheema,[a] Abdul Wahid[b] and Kadambot HM Siddique[c,d]

Abstract

Allelopathy is a naturally occurring ecological phenomenon of interference among organisms that may be employed for managing weeds, insect pests and diseases in field crops. In field crops, allelopathy can be used following rotation, using cover crops, mulching and plant extracts for natural pest management. Application of allelopathic plant extracts can effectively control weeds and insect pests. However, mixtures of allelopathic water extracts are more effective than the application of single-plant extract in this regard. Combined application of allelopathic extract and reduced herbicide dose (up to half the standard dose) give as much weed control as the standard herbicide dose in several field crops. Lower doses of herbicides may help to reduce the development of herbicide resistance in weed ecotypes. Allelopathy thus offers an attractive environmentally friendly alternative to pesticides in agricultural pest management. In this review, application of allelopathy for natural pest management, particularly in small-farm intensive agricultural systems, is discussed.

Keywords: allelochemicals; environment; weeds; insect pests; diseases; crop rotation; mulching; cover crops

1 INTRODUCTION

Allelopathy is a phenomenon whereby secondary metabolites synthesised by fungi, viruses, microorganisms and plants influence biological and agricultural systems, which may be either stimulatory or inhibitory.[1] The word allelopathy is derived from two Greek words: 'allelon', meaning 'of each other', and 'pathos', meaning 'to suffer'.[2,3] This ancient concept was known to classical researchers in the Greek and Roman era.[4] Detrimental effects of crop plants on other plants were observed by Theophrastus[5] and by Pliny II,[6] while De Candolle[7] considered allelopathy to be soil sickness. The term 'allelopathy' was first used by Austrian plant physiologist Molísch,[8] who defined it as the chemical interaction among plants and microorganisms.

However, according to Rice,[9] allelopathy is the influene of one plant on the growth of another one, including microorganisms, by the release of chemical compounds into the environment. These chemicals are usually secondary plant metabolites or byproducts of the principal metabolic pathways in plants. They are non-nutritional and can be synthesised in any plant part, i.e. leaves, stems, roots, bark, seeds, etc. Under favourable environmental conditions, allelochemicals are released into the environment through the processes of volatilisation, root exudation, decomposition and/or leaching, thereby affecting the growth of adjacent plants.[9,10] Nonetheless, not all allelochemicals are involved in vital physiological events within the plant system.

Allelopathy involves the synthesis of plant bioactive compounds, known as allelochemicals, capable of acting as natural pesticides[11,12] and can resolve problems such as resistance development in pest biotypes, health defects and soil and environmental pollution caused by the indiscriminate use of synthetic agrochemicals.[12–14] Allelopathic crops, when used as cover crops, mulch, smother crops, intercrops or green manures, or grown in rotational sequences, can combat biotic stresses such as weed infestation, insect pests and disease pathogens and additionally build up fertility and organic matter status of soil, thereby reducing soil erosion, and improve farm yields.[15,16] Thus, allelopathy may be exploited profitably in many ways. In this regard, Birkett *et al*.[17] have mentioned the following pragmatic options of pest management using allelopathy:

(a) Exploitation of traditional intercropping approaches with plants such as *Mentha* spp., *Saturega montana* L. and cultivated members of the genus *Ocimum* to suppress weeds.[18] The essential oils from these plants are applied to soil to replace commonly used methyl bromide. Control of noxious weeds and parasitic plants such as strigas [*Striga hermonthica* (Del.) Benth. and *S. riga asiatica* (L.) Kuntze] have been successful in intercropping, even with aggressive competitors such as sweet potato [*Ipomaea batatus* (L.) Lam.].[19]

(b) Effective control of *S. hermonthica* (Del.) Benth. infestation in maize (*Zea mays* L.) by two leguminous intercropping plants – greenleaf [*Desmodium intortum* (Mill.) Urb.] and silverleaf [*D. uncinatum* (Jacq.) DC.] – which also work

---

* Correspondence to: Muhammad Farooq, Department of Agronomy, University of Agriculture, Faisalabad 38040, Pakistan. E-mail: farooqcp@gmail.com

a Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

b Department of Botany, University of Agriculture, Faisalabad, Pakistan

c The UWA Institute of Agriculture, The University of Western Australia, Crawley, WA, Australia

d College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia

against stem borer in maize owing to their insect-repelling properties.[20] Farmer-managed field trials significantly increased maize yield (almost double) by intercropping with these legumes compared with traditional intercropping with hemp (*Crotolaria* spp.), cowpea [*Vigna unguiculata* (L.) Walp.] and soybean [*Glycine max* (L.) Merr.]. Khan *et al.*[20] suggested that the mechanism(s) involved are principally allelopathy rather than nitrogen fixation. Further, Hooper *et al.*[21] identified a *C*-glycosylflavonoid named isoschaftoside from silverleaf to be responsible for allelopathic suppression of *Striga* in maize–silverleaf intercropping.

(c) Using leguminous cover crops with allelopathic properties such as velvet bean [*Mucuna pruriens* (L.) DC.] proved beneficial in rice (*Oryza sativa* L.) cultivation and in maize and kidney bean (*Phaseolus vulgaris* L.) intercropping systems in Japan.[22,23] Increase in rice yield was attributed to both nitrogen fixation and legume allelopathy.

(d) Germination stimulants and other regulatory signal compounds produced by allelopathic plants can influence crop-weed interactions.

Pesticide application has become the most widely adopted method for controlling weeds, insect pests and disease pathogens for successful crop production, but their non-judicious use also registers ill effects on soil, water, air, humans and animal health.[24] Surface water and groundwater used for human and livestock consumption may be contaminated with pesticides.[25] Residues of pesticides from plants or soil enter the food chain, which may prove hazardous by causing dangerous diseases to humans and animals.[26]

Wise exploitation of allelopathy in cropping systems may be an effective, economical and natural method of pest management, and a substitute for heavy use of pesticides. Pesticide use may be reduced by exploiting allelopathy as an alternate pest management tool in sustainable intensive crop production. Several researchers have described allelochemicals as natural pesticides.[12,27–32] Allelochemicals usually have a mode of action different from synthetic herbicides,[12] being more easily and rapidly degradable owing to a shorter half-life, with comparatively fewer halogen substituents and no unnatural ring structures.[12,33,34] Phytochemicals have low or no toxicity to animals and beneficial insects, possess an array of activity with varying and diverse site of action and have a comparatively high degradation rate.[35,36] Allelochemicals may influence vital physiological processes such as respiration, photosynthesis, cell division and elongation, membrane fluidity, protein biosynthesis and activity of many enzymes, and may also affect tissue water status.[37] Allelochemicals are usually more effective in mixtures than singly to influence targets.[38] Previous reviews on allelopathy include research on allelopathic potential of plants,[39,40] genetic differences among cultivars to suppress crops and weeds,[40] identification of allelochemicals,[41] significance of allelopathy in ecosystems[15,42,43] and possibilities of using allelopathic crops for weed management in field crops.[11,39,40] In the present review, the possible use of allelopathy as an alternative to pesticides for managing weeds, insect pests and diseases, especially in small-farm intensive agricultural systems, is discussed.

2 WEED MANAGEMENT

Allelopathic species suppress weeds when employed in the field following crop rotation,[44] cover or smother crops,[15,39] intercropping, crop residue incorporation,[15,39,41,44] mulching[15,41] (Table 1) and allelopathic crop water extracts (Table 2).[16,30,32,45] Various management strategies for weed management using allelopathy are detailed below.

2.1 Crop rotation

Crop rotation is the sequential sowing of various crops in a particular field over a definite time period. In crop rotation, allelopathic or smothering crops use allelochemicals exuded by roots and released by decomposition of preceding crop residues to suppress weeds, disease pathogens and insect pests.[46–49] A properly designed crop rotation can increase yield by around 20%.[50] Crop rotation leads to numerous benefits over monocultures. Special attention should be paid to pest management when designing the rotation. Factors such as different root systems and plant architechure, differences in sowing and harvesting times, allelopathy, varying soil and crop management techniques and diverse cultural practices may be responsible for pest suppression and other benefits in a rotation.[48] Plant-released allelochemicals through root exudation and litter decomposition in rotational sequence suppress weeds. Crop rotation is also helpful in neutralising potential autotoxic effects associated with allelochemicals. Crops following sorghum (*Sorghum bicolor* L.) face less weed competition owing to suppression of weeds by allelochemicals added to soil by the sorghum crop.[51]

Rice–wheat is a major cropping system in many Asian countries. Heavily infested with weeds, this system largely relies on herbicide inputs for weed control. Integration of smothering allelopathic crops such as pearl millet (*Pennisetum glaucum* L.), maize and sorghum in the rice–wheat cropping system, grown after harvesting wheat (*Triticum aestivum* L.) and before rice transplantation, offers effective weed control for the upcoming rice crop for at least 45 days. Fodder crops such as oats (*Avena sativa* L.) or Egyptian clover (*Trifolium alexandrinum* L.) can be grown in wheat fields heavily infested with weeds for natural weed control for at least one season.[48] *Orobanche minor* (JE Smith), a parasitic weed infesting many crops, can be avoided in red clover (*Trifolium pratense* L.) if sown in wheat-vacated fields. Wheat has the potential for integration as a trap crop as it stimulates parasitic seed germination without attachment, so working as a false host. This can therefore be used to suppress the parasitic weed infestation.[52]

Nevertheless, damaging consequences of an allelopathic crop in rotation have also been observed. For instance, in a sorghum–wheat rotation, allelochemicals exuded from sorghum affected the development of the subsequent wheat crop.[33] Investigation of rotational sequences with allelopathic effects to control weeds and screening and development of crop varieties with allelopathic effects against pests are currently needed.

