REVIEW ARTICLE Agricultural Reviews, Volume 41 Issue 4: 380-386 (December 2020)

Role of Allelopathy in Weed Management: A Review

A. Sathishkumar[1], G. Srinivasan[1], E. Subramanian[2], P. Rajesh[3]

10.18805/ag.R-2031

ABSTRACT

Allelopathy is the releasing of allelopathic compounds by one plant species that inhibit the growth and development of neighbouring plants of another species. Weeds, besides removing moisture and nutrients, harbour insects and diseases. Manual weed management practices are laborious and expensive. In spite of herbicides being effective in increasing yield, indiscriminate use of herbicides has resulted in serious ecological implications such as development of herbicide resistance weeds and shift in weed population. Recently, research attention has been focused to find out alternative strategies for chemical weed control in several crops. Reduction in herbicide use is one of major goals of modern agriculture and there is much emphasis in search for alternative weed management strategies that are cheap, safe and sustainable. Allelopathy is considered as an effective, economical and environment friendly weed management approach. The release of allelopathic compounds from leaves, flowers, seeds, stems and roots of living and decomposing plant materials can influence weed density and growth. Keeping this in view, the literatures on allelopathic effect of crops and trees on weeds are reviewed in this paper.

Key words: Allelopathy, Herbicides, Herbicide resistance, Weeds, Weed management.

The term allelopathy was coined by a plant physiologist Molisch (1937), consisting of two Greek words, *allelon* meaning 'mutual' and *pathos* meaning 'to suffer', harmful effects on each other (Chon and Nelson, 2012). Allelopathy is a natural ecological phenomenon in which different organisms affect the functioning of other organisms in their vicinity, negatively or positively (Rice, 1984). Allelopathy is the releasing of allelopathic compounds by one plant species that inhibit the growth and development of neighbouring plants of another species (Weston and Duke, 2003). The release of allelopathic compounds from leaves, flowers, seeds, stems and roots of living and decomposing plant materials can influence weed density and growth (Tesio and Ferrero, 2010). The allelopathic crops can be used as intercrops, mulches or water extracts (Fujii, 2003). Sorghum and sunflower are considered highly allelopathic crops, producing many allelopathic compounds like sorgoleone, glycosides, alkaloids, flavonoids, phenolics and terpenoids (Iqbal and Cheema, 2008).

Chemicals thus released, the allelochemicals, are mostly secondary metabolites, which are produced as by products during different physiological processes in plants (Farooq *et al*., 2011a and Bhadoria, 2011). Important secondary metabolites identified as allelochemicals are phenolics, alkaloids, flavonoids, terpenoids, momilactone, hydroxamic acids, brassinosteroids, jasmonates, salicylates, glucosinolates, carbohydrates and amino acids (Kruse *et al.,* 2000; Jabran and Farooq, 2012). Action of these compounds is concentration dependent (Einhellig, 1986) as they inhibit the plant growth at high concentrations and promote that at low concentrations (Narwal, 1994). These allelochemicals may thus be used as natural pesticides at high concentration (Farooq *et al.,* 2009b). Inhibitory role of allelochemicals is well explored and has been directly and indirectly used for weed management. A lot of research work has been done to explore the inhibitory potential of different allelopathic crops and trees for weed management (Farooq *et al.,* 2011b).

It is pragmatic substitute of synthetic herbicides as allelochemicals do not have residual or toxic effects (Bhadoria, 2011). This inhibitory feature is attributed to the blockage or cessation of important physiological and metabolic processes of plant. On the other hand, allelochemicals promote growth and impart resistance against several abiotic stresses (Farooq *et al*., 2009 a) at low concentrations. Only a few studies have been carried out to investigate the growth promotion by the allelochemicals. Application of water extracts of allelopathic compounds at lower concentrations stimulates germination and growth of different crops (Cheema *et al.,* 2012). Application of allelochemicals at low concentrations to crops can be a cost-effective and efficient way to promote growth and to enhance crop productivity (Oudhia *et al.,* 1988).

[1]Department of Agronomy, Agricultural College and Research Institute, Madurai-625 104, Tamil Nadu, India.
[2]Department of Farm Management, Agricultural College and Research Institute, Madurai-625 104, Tamil Nadu, India.
[3]Department of Crop Management, RVS Agricultural College, Thanjavur-613 402, Tamil Nadu, India.

Corresponding Author: A. Sathishkumar, Department of Agronomy, Agricultural College and Research Institute, Madurai-625 104, Tamil Nadu, India. Email: sathishkumar08668@gmail.com

How to cite this article: Sathishkumar, A., Srinivasan, G., Subramanian, E. and Rajesh, P. (2020). Role of Allelopathy in Weed Management: A Review. Agricultural Reviews. 41(4): 380-386.

Submitted: 10-06-