2.2 Cover crops

Cover crops are grown to control weeds, conserve soil, suppress insects, nematodes and other disease pathogens, enhance nutrient recycling and supply fodder.[53–58] Important cover crops include sunhemp (*Crotalaria juncea* L.), yellow sweet clover [*Melilotus officinalis* (L.) Pall.], sorghum, cowpea, alfalfa (*Medicago sativa* L.), velvet bean, red clover and ryegrass (*Lolium perenne* L.).

Legume crops such as velvet bean, jumbie bean [*Leucaena leucocephala* (Lam.) de Wit], wild tamarind [*Lysiloma latisili-quum* (L.) Benth.] and jack bean [*Canavalia ensiformis* (L.) DC.], used as cover crops in maize, substantially reduced the barnyardgrass

Table 1. Allelopathic inhibition of weeds with various mulches, crop residues and cover crops

Allelopathic source	Application mode	Rate (t ha^{-1})	Dominant weed species	Weed control (over control)[a]	Increase in yield (over control)	Reference
Black mustard (*Brassica nigra* L.)	Mulch	Incorporated in soil 30 DAS	*Avena fatua* L.	68% reduction in DW	–	Turk and Tawaha[119]
Lilyturf (*Ophiopogon japonicus* K.)	Mixed in soil as powder	5	*Monocharia vaginalis* P.,	82.6%	–	Lin *et al.*[120]
Lilyturf		10	*Cyperus difformis* L., *Bidens biternata* L.	100%	–	
Billy goat weed (*Ageratum conyzoides* L.)	Mixed in soil as powder	2	*Echinochloa crus-galli* L.	70% reduction in growth	–	Xuan *et al.*[121]
Billy goat weed			*Monochoria vaginalis* L.	100%	–	
Billy goat weed			*Echinochloa crus-galli* L., *Monochoria vaginalis* L., *Aeschynomene indica* L.	75%	14%	
Billy goat weed			*Aeschynomene indica*	100%	–	
Billy goat weed			*Echinochloa crus-galli* L., *Monochoria vaginalis* L., *Aeschynomene indica* L.	85.5% reduction in weed density and 75.3% in DW	23.3%	
Hairy beggarticks (*Bidens pilosa* L.)	Dried material applied as mulch	2	*Fimbristylis miliacea* L., *Marsilea quadrifolia* L., *Leptochloa chinensis* L., *Rotala indica* L., *Cyperus difformis* L., *Sphenochlea zeylanica*, *Murdannia keisak* Hassk.), *Commelina diffusa* L., *Jussiacea decurrens* Walt., *Brachiaria mutica* Forssk., *Dactyloctenium aegyptium* L., *Monochoria vaginalis* L.	84.9%	23.3%	Hong *et al.*[122]
White tephrosia (*Tephrosia candida* L.)	Dried material applied as mulch	2		81.1%	23.3%	
Kabling-parang (*Anisomeles indica* L.)	Dried leaf powder mulch	1	*Phalaris minor* Retz.	Reduction in *Phalaris minor* density (32.6%) and DW (33.9%)	92.9%	Batish *et al.*[77]
		2		Reduction in *Phalaris minor* density (42.6%) and DW (45.5%)	99.6%	
		4		Reduction in *Phalaris minor* density (53.5%) and DW (60.2%)	74.2%	
		6		Reduction in *Phalaris minor* density (67.8%) and DW (72.9%)	17.8%	

Table 1. (*Continued*)

Allelopathic source	Application mode	Rate (t ha^{-1})	Dominant weed species	Weed control (over control)[a]	Increase in yield (over control)	Reference
	Dried root powder mulch	1		Reduction in *Phalaris minor* density (38.6%) and DW (40.4%)	96.4%	
		2		Reduction in *Phalaris minor* density (52.2%) and DW (50.6%)	105.85%	
		4		Reduction in *Phalaris minor* density (64.5%) and DW (65.3%)	80.0%	
		6		Reduction in *Phalaris minor* density (68.3%) and DW (74.6%)	38.7%	
Mexican marigold (*Tagetes minuta* L.)	Dried leaf powder mulch	1	*Echinochloa crus-galli* L., *Cyperus rotundus* L.	Reduction in total weed density (29.8%) and DW (41.2%)	33.8%	Batish *et al.*[76]
		2		Reduction in total weed density (69.5%) and DW (75.1%)	58.6%	
Rye (*Secale cereale* L.)	Cover crop	–	*Sida spinosa* L., *Portulaca oleracea* L., *Xanthium strumarium* L., *Ipomaea* spp., *Cassia obtusifolia* L., *Amaranthus* spp.	80–90%	–	Nagabhushana *et al.*[123]

[a] DW: dry weight.

Table 2. Allelopathic potential of water extracts for weed suppression in field crops

Allelopathic extract	Frequency (number of sprays); time of application (days after spraying)	Crop	Weed species	Weed control (%)	Yield increase (%)	Reference
Sorghum (*Sorghum bicolor* L.)	Three sprays; 15, 30, 45	Cotton	*Trianthema portulacastrum* L.	Reduction in total weed density (47%) and DW (29%)	45	Cheema *et al.*[124]
	One spray; 30	Wheat	*Fumaria indica* Hauskn.,	Reduction in total weed density (21.6%) and DW (35.4%)	11	Cheema and Khaliq[80]
	Two sprays; 30, 60		*Phalaris minor* Retz.,	Reduction in total weed density (23.1%) and DW (38.7%)	15	
	Two sprays; 30, 60		*Rumex dentatus* L.,	Reduction in total weed density (44.2%) and DW (49%)	20	
	Two sprays; 30, 60		*Chenopodium album* L.	Reduction in total weed density (39.0%) and DW (36.0%)	14	
	Two sprays; 30, 60	Mungbean	*Cyperus rotundus* L.,	Reduction in total weed density (17.54%) and DW (23.73%)	8.23	Cheema *et al.*[125]
	Two sprays; 30, 60		*Chenopodium album* L., *Convolvulus arvensis* L.	Reduction in total weed density (31.58%) and DW (44.11%)	17.75	
	One spray; 20	Cotton	*Trianthema portulacastrum* L.,	Reduction in total weed DW (32.6%)	17.7	Cheema *et al.*[126]
	Two sprays; 20, 40		*Convolvulus arvensis* L.,	Reduction in total weed DW (35.2%)	59.0	
	Three sprays; 20, 40, 60		*Cynodon dactylon* L., *C. rotundus* L.	Reduction in total weed DW (40.1%)	23.0	
	One spray; 20	Sunflower	*Cyperus rotundus* L.,	Reduction in total weed density (19.3%) and DW (27.2%)	7.7	Nawaz *et al.*[127]
	One spray; 40		*Trianthema portulacastrum* L.	Reduction in total weed density (15.8%) and DW (19.12%)	3.6	
	Two sprays; 30, 40	Wheat	*Phalaris minor* Retz.,	Reduction in total weed density (16.53%)	1.58	Cheema *et al.*[90]
Sunflower (*Helianthus annuus* L.)	Two sprays; 30, 40		*Avena fatua* L.,	Reduction in total weed density (33.59%) and DW (2.22%)	5.50	
Eucalyptus (*Eucalyptus camaldulensis* L.)	Two sprays; 30, 40		*Melilotus officinalis* L.,	Reduction in total weed density (15.86%) and DW (22.75%)	–	
Sorghum + sunflower + eucalyptus	One spray; 30		*Rumex obtusifolius* L.	Reduction in total weed density (27.53%) and DW (34.26%)	3.47	
Sorghum	Two sprays; 30, 40		*Phalaris minor* Retz.	DW reduction in *Phalaris minor* (23–41%) and *Avena fatua* (21–41%)	39	Jamil *et al.*[38]
Sorghum + eucalyptus	Two sprays; 30, 40		*Avena fatua* L.	DW reduction in *Phalaris minor* (13–28%) and *Avena fatua* (28–32%)	47.5	
Sorghum + sunflower[a]	Two sprays; 30, 40			DW reduction in *Phalaris minor* (30–35%) and *Avena fatua* (24–39%)	62	
Sorghum + sesame (*Sesamum indicum* L.)	Two, 30, 40			DW reduction in *Phalaris minor* (21–24%) and *Avena fatua* (19–24%)	44	
Sorghum + tobacco (*Nicotiana tobaccum* L.)	Two, 30, 40			DW reduction in *Phalaris minor* (10–14%) and *Avena fatua* (14%)	18.5	
Sorghum + brassica	Two, 30, 40			DW reduction in *Phalaris minor* (21–27%) and *Avena fatua* (18–24%)	19	
Sorghum + sunflower[b]	Two, 30, 40			DW reduction in *Phalaris minor* (36–55%) and *Avena fatua* (42–62%)	53.5%	

[a] Two sprays, 6 L ha^{-1} each.
[b] Two sprays, 12 L ha^{-1} each.

[*Echinochloa crus-galli* (L.) Beauv] population; however, velvet bean was the best cover crop for weed control.[59] Likewise, barley (*Hordeum vulgare* L.) grown as a cover crop for weed control in soybean suppressed weeds such as crabgrass [*Digitaria ciliaris* (Retz.) Koel.] and barnyardgrass.[60] The smothering effects of velvet bean, jack bean and hyacinth bean (*Lablab purpureus* L.) effectively controlled mission grass [*Pennisetum polystachion* (L.) Schult.], a troublesome weed in rubber plantations.[61]

Spiderlily (*Lycoris radiate* L.) is used as a ground cover crop to suppress weeds or is incorporated into soil as mulch. Dead leaves of spiderlily contain the allelochemical lycorine (0.08%) which inhibits emergence and reduces root and shoot growth and root dry weight of rice weeds.[62] Among leaf extracts of 71 plant species, lettuce (*Lactuca sativa* L.) growth was suppressed by most cover crops including trefoil [*Oxalis brasiliensis* Lodd. ex Knowl. & West.), star-of-Bethlehem (*Ornithogalum umbellatum* L.), moss pink (*Phlox subulata* L.), European pennyroyal (*Mentha pulegium* L.), red spiderlily [*Lycoris radiate* (L. Herit.) Herb], creeping thyme (*Thymus serpyllum* L.) and roman chamomile (*Chamaemelum nobile* L.). Trefoil, red spiderlily, moss pink, trefoil and creeping thyme leached in agar reduced the radicle length of weed species by 8–31, 14–24, 11–43, 31–74 and 22–67%, respectively, of the untreated control.[63]

Cover crops incorporated into soil as green manure can delay planting and emergence owing to excess soil moisture, have phytotoxic effects on major crops and increase nitrogen immobilisation.[64] This can, however, be avoided through the adoption of good management practices and by optimising and integrating cover crops in a cropping system.[65]

2.3 Mulching

Mulch is spread over the soil surface to suppress weeds, among other strategies. Mulches obstruct seed germination of weeds and inhibit weed seedling growth through the release of allelochemicals.[66,67] Established weeds, however, are difficult to control with mulches. In addition to weed suppression, use of allelopathic crop residues as surface mulch benefits agricultural sustainability by adding organic matter to soil, conserving soil moisture, improving water infiltration into soil, decreasing the impact of raindrops on soil, modifying/regulating soil temperature, enhancing biological activities in soil and controlling soil erosion.[68–70]

Allelopathic plant mulches applied to rice fields at 1–2 t ha^{-1} suppressed noxious paddy weeds such as barnyardgrass, purple nutsedge (*Cyperus rotundus* L.), flat sedge (*C. difformis* L.) and jungle rice [*Echinochloa colonum* (L.) Link.] by more than 70% and increased paddy yield by 20%.[71] Soils amended with olive wastes (10 cm deep) suppressed weed species including annual meadow grass (*Poa annua* L.), common chickweed (*Stellaria media* L.), shepherd's purse (*Capsella bursa-pastoris* L.), German chamomile [*Matricaria chamomilla* (L.) Rydb.] and henbit deadnettle (*Lamium amplexicaule* L.) in crops such as sunflower (*Helianthus annuus* L.), wheat and maize.[72] Surface mulch of purple passionfruit (*Passiflora edulis* L.) applied at 2 t ha^{-1} in paddy fields reduced the population of barnyardgrass and monochoria (*Monochoria vaginalis* L.) weeds and increased rice yields by 35% compared with the control, while ten allelochemicals from coumarins, long-chain fatty acids and lactones were discovered.[73] Rice hull and bran were also effective in controlling paddy weed when applied at 1 t ha^{-1}.[74] Likewise, the release of phytotoxic substances from alfalfa plant parts after decomposition was inhibitory to troublesome weeds such as barnyardgrass and monochoria.[75] Wheat residues as soil cover reduced weed density and dry weight while conserving soil moisture.[67] Amending soil with 1–2 t ha^{-1} of mint marigold (*Tagetes minuta* L.), a medicinal plant, suppressed problematic rice weeds – barnyardgrass and purple nutsedge – while leaf and root powder of Indian catmint [*Anisomeles indica* (L.) Kuntze] applied as mulch in wheat fields significantly reduced density and dry mass of littleseed canarygrass (*Phalaris minor* Ritz.) and improved plant height, tillering dry matter and grain yield.[76,77]

Teasdale and Mohler[66] reported quantitative relationships between emergence and mulch properties with mulches such as maize stalks, rye (*Secale cereale* L.), crimson clover (*T. incarnatum* L.), hairy vetch (*Vicia villosa* Roth), *Quercus* leaves and landscape fabric strips. The sensitivity of weed species to mulch was in the order: common tumble weed (*Amaranthus retroflexus* L.) > lambsquarters (*Chenopodium album* L.) > giant foxtail (*Setaria faberi* Herrm.) > velvetleaf [(*Abutilon theophrasti* (L.) Rusby)], regardless of mulch material. Another study by Gruber *et al.*[78] determined the effect of wood chips [0 (control), 80 and 160 m^3 ha^{-1} annually] derived from hedgerow and tree mulch on weeds of organically grown wheat. Wood chip mulch effectively suppressed weeds in the field, while their allelopathic potential in the laboratory reduced germination rates in oilseed rape (*Brassica napus* L.), blackgrass (*Alopecurus myosuroides* Huds) and field poppy (*Papaver rhoeas* L.). Wood chips also improved organic matter, nutrient levels and water storage capabilities of the soil.

2.4 Allelopathic water extracts

Water-soluble secondary metabolites or allelochemicals present in the plant tissues are extracted in water to use them for pest management.[10] Water extracts can be used as a medium for the expression of allelochemical activity to depress the growth of other organisms.[10,11] Several researchers have suggested the use of allelochemicals extracted in water for weed suppression in the laboratory and also application under field conditions.[27,31,32] Jabran *et al.*[31,32] and Jamil *et al.*[38] described the utilisation of allelopathic water extract as an important and useful way of exploiting the allelopathic potential of crop plants to manage weeds. Water extracts of mature sorghum plants substantially reduced the weed population and biomass.[79,80]

In wheat, application of sorghum water extracts at various rates and frequencies has been found to reduce weed growth and density, with a simultaneous increase in grain yield.[79,80] Application of sorghum water extract 30 and 60 days after sowing reduced the weed biomass and density by 49 and 44% respectively (Table 2), with increase in grain yield (21%), when applied at 1 : 10 w/v ratio.[80] Nevertheless, single and multiple application of allelopathic extracts provided similar levels of weed supreesion and yield increase.[80] Application of sorghum water extract substantially reduced the population of lambsquarters (*C. album*), lesser swinecress (*Coronopus didymus* L.), toothed dock (*Rumex dentatus* L.) and Indian fumitory (*Fumaria perviflora* Lam.) when applied at 10 and 50% concentration. In this regard, maximum application of 10% sorghum water extract at 60 DAS provided the better control, with 53 and 36% reduction in weed biomass and population respectively, and with a yield increase of 14%.[79] In another study, application of sorghum water extract (one and two sprays) significantly reduced the lambsquarters, littleseed canarygrass, wild oat (*Avena fatua* L.), field bindweed (*Convolvulus arvensis* L.) and toothed dock density by 22–39%, but the density and biomass of sweet clover either increased or remained unchanged.[81] In another experiment, single and double applications of sorghum water extract increased the wheat grain yield by 13.5 and 18.6% compared with the control. This increase in grain yield was attributed to allelopathic supression of weeds.[82]

In a range of field crops, however, the sole application of sorghum water extract had the desired level of weed control. For instance, application of sorghum water extract suppressed weeds by 35–49, 40, 37–41, 18–50 and 44% in wheat,[81] cotton (*Gossypium hirsutum* L.),[83] rice,[84] maize,[85] canola (*Brassica campestris* L.)[31,45] and mungbean (*Vigna radiata* L.)[86] respectively. Duke and Lydon[87] reported synergism of allelochemicals from different plant extracts. Actually, the bioavailability and phytotoxicity of the allelochemicals existing in mixtures are enhanced by interactions among them. For example, the persistence of phenolic acids after decomposition of *Centaurea maculosa* was more prolonged for compounds in mixtures than for the single compounds.[88,89] Cheema *et al.*[90] tested the idea with the application of sorghum mixed with sunflower and eucalyptus (*Eucalyptus camaldulensis* L.) water extracts. Interestingly, mixed application of sorghum, sunflower and eucalyptus water extracts was more effective for weed control in wheat compared with the sole application of sorghum water extract (Table 2).[90] Taking it further, Jamil *et al.*[38] applied sorghum water extract alone and in combination with sesame (*Sesamum indicum* L.), tobacco (*Nicotiana tobaccum* L.), eucalyptus, sunflower and brassica (*B. compestris* L.) for controlling wild oat (*A. fatua*) and little seed canary grass in wheat. Application of sunflower and sorghum extracts (each at 12 L ha^{-1}) was more effective than others as it reduced little seed canary grass and wild oat biomass by 36–55 and 42–62% respectively (Table 2). Application of sorghum and sunflower extracts at 6 L ha^{-1} each increased wheat grain yield by 89% in the first year and by 35% in the second year of experimentation over weedy check.[38]

2.5 Combined effect of allelopathic water extracts and herbicides

Substantial scope exists to reduce the herbicide rate if applied together with allelopathic water extracts. For weed control in wheat, for example, when applied in combination with sorghum water extract (12 L ha^{-1}), the rate of isoproturon application was decreased by 50–60% (Table 3).[91,92] In studies on weed management in cotton and maize, at sowing, a half-dose application of atrazine (150 g ha^{-1}) in combination with sorghum water extract (at 12 L ha^{-1}) controlled weeds, paralleling a full dose (Table 3).[83,93] These authors further observed that the combined application of sorghum water extract (at 12 L ha^{-1}) and pendimethalin at one-third of the standard dose produced more seed cotton yield than the full dose, even though weed supression was relatively less. In another study, weed suppression from the combined application of sorghum extract and reduced herbicide dose (400 g ha^{-1}) and a full dose of isoproturon (1 kg ha^{-1}) was similar during the first year.[91]

Recent field studies evaluated allelopathic suppression of weeds in a canola field using crop water extracts – sorghum, sunflower, brassica and rice – applied in combination with reduced doses of pendimethalin (one-third and half the recommended dose).[31,45] Crop water extracts at 15 L ha^{-1} each combined with pendimethalin at 400 and 600 g ha^{-1} were sprayed immediately after sowing, while the standard dose of pendimethalin was taken as control. Application of rice and sorghum water extracts in combination with a half-dose of pendimethalin suppressed the total weed population the most – by 67.58 and 66.21% at 40 and 60 DAS respectively. All treatments reduced total weed dry weight by more than 80% at 40 DAS, while at 60 DAS the reductions ranged from 44.93 to 63.99%. Plots treated with sorghum and sunflower water extracts + 600 g ha^{-1} pendimethalin recorded maximum seed yields of 2.6 Mg ha^{-1}, which was 39.99% more than the control. The authors concluded that 50–67% less herbicide combined with allelopathic water extracts may be effective for weed control and increase yields in canola.[31,45]

3 INSECT PEST MANAGEMENT

Extensive use of synthetic insecticides usually has negative effects on the environment and on human and animal health and, most critically, develops resistance among insects.[94–96] Scientists are therefore turning towards natural insect suppressants.[12,27,97,98] Neem (*Azadirachta indica* L.) seed oil exhibits antifeedant properties against nymphs and adults of strawberry aphids [*Chaetosiphon fragaefolii* (Cockerell)],[99] while azadrichtin, an allelochemical from neem plant parts, effectively inhibits insects including green cicadellid [*Jacobiasca lybica* (Bergevin and Zanon)], whitefly [*Bemisia tabaci* (Gennadius)] and *Ashbya gossypii* Guill.[97] Conifer plantations treated with neem oil deter feeding activity of large pine weevil (*Hylobius abietis* L.) for 3 months. Sitka spruce [*Picea sitchensis* (Bong.)] seedlings without neem oil treatment were killed by the feeding weevil, while those treated with neem oil (30 cm above the root collar) were not affected; azadirachtin, nimbin and salannin are the allelochemicals identified in neem oil.[100]

Similarly, Ding *et al.*[101] noted resistance in some wheat cultivars against wheat midge [*Sitodiplosis mosellana* (Géhin)], possibly owing to phenolics production – ferulic acid and *p*-coumaric acid. Ferulic acid killed hatched larvae when the concentration was above 0.35 mg g^{-1} of fresh plant tissue. Decomposing residues of cover crops improved soil nutrient status and released allelochemicals that deter plant pests, particularly soil-borne disease pathogens.[56,102]

Exposure to volatile oils from eucalyptus (*Eucalyptus globulus* L.) during larval periods of rice moth (*Corcyra cephalonica* St) severely affected post-embryonic development and adult emergence (Table 4).[103] Common rue (*Ruta graveolens* L.), a scented plant containing the allelochemicals coumarins and flavanoides, has the potential to suppress Mediterranean fruit fly [*Ceratitis capitata* (Wiedemann)] and mosquito (*Culex pipiens* L.) larvae. Jabran *et al.*[27] evaluated the effectiveness of allelopathic water extracts of sorghum, mustard and sunflower, along with combinations of sorghum and mulberry (*Morus alba* L.) and sorghum and sunflower, for controlling aphids and sucking insects of *Brassica* spp. Sorghum water extracts were most effective (62.5% aphid mortality) at a concentration of 8%, and sunflower water extracts (16% concentration) resulted in 52.5% aphid mortality. Combination water extracts (16%) of sorghum and mulberry resulted in 45.7% aphid mortality, and sorghum and sunflower had 57.5% mortality.

Mortality in mosquito larvae was 50 and 100% when treated with leachates at 1 and 2% w/v. Absolute mortality of medfly eggs, delay in metamorphosis of first-instar larvae for 2 days, failure of pupae to produce adults and a 26% reduction in pupal population resulted when 10% extract was mixed in the artificial diet.[104]

Ethanol extracts from leaves of California pepper tree (*Schinus molle* L.) imparted insecticidal effects on adults of the elm leaf beetle (*Xanthogaleruca luteola* Müller.) by killing more than 97% of the population at concentrations of 4.3 and 4.7% w/v, while their water extract exhibited complete inhibition of feeding activity of the insect pest.[105] Kong[98] reviewed the allelopathic activity of three weeds including great ragweed (*Ambrosia trifida* L.), chick weed (*Ageratum conyzoides* L.) and Spanish flag (*Lantana*

Table 3. Combined application of allelopathic water extracts and reduced herbicide doses for weed suppression in field crops

				Weed control (%)		Yield increase (%)		
Allelopathic extract	Herbicide	Crop	Weed species	Standard herbicide	Herbicide (1/2 dose) + allelopathic extract	Standard herbicide	Herbicide (1/2 dose) + allelopathic extract	Reference
Sorghum + brassica (15 L ha^{-1} each)	Pendimethalin (1.2 kg a.i. ha^{-1})	Canola	*Trianthema portulacastrum* L.	100% reduction in density and DW	Reduction in density (91.3%) and DW (94.18%)	35.99	39.99	Jabran *et al.*[31,45]
			Cyperus rotundus L.	Reduction in density (32.2%) and DW (6.34%)	Reduction in density (42.82%) and DW (37.46%)			
			Chenopodium album L.	Reduction in density (78.37%) and DW (83.07%)	Reduction in density (74.27%) and DW (62.2%)			
			Coronopus didymus (L.) Sm.	Reduction in density (39.39%) and DW (37.25%)	Reduction in density (66.09%) and DW (70.45%)			
Sorghum	Isoproturon	Wheat	*Phalaris minor* Ritz.,	Reduction in total weed density (94.10%) and DW (78.52%)	Reduction in total weed density (94.25%) and DW (64.82%)	33.87	32.25	Cheema *et al.*[91]
(12 L ha^{-1})	(1 kg a.i. ha^{-1})		*Melilotus parviflora* Desf., *Coronopus didymus* (L.) Sm.					
Sorghum + sunflower	Pendimethalin	Sunflower	*Chenopodium album* L.,	Reduction in total weed density (95%) and DW (86%)	Reduction in total weed density (84%) and DW (67.26%)	19	16.44	Awan *et al.*[128]
(15 L ha^{-1} each)	(825 mL ha^{-1})[a]		*Melitotus indica* L.					
Sorghum	S. metolachlor	Cotton	*Cyperus rotundus* L.	Reduction in weed density (82%) and DW (86%)	77% reduction in both weed density and DW	33.85	31.57	Iqbal and Cheema[129]
(12 L ha^{-1})	(2.15 kg a.i. ha^{-1})							
Sorghum	Pendimethalin	Cotton	*Cyperus* rotundus L.	Reduction in weed density (34.78) and DW (50.98%)	Reduction in weed density (39.13%) and DW (37.25%)	19.96	7.97	Iqbal *et al.*[83]
(10 L ha^{-1})	(1 kg a.i. ha^{-1})							
			Trianthema portulacastrum L.	Reduction in weed density (50.54%) and DW (70.08%)	Reduction in weed density (51.92%) and DW (50.31%)			
	S. metolachlor		*Cyperus rotundus* L.	Reduction in weed density (52.17%) and DW (61.41%)	Reduction in weed density (47.82%) and DW (62.82%)	18.14	3.52	
	(2 kg a.i. ha^{-1})							
			Trianthema portulacastrum L.	Reduction in weed density (53.84%) and DW (56.91%)	Reduction in weed density (53.85%) and DW (56.60%)			

[a] As Stomp 330E.

Table 4. Allelopathic suppression of insect pests

Allelopathic source	Application rate/mode	Insect suppression	Reference
NeemAzal-T/S®	20 g a.i. ha^{-1}	91.88% mortality of *Jacobiasca lybica* (Berg. and Zanon) nymphs	El Shafie and Basedow[97]
California pepper tree (*Schinus molle* Rev L.)	Ethanol extract (4.7% w/v)	91.77% mortality of elm leaf beetle (*Xanthogaleruca luteola* Müller)	Huerta *et al.*[105]
	Water extract (5.6% w/v)	27.78% mortality of elm leaf beetle (*Xanthogaleruca luteola* Müller)	
Fig-leaf goosefoot (*Chenopodium ficifolium* Sm.)	Ethanol extract (5000 mg mL^{-1})	86% control of aphid (*Aphis gossypii* Glover)	Dang *et al.*[130]
	Methanol extract (5000 mg mL^{-1})	83% control of aphid (*Aphis gossypii* Glover)	
	n-Hexane extract (5000 mg mL^{-1})	54% control of aphid (*Aphis gossypii* Glover)	
	Acetone extract (5000 mg mL^{-1})	47% control of aphid (*Aphis gossypii* Glover)	
Eucalyptus (*Eucalyptus camaldulensis* L.)	Oil volatiles	Reduction in male (78%) and female (66.67%) adults of *Corcyra cephalonica* St	Pathak and Krishna[103]
Neem (*Azadirachta indica* L.)	Oil volatiles	Reduction in male (26%) adults of *Corcyra cephalonica*, St	
Birbira (*Milletia ferruginea* Hochst.)	Seed crude extract	93–100% mortality of adult *Macrotermes* termites	Jembere *et al.*[131]
		45–60% mortality of sorghum chaffer (*Pachnoda interrupta* Oliver)	
Neem	Seed kernels water extract (2%)	Reduction in flower thrip (*Taeniothrips sjostedti* Trybom) (54%) and pod borer (*Heliothis armigera* Hb.) (32%) incidence	Hongo and Karel[132]
	Leaf water extract (4%)	Reduction in flower thrip (*Taeniothrips sjostedti* Trybom) (45%) and pod borer (*Heliothis armigera* Hb.) (24%) incidence	
Tomato (*Lycopersicon esculentum* L.)	Leaf water extract (4%)	Reduction in flower thrip (*Taeniothrips sjostedti* Trybom) (32%) and pod borer (*Heliothis armigera* Hb.) (12%) incidence	
Hot pepper (*Capsicum unnuum* L.)	Fruit water extract (2%)	Reduction in flower thrip (*Taeniothrips sjostedti* Trybom) (54%) and pod borer (*Heliothis armigera* Hb.) (31%) incidence	

Table 5. Allelopathic suppression of pathogens, nematodes and diseases

Allelopathic source	Application mode/rate	Pathogen/disease suppression	Reference
Barley (*Hordeum vulgare* L.) + potato	Grown in rotation	55.1% reduction in inoculum intensity of *Rhizoctonia solani* (JG Kühn)	Larkin and Griffin[133]
Turnip (*Brassica rapa* L.) + potato	Grown in rotation	56.2% reduction in inoculum intensity of *Rhizoctonia solani*(JG Kühn)	
Indian mustard (*Brassica juncea* L.) + potato	Grown in rotation	45.5% reduction in inoculum intensity of *Rhizoctonia solani*(JG Kühn)	
Rice (*Oryza sativa* L.)	Root exudates (1.5 mL)	37% reduction in germination of *Fusarium oxysporum* f. sp. *Niveum* spores	Ren *et al.*[134]
Rice	Root exudates (20 mL)	71.88% reduction in spore reproduction of *Fusarium oxysporum* f. sp. *Niveum*	
Neem (*Azadirachta indica* L.)	Leaf water extract (20% w/v)	53.22% reduction in the growth of *Fusarium solani* f. sp. melongenae	Joseph *et al.*[135]
Sweet wormwood (*Artemisia annua* L.)	Leaf water extract (20% w/v)	42.20% reduction in the growth of *Fusarium solani* f. sp. melongenae	
Eucalyptus (*Eucalyptus globulus* Labill)	Leaf water extract (20% w/v)	46.76% reduction in the growth of *Fusarium solani* f. sp. melongenae	
Tulsi (*Ocimum sanctum* L.)	Leaf water extract (20% w/v)	43.98% reduction in the growth of *Fusarium solani* f. sp. melongenae	
Rhubarb (*Rheum emodi* Wall)	Leaf water extract (20% w/v)	37.19% reduction in the growth of *Fusarium solani* f. sp. melongenae	
Neem (*Azadirachta indica* L.) cake	3% (w/w)	61.03% reduction in root-knot nematode (*Meloidogyne javanica*) females per root	Javed *et al.*[110]
Neem cake	3% (w/w)	63.7% reduction in root-knot nematode egg masses per root	
Neem leaves	3% (w/w)	38.3% reduction in root-knot nematode females per root	
Neem leaves	3% (w/w)	60.34% reduction in root-knot nematode egg masses per root	

camara L.) against insect pest and other pests. These weed species possessed allelochemicals that were not only inhibitory to insects such as cowpea weevil [*Callosbruchus maculatus* (Fabricius)] but also effective in controlling weeds and diseases.

4 DISEASE MANAGEMENT

Plant disease is a serious issue causing detrimental effects on many crops including cereals, oilseeds, etc., and especially vegetables. A number of soil-borne diseases cause substantial losses to crop production by disturbing the crop stand and lowering product quality. Although cultural practices such as burning infected plant debris and using resistant cultivars have long been used, diseases still cause abundant losses in crop yields. Chemical disease control for most diseases is either unavailable or ineffective. Plant pathogens can be suppressed using allelopathic crops in different ways.

Intercropping creates a microclimate, which is helpful for reducing disease intensity.[106] Sugi [*Cryptomeria japonica* (L. f.) D. Don] bark has inhibitory effects against diseases causing root infections in tomato (*Lycopersicon esculentum* L.).[107] Root exudates from Chinese chive (*Allium tuberosum* L.) inhibit multiplication of bacterial wilt (*Pseudomonas solanacearum* Smith). When intercropped with tomato, Chinese chive suppressed bacterial wilt while having no negative effect on the tomato.[108] Certain volatile allelochemicals are exuded from aerial parts of marigold (*Tagetes erecta* L.). When intercropped with tomato, marigold suppressed tomato early blight disease caused by *Alternaria solani* (Ell. and Mart.) Jones and Grout. by more than 90%.[107] Bacterial wilt of tomato (*Ps. solanacearum*) has been well controlled by intercropping tomato with cowpea.[109]

Neem leaves or neem cakes applied to soil have long-term effects (for 16 weeks) on the development of root-knot nematodes [*Meloidogyne javanica* (Treub.) Chitwood] (Table 5).[110] *Brassica* spp. produce volatile sulfur compounds (glucosinolates) in the soil microenvironment, which are converted to isothiocyanates through biofumigation to suppress soil organisms. These compounds can reduce fungal pathogens[111] and nematodes in the soil.

Huang *et al.*[112] evaluated the potential of wheat, barley, oat, rye, canola, sweet clover and lentil (*Lens culinaris* L.) water extracts (1, 2 or 4% w/v) in suppressing the lesion development of *Sclerotinia sclerotiorum* (Lib.), the germination of ascospores and the carpogenic germination of sclerotia on detached bean leaves. Application of 1% extract of canola, 2% extracts of barley, canola, oat and lentil and 4% extracts of all seven crops substantially reduced sclerotia germination compared with the water control. However, 1, 2 and 4% extracts of barley and 1 and 4% extracts of oat suppressed ascospore germination, while these concentrations of sweet clover, wheat, canola, lentil and rye extracts promoted ascospore germination. Inoculation of detached bean leaves with ascospores of *S. sclerotiorum* mixed with 4% crop extracts of barley, oat or sweet clover significantly reduced the lesion severity index compared with leaves inoculated with water + *S. sclerotiorum*. Inoculation with 4% wheat extract significantly increased the lesion severity index. Fukuta *et al.*[113] evaluated the comparative *in vitro* antibacterial, fungicidal, antioxidant and herbicidal activities of momilactone A and B. Momilactone B had higher antifungal, antibacterial and herbicidal action than momilactone A, although its antioxidant property was less than that of momilactone A.

Hashem *et al.*[114] evaluated basil (*Ocimum basilicum* L.), cumin (*Cuminum cyminum* L.) and rose geranium (*Pelargonium graveolens* L.) oil against root rot disease in cumin (*Cuminum cyminum*

L.), caused by Fusarium spp., and found these oils to be inhibitory to *Fusarium oxysporum, F. moniliforme, F. solani, F. lateritium, F. equiseti* and *F. dimerum*. Under *in vitro* greenhouse and field conditions, seed and soil treatment with basil, cumin and rose geranium oil was effective not only in decreasing root rot disease but also in improving growth parameters such as fresh weight, plant height, branch numbers, etc. Similarly, extract of seaweed at 0.3% concentration applied on sorghum seeds was effective in suppressing pathogens including *Bipolaris sorghicola, Fusarium verticilloides, Trichothecium roseum, F. solani, Curvularia lunata, Cladosporium cladosporioides, Alternaria alternata, A. strictum, F. oxysporum, Aspergillus flavipes*, etc., and improving the activity of defence enzymes including peroxidase, β-1,3-glucanase, phenylalanine ammonia lyase and chitinase activity.[115] The seed meal Ethiopian mustard (*Brassica carinata* L.) in the form of a commercial product at 2.5 t ha^{-1} was effective in reducing root-knot nematode (*Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley) incidence in potato (*Solanum tuberosum* L.) and increasing yield of potato.[116]

Two allelochemicals from rice, 5,7,40-trihydroxy-30,50-dimethoxyflavone (a flavone) and 3-isopropyl-5-acetoxycyclohexene-2-one-1 (a cyclohexenone), inhibited two fungal pathogens [*Rhizoctonia solani* Kühn and *Pyricularia oryzae* (Cavara)] by suppressing the germination of spores, and were suggested to be a part of the defence mechanism of rice against weeds and diseases.[117] A similar case was observed for insect populations where their prevalance was higher in lower plant diversity.[118]

5 CONCLUSION

Many plants, in particular rice, sunflower, sorghum, wheat, eucalyptus, mulberry, billy goat weed, white tephrosia, kablingparang, mexican marigold, neem, california pepper, etc., have strong allelopathic potential, which may be used for managing weeds, insect pests and diseases effectively. Nonetheless, special care is required in this regard to avoid any detrimental impact of the allelopathic phenomenon on agricultural systems.

An allelopathic crop has the potential to control weeds when planted in rotational sequence or used as a smother crop or mulch, especially in conservation cropping systems. Moreover, the combined application of synthetic herbicides (at reduced rates) and allelopathic extracts may give as effective a control as is obtained from the standard dose of herbicides. Interactions among potential allelopathic plants, target pests and other non-target organisms also need to be considered.[136] Allelochemistry may be employed to obtain the basic templates for developing new synthetic herbicides.[136]

REFERENCES

1 Torres A, Oliva RM, Castellano D and Cross P, *Proc First World Congress on Allelopathy – A Science for the Future*, 16–20 September 1996, Cádiz, Spain (1996).

2 Rizvi SJH, Haque H, Singh VK and Rizvi V, A discipline called allelopathy, in *Allelopathy: Basic and Applied Aspects*, ed. by Rizvi SJH and Rizvi V. Chapman and Hall, London, UK, pp. 1–10 (1992).

3 Lux-Endrich A and Hock B, Allelopathy, in *Plant Toxicology*, ed. by Hock B and Elstner EF. CRC Press, New York, NY (2004).

4 Wills RJ, *The History of Allelopathy*. Springer, Dordrecht, The Netherlands (2007).

5 Theophrastus, *Enquiry into Plants*, translated by Hort AF. Loeb Classical, Harvard University Press, Cambridge, MA (1980).

6 Pliny S, *Naturalis History*, translated by Rackman H, Eichholz DE and Jones WHS. Loeb Classic Library, Harvard University Press, Cambridge, MA/London, UK (1938–1963).

7 De Candolle MAP, *Physiologie Vegetale, Tomme III*. Bechet Jeune, Lib., Fac. Med., Paris, France, pp. 1474–1475 (1832).

8 Molísch H, *Der Einfluss einer Pfalnze auf die Andere-allelopathie*. Fischer, Jena, Germany (1937).

9 Rice EL, *Allelopathy*. Academic Press, Orlando, FL (1984).

10 Bonanomi G, Sicurezza MG, Caporaso S, Esposito A and Mazzoleni S, Phytotoxicity dynamics of decaying plant materials. *New Phytol* **169**:571–578 (2006).

11 Macías FA, Molinillo JM, Varela RM and Galindo JC, Allelopathy – a natural alternative for weed control. *Pest Manag Sci* **63**:327–348 (2007).

12 Dayan FE, Cantrell CL and Duke SO, Natural products in crop protection. *Bioorg Med Chem* **17**:4022–4034 (2009).

13 Zhu Y and Li QX, Movement of bromacil and hexazinone in soils of Hawaiian pineapple fields. *Chemosphere* **49**:669–674 (2002).

14 Roeleveld N and Bretveld R, The impact of pesticides on male fertility. *Curr Opin Obstet Gyn* **20**:229–233 (2008).

15 Khanh TD, Chung MI, Xuan TD and Tawata S, The exploitation of crop allelopathy in sustainable agricultural production. *J Agron Crop Sci* **191**:172–184 (2005).

16 Jabran K, Cheema ZA, Farooq M and Khaliq A, Evaluation of fertigation and foliar application of some fertilizers alone and in combination with allelopathic water extracts in wheat. *Proc International Workshop on Allelopathy – Current Trends and Future Applications*, 18–21 March 2007, University of Agriculture, Faisalabad, Pakistan, pp. 30 (2007).

17 Birkett MA, Chamberlain K, Hooper AM and Pickett JA, Does allelopathy offer real promise for practical weed management and for explaining rhizosphere interactions involving plants? *Plant Soil* **232**:31–39 (2001).

18 Shlevin E, ICM in practice with vegetable crops. *Abstracts of SCI Meeting on the Economic and Commercial Impact of Integrated Pest Management*, SCI, London, UK, pp. 37 (2000).

19 Oswald A, Ransom JK, Kroschel J and Sauerborn J, Suppression of Striga on maize with intercrops, in *Maize Production Technology for the Future: Challenges and Opportunities*, 6th Eastern and Southern African Regional Maize Conference, p. 27 (1998).

20 Khan ZR, Pickett JA, van den Berg J, Wadhams LJ and Woodcock CM, Exploiting chemical ecology and species diversity: stem borer and striga control for maize and sorghum in Africa. *Pest Manag Sci* **56**:957–962 (2000).

21 Hooper AM, Hassanali A, Chamberlain K, Khan Z and Pickett JA, New genetic opportunities from legume intercrops for controlling *Striga* spp. parasitic weeds. *Pest Manag Sci* **65**:546–552 (2009).

22 Azumi M, Abdullah MZ and Fujii Y, Exploratory study on allelopathic effect of selected Malaysian rice varieties and rice field weed species. *J Trop Agric Food Sci* **28**:39–54 (2000).

23 Fujii Y, Allelopathy in the natural and agricultural ecosystems and isolation of potent allelochemicals from velvet bean (*Mucuna pruriens*) and hairy vetch (*Vicia villosa*). *Biol Sci Space* **17**:6–13 (2003).

24 Judith CS, Lemley AT, Hogan SI, Weismiller RA and Hornsby AG, *Health Effects of Drinking Water Contaminants*. [Online]. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida (2001). Available: http://edis.ifas.ufl.edu/SS299 [15 September 2010].

25 Snelder DJ, Masipiqueña MD and de Snoo GR, Risk assessment of pesticide usage by smallholder farmers in the Cagayan Valley (Philippines). *Crop Prot* **27**:747–762 (2008).

26 McKinlay R, Plant JA, Bell JNB and Voulvoulis N, Calculating human exposure to endocrine disrupting pesticides via agricultural and non-agricultural exposure routes. *Sci Tot Environ* **398**:1–12 (2008).

27 Jabran K, Cheema ZA, Farooq M and Khaliq A, Evaluation of effectiveness of some allelopathic crop water extracts against aphid (*Aphis pomi*). *Proc International Workshop on Allelopathy – Current Trends and Future Aplications*, 18–21 March 2007, University of Agriculture, Faisalabad, Pakistan, pp. 31 (2007).

28 Cheema ZA, Mushtaq MN, Farooq M, Hussain A and Islamuddin S, Purple nutsedge management with allelopathic sorghum. *Allelop J* **23**:305–312 (2009).

29 Kordali S, Cakir A, Akcin TA, Mete E, Akcin A, Aydin T, *et al.*, Antifungal and herbicidal properties of essential oils and *n*-hexane extracts

of *Achillea gypsicola* Hub-Mor. and *Achillea biebersteinii* Afan. (Asteraceae). *Ind Crop Prod* **29**:562–570 (2009).

30 Rastogi RP and Sinha RP, Biotechnological and industrial significance of cyanobacterial secondary metabolites. *Biotechnol Adv* **27**:521–539 (2009).

31 Jabran K, Cheema ZA, Farooq M and Hussain M, Lower doses of pendimethalin mixed with allelopathic crop water extracts for weed management in canola (*Brassica napus*). *Internat J Agric Biol* **12**:335–340 (2010).

32 Jabran K, Farooq M, Hussain M, Rehman H and Ali MA, Wild oat (*Avena fatua* L.) and canary grass (*Phalaris minor* Ritz.) management through allelopathy. *J Plant Prot Res* **50**:32–35 (2010).

33 Roth CM, Shroyer JP and Paulsen GM, Allelopathy of sorghum on wheat under several tillage systems. *Agron J* **92**:885–860 (2000).

34 Papadopoulos A and Alderson P, A new method for collecting isothiocyanates released from plant residues incorporated in soil. *Ann Appl Biol* **151**:61–65 (2007).

35 Regnault-Roger C, Staff V, Philogène B, Terrón P and Vincent C, *Biopesticidas de Origen Vegetal*. Ediciones Mundi-Prensa, Madrid, Spain (2004).

36 Cloyd R, Natural instincts: are natural insecticides safer and better than conventional insecticides? *Am Nurseryman* **200**:41 (2004).

37 Field B, Jordán F and Osbourn A, First encounters – deployment of defence-related natural products by plants. *New Phytol* **172**:193–207 (2006).

38 Jamil M, Cheema ZA, Mushtaq MN, Farooq M and Cheema MA, Alternative control of wild oat and canary grass in wheat fields by allelopathic plant water extracts. *Agron Sustain Dev* **29**:475–482 (2009).

39 Bhowmik PC and Inderjit , Challenges and opportunities in implementing allelopathy for natural weed management. *Crop Prot* **22**:661–671 (2003).

40 Weston LA and Duke SO, Weed and crop allelopathy. *Crit Rev Plant Sci* **22**:367–389 (2003).

41 Singh HP, Batish DR and Kohli RK, Allelopathic interactions and allelochemicals: new possibilities for sustainable weed management. *Crit Rev Plant Sci* **22**:239–311 (2003).

42 Rizvi SJH, Tahir M, Rizvi V, Kohli RK and Ansari A, Allelopathic interactions in agroforestry systems. *Crit Rev Plant Sci* **18**:773–779 (1999).

43 Kruse M, Strandberg M and Strandberg B, Ecological effects of allelopathic plants – a review. NERI Technical Report No. 315, National Environmental Research Institute, Silkeborg, Denmark (2000).

44 Wu H, Pratley J, Lemerle D and Haig T, Crop cultivars with allelopathic capability. *Weed Res* **39**:171–180 (1999).

45 Jabran K, Cheema ZA, Farooq M, Basra SMA, Hussain M and Rehman H, Tank mixing of allelopathic crop water extracts with pendimethalin helps in the management of weeds in canola (*Brassica napus*) field. *Internat J Agric Biol* **10**:293–296 (2008).

46 Mamolos AP and Kalburtji KL, Significance of allelopathy in crop rotation. *J Crop Prod* **4**:197–218 (2001).

47 Narwal SS, Weed management in rice: wheat rotation by allelopathy. *Crit Rev Plant Sci* **19**:249–266 (2000).

48 Peters RD, Sturz AV, Carter MR and Sanderson JB, Developing disease-suppressive soils through crop rotation and tillage management practices. *Soil Tillage Res* **72**:181–192 (2003).

49 Voll E, Franchini JC, Tomazon R, Cruz D, Gazziero DL, Brighenti AM, *et al.*, Chemical interactions of *Brachiaria plantaginea* with *Commelina bengalensis* and *Acanthospermum hispidum* in soybean cropping systems. *J Chem Ecol* **30**:1467–1475 (2004).

50 Sauerborn JH, Sprich H and Mercer-Quarshie H, Crop rotation to improve agricultural production in Sub-Saharan Africa. *J Agron Crop Sci* **184**:67–72 (2000).

51 Einhellig FA and Rasmussen JA, Prior cropping with grain sorghum inhibits weeds. *J Chem Ecol* **15**:951–960 (1989).

52 Lins RD, Colquhoun JB and Mallory-Smith CA, Investigation of wheat as a trap crop for control of *Orobanche minor*. *Weed Res* **46**:313–318 (2006).

53 Brandsæter LO, Smeby T, Tronsmo AM and Netland J, Winter annual legumes for use as cover crops in row crops in northern regions: II. frost resistance study. *Crop Sci* **40**:175–181 (2000).

54 Hartwig NL and Ammon HU, Cover crops and living mulches. *Weed Sci* **50**:688–699 (2002).

55 Ekeleme F, Chikoye D and Akobundu IO, Changes in size and composition of weed communities during planted and natural fallows. *Basic Appl Ecol* **5**:25–33 (2004).

56 Gallandt ER and Haramoto ER, Brassica cover cropping for weed management: a review. *Renew Agric Food Syst* **19**:87–198 (2004).

57 Hiltbrunner J, Liedgens M, Bloch L, Stamp P and Streit B, Legume cover crops as living mulches for winter wheat: components of biomass and the control of weeds. *Eur J Agron* **26**:21–29 (2007).

58 Krambergera B, Gselmana A, Janzekovic M, Kaligaric M and Bracko B, Effects of cover crops on soil mineral nitrogen and on the yield and nitrogen content of maize. *Eur J Agron* **31**:103–109 (2009).

59 Caamal-Maldonado JA, Jimeńez-Osornio JJ, Torres-Barragań A and Anaya AL, The use of allelopathic legume cover and mulch species for weed control in cropping systems. *Agron J* **93**:27–36 (2001).

60 Kobayashi H, Miura S and Oyanagi A, Effects of winter barley as a cover crop on the weed vegetation in a no-tillage soybean. *Weed Biol Manag* **4**:195–205 (2004).

61 Kobayashi Y, Ito M and Suwanarak K, Evaluation of smothering effect of four legume covers on *Pennisetum polystachion* ssp. Setosum (Swartz) Brunken. *Weed Biol Manag* **3**:222–227 (2003).

62 Iqbal Z, Nasir H, Hiradate S and Fujii Y, Plant growth inhibitory activity of *Lycoris radiate* Herb. and the possible involvement of lycorine as an allelochemical. *Weed Biol Manag* **6**:221–227 (2006).

63 Shiraishi S, Watanabe I, Kuno K and Fujii Y, Allelopathic activity of leaching from dry leaves and exudate from roots of ground cover plants assayed on agar. *Weed Biol Manag* **2**:133–142 (2002).

64 Bradow JM, Inhibitions of cotton seedling growth by volatile ketones emitted by cover crop residues. *J Chem Ecol* **19**:1085–1108 (1993).

65 Caporali F, Campiglia E, Mancinelli R and Paolini R, Maize performances as influenced by winter cover crop green manuring. *Ital J Agron* **8**:37–45 (2004).

66 Teasdale JR and Mohler CL, The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Sci* **48**:385–392 (2000).

67 Bilalis D, Sidiras N, Economou G and Vakali C, Effect of different levels of wheat straw soil surface coverage on weed flora in *Vicia faba* crops. *J Agron Crop Sci* **189**:233–241 (2003).

68 Tiquia SM, Lloyd J, Herms DA, Hoitink HAJ and Michel FC, Jr, Effects of mulching and fertilization on soil nutrients, microbial activity and rhizosphere bacterial community structure determined by analysis of TRFLPs of PCR-amplified 16S rRNA genes. *Appl Soil Ecol* **2**:31–48 (2002).

69 Döring TF, Brandt M, Heß J, Finckh MR and Saucke H, Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. *Field Crop Res* **94**:238–249 (2005).

70 Ghosh PK, Dayal D, Bandyopadhyay KK and Mohanty M, Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. *Field Crops Res* **99**:76–86 (2006).

71 Xuan TD, Shinkichi T, Khanh TD and Min CI, Biological control of weeds and plant pathogens in paddy rice by exploiting plant allelopathy: an overview. *Crop Prot* **24**:197–206 (2005).

72 Boz Ö, Doğan MN and Albay F, Olive processing wastes for weed control. *Weed Res* **43**:439–443 (2003).

73 Khanh TD, Chung IM, Tawata S and Xuan TD, Weed suppression by *Passiflora edulis* and its potential allelochemicals. *Weed Res* **46**:296–303 (2006).

74 Xuan TD, Tsuzuki E, Terao H, Matsuo M, Khanh TD, Murayama S, *et al.*, Alfalfa, rice by-products and their incorporation for weed control in rice. *Weed Biology Manag* **3**:137–144 (2003).

75 Xuan TD, Tawata S, Khanh TD and Chung IM, Decomposition of allelopathic plants in soil. *J Agron Crop Sci* **191**:162–171 (2005).

76 Batish DR, Arora K, Singh HP and Kohli RK, Potential utilization of dried powder of tagetes minuta as a natural herbicide for managing rice weeds. *Crop Prot* **26**:566–571 (2007).

77 Batish DR, Kaura M, Singh HP and Kohli RK, Phytotoxicity of a medicinal plant, *Anisomeles indica*, against *Phalaris minor* and its potential use as natural herbicide in wheat fields. *Crop Prot* **26**:948–952 (2007).

78 Gruber S, Acharya D and Claupein W, Wood chips used for weed control in organic farming. *J Plant Dis Prot* **21**:395–400 (2008).

79 Cheema ZA, Luqman M and Khaliq A, Use of allelopathic extracts of sorghum and sunflower herbage for weed control in wheat. *J Animal Plant Sci* **7**:91–93 (1997).

80 Cheema ZA and Khaliq A, Use of sorghum allelopathic properties to control weeds in irrigated wheat in semi arid region of Punjab. *Agric Ecosyst Environ* **79**:105–112 (2000).

81 Cheema ZA, Iqbal M and Ahmad R, Response of wheat varieties and some Rabi weeds to allelopathic effects of sorghum water extract. *Internat J Agric Biol* **4**:52–55 (2002).

82 Cheema ZA, Khaliq A and Ali K, Efficacy of sorgaab for weed control in wheat grown at different fertility levels. *Pak J Weed Sci Res* **8**:33–38 (2002).

83 Iqbal J, Cheema ZA and Mushtaq MN, Allelopathic crop water extracts reduce the herbicide dose for weed control in cotton (*Gossypium hirsutum*). *Internat J Agric Biol* **11**:360–366 (2009).

84 Irshad A and Cheema ZA, Effect of sorghum extract on management of barnyardgrass in rice crop. *Allelop J* **14**:205–212 (2004).

85 Cheema ZA, Khaliq A and Saeed S, Weed control in maize (*Zea mays* L.) through sorghum allelopathy. *J Sustain Agric* **23**:73–86 (2004).

86 Cheema ZA, Khaliq A and Akhtar S, Use of sorgaab (sorghum water extract) as a natural weed inhibitor in spring mungbean. *Internat J Agric Biol* **3**:515–518 (2001).

87 Duke SO and Lydon J, Natural phytotoxins as herbicides, in *Pest Control with Enhanced Environmental Safety*, ed. by Duke SO, Menn JJ and Plimmer JR. *ACS Symposium Series* 524, American Chemical Society, Washington DC, pp. 111–121 (1993).

88 Tharayil N, Bhowmik PC and Xing B, Preferential sorption of phenolic phytotoxins to soil: implications for altering the availability of allelochemicals. *J Agric Food Chem* **54**:3033–3040 (2006).

89 Tharayil N, Bhowmik PC and Xing B, Bioavailability of allelochemicals as affected by companion compounds in soil matrices. *J Agric Food Chem* **56**:3706–3713 (2008).

90 Cheema ZA, Khaliq A and Mubeen M, Response of wheat and winter weeds to foliar application of different plant water extracts of sorghum (*Sorghum bicolor*). *Pak J Weed Sci Res* **9**:89–97 (2003).

91 Cheema ZA, Jaffer I and Khaliq A, Reducing isoproturon dose in combination with sorgaab for weed control in wheat. *Pak J Weed Sci Res* **9**:153–160 (2003).

92 Cheema ZA, Khaliq A and Farooq R, Effect of concentrated sorgaab in combination with herbicides and a surfactant in wheat. *J Animal Plant Sci* **13**:10–13 (2003).

93 Cheema ZA, Farid MS and Khaliq A, Efficacy of concentrated sorgaab in combination with low rates of atrazine for weed control in maize. *J Anim Plant Sci* **13**:48–51 (2003).

94 Wahid A, Editorial: Pesticides, environment and the developing world. *Res J Chem Environ* **8**:3–4 (2004).

95 Juraske R, Antón A, Castells F and Huijbregts MAJ, Pest screen: a screening approach for scoring and ranking pesticides by their environmental and toxicological concern. *Environ Inter* **33**:886–893 (2007).

96 Sukhoruchenko GI and Dolzhenko VI, Problems of resistance development in arthropod pests of agricultural crops in Russia. *EPPO Bull* **38**:119–126 (2008).

97 El Shafie HAF and Basedow T, The efficacy of different neem preparations for the control of insects damaging potatoes and eggplants in the Sudan. *Crop Prot* **22**:1015–1021 (2003).

98 Kong CH, Ecological pest management and control by using allelopathic weeds (*Ageratum conyzoides, Ambrosia trifida*, and *Lantana camara*) and their allelochemicals in China. *Weed Biol Manag* **10**:73–80 (2010).

99 Lowery DT and Isman MB, Antifeedant activity of extracts from neem, *Azadirachta indica*, to strawberry aphid, *Chaetosiphon fragaefolii*. *J Chem Ecol* **19**:1761–1773 (1993).

100 Thacker JRM, Bryan WJ, McGinley C, Heritage S and Strang RHC, Field and laboratory studies on the effects of neem (*Azadirachta indica*) oil on the feeding activity of the large pine weevil (*Hylobius abietis* L.) and implications for pest control in commercial conifer plantations. *Crop Prot* **22**:753–760 (2003).

101 Ding H, Lamb RJ and Ames N, Inducible production of phenolic acids in wheat and antibiotic resistance to *Sitodiplosis mosellana*. *J Chem Ecol* **26**:969–985 (2000).

102 Conklin AE, Erich MS, Liebman M, Lambert D, Gallandt ER and Halteman WA, Effects of red clover (*Trifolium pratense*) green manure and compost soil amendments on wild mustard (*Brassica kaber*) growth and incidence of disease. *Plant Soil* **238**:245–256 (2002).

103 Pathak PH and Krishna SS, Postembryonic development and reproduction in *Corcyra cephalonica* (Stainton) (*Lepidoptera: Pyralidae*) on exposure to eucalyptus and neem oil volatiles. *J Chem Ecol* **19**:2553–2558 (1991).

104 Aliotta G, Mallik AU and Pollio A, Historical examples of allelopathy and ethnobotany from the mediterranean region, in *Allelopathy in Sustainable Agriculture and Forestry*, ed. by Zeng RS, Malik AU and Luo SM. Springer, Dordrecht, The Netherlands, pp. 11–24 (2008).

105 Huerta A, Chiffelle I, Puga K, Azúa F and Araya JE, Toxicity and repellence of aqueous and ethanolic extracts from *Schinus molle* on elm leaf beetle *Xanthogaleruca luteola*. *Crop Prot* **29**:1118–1123 (2010).

106 Gómez-Rodríguez O, Zavaleta-Mejía E, González-Hernández VA, Livera-Muñoz M and Cárdenas-Soriano E, Allelopathy and microclimatic modification of intercropping with marigold on tomato early blight disease development. *Field Crops Res* **83**:27–34 (2003).

107 Yu JQ and Matsui Y, Effects of root exudates of cucumber (*Cucumis sativus*) and allelochemicals on ion uptake by cucumber seedlings. *J Chem Ecol* **23**:817–827 (1997).

108 Yu JQ, Allelopathic suppression of *Pseudomonas solanacearum* infection of tomato (*Lycopersicon esculentum*) in a tomato–Chinese chive (*Allium tuberosum*) intercropping system. *J Chem Ecol* **25**:2409–2417 (1999).

109 Michell VV, Wang JF, Midmore DJ and Hartman GL, Effects of intercropping and soil amendment with urea and calcium oxide on the incidence of bacterial wilt of tomato and survival of soil-borne *Pseudomonas solanacearum* in Taiwan. *Plant Pathol* **46**:600–610 (1997).

110 Javed N, Gowen SR, Inam-ul-Haq M, Abdullah K and Shahina F, Systemic and persistent effect of neem (*Azadirachta indica*) formulations against root-knot nematodes, *Meloidogyne javanica*, and their storage life. *Crop Prot* **26**:911–916 (2007).

111 Cohen MF, Yamasaki H and Mazzola M, *Brassica napus* seed meal soil amendment modifies microbial community structure, nitric oxide production and incidence of Rhizoctonia root rot. *Soil Biol Biochem* **37**:1215–1227 (2005).

112 Huang HC, Erickson RS and Moyer JR, Effect of crop extracts on carpogenic germination of sclerotia, germination of ascospores and lesion development of *Sclerotinia sclerotiorum*. *Allelop J* **20**:269–278 (2007).

113 Fukuta M, Xuan TD, Deba F, Tawata S, Khanh TD and Chung IM, Comparative efficacies *in vitro* of antibacterial, fungicidal, antioxidant, and herbicidal activities of momilatones A and B. *J Plant Inter* **2**:245–251 (2007).

114 Hashem M, Moharam AM, Zaied AA and Saleh FEM, Efficacy of essential oils in the control of cumin root rot disease caused by *Fusarium* spp. *Crop Prot* **29**:1111–1117 (2010).

115 Raghavendra VB, Lokesh S, Govindappa M and Kumar TV, Dravya – as an organic agent for the management of seed-borne fungi of sorghum and its role in the induction of defense enzymes. *Pestc Biochem Physiol* **89**:190–197 (2007).

116 Henderson DR, Riga E, Ramirez RA, Wilson J and Snyder WE, Mustard biofumigation disrupts biological control by *Steinernema* spp. Nematodes in the soil. *Biol Control* **48**:316–322 (2009).

117 Kong C, Liang W, Xu X, Hu F, Wang P and Jiang Y, Release and activity of allelochemicals from allelopathic rice seedlings. *J Agric Food Chem* **52**:2861–2865 (2004).

118 Haddad NM, Tilman D, Haarstad J, Ritchie M and Knops JMH, Contrasting effects of plant richness and composition on insect communities: a field experiment. *Am Nat* **158**:17–35 (2001).

119 Turk MA and Tawaha AM, Allelopathic effect of black mustard (*Brassica nigra* L.) on germination and growth of wild oat (*Avena fatua* L.). *Crop Prot* **22**:673–677 (2003).

120 Lin D, Tsuzuki E, Sugimoto Y, Dong Y, Matsuo M and Terao H, Assessment of dwarf lilyturf (*Ophiopogon japonicus* K.) dried powders for weed control in transplanted rice. *Crop Prot* **22**:431–435 (2003).

121 Xuan TD, Shinkichi T, Hong NH, Khanh TD and Min CI, Assessment of phytotoxic action of *Ageratum conyzoides* L. (billy goat weed) on weeds. *Crop Prot* **23**:915–922 (2004).

122 Hong NH, Xuan TD, Eiji T and Khanh TD, Paddy weed control by higher plants from Southeast Asia. *Crop Prot* **23**:255–261 (2004).

123 Nagabhushana GG, Worsham AD and Yenish JP, Allelopathic cover crops to reduce herbicide use in sustainable agricultural systems. *Allelop J* **8**:133–146 (2001).

124 Cheema ZA, Khaliq A and Tariq M, Evaluation of concentrated sorgaab alone and in combination with reduced rates of three pre-emergence herbicides for weed control in cotton (*Gossypium hirsutum* L.). *Internat J Agric Biol* **4**:549–552 (2002).

125 Cheema ZA, Khaliq A and Akhtar S, Use of sorgaab (sorghum water extract) as a natural weed inhibitor in spring mungbean. *Internat J Agric Biol* **3**:515–518 (2001).

126 Cheema ZA, Asim M and Khaliq A, Sorghum allelopathy for weed control in cotton (*Gossypium arboreum* L.). *Internat J Agric Biol* **2**:37–40 (2000).

127 Nawaz R, Ahmad R, Cheema ZA and Mehmood T, Effect of row spacing and sorgaab on sunflower and its weeds. *Internat J Agric Biol* **3**:360–362 (2001).

128 Awan IU, Khan MA, Zareef M and Khan EA, Weed management in sunflower with allelopathic water extract and reduced doses of a herbicide. *Pak J Weed Sci Res* **15**:19–30 (2009).

129 Iqbal J and Cheema ZA, Purple nutsedge (*Cyperus rotundus* L.) management in cotton with combined application of sorgaab and s-metolachlor. *Pak J Bot* **40**:2383–2391 (2008).

130 Dang QL, Lee GY, Choi YH, Choi GJ, Jang KS, Park MS, *et al.*, Insecticidal activities of crude extracts and phospholipids from *Chenopodium ficifolium* against melon and cotton aphid, *Aphis gossypii*. *Crop Prot* **29**:1124–1129 (2010).

131 Jembere B, Getahun D, Negash M and Seyoum E, Toxicity of birbira (*Milletia ferruginea*) seed crude extracts to some insect pests as compared to other botanical and synthetic insecticides. *Proc 11th NAPRECA Symposium*, 9–12 August 2005, Antananarivo, Madagascar, pp. 88–96 (2005).

132 Hongo H and Karel AK, Effect of plant extracts on insect pests of common beans. *J Appl Entomol* **102**:164–169 (1986).

133 Larkin RP and Griffin TS, Control of soilborne potato diseases using Brassica green manures. *Crop Prot* **26**:1067–1077 (2007).

134 Ren L, Su S, Yang X, Xu Y, Huang Q and Shen Q, Intercropping with aerobic rice suppressed *Fusarium* wilt in watermelon. *Soil Biol Biochem* **40**:834–844 (2008).

135 Joseph B, Dar MA and Kumar V, Bioefficacy of plant extracts to control *Fusarium solani* f. sp. melongenae incitant of brinjal wilt. *Global J Biotech Biochem* **3**:56–59 (2008).

136 Ferguson JJ and Rathinasabapathi B, Allelopathy: how plants suppress other plants. IFAS Extension, University of Florida, Gainesville, FL, HS944, pp. 1–3 (2009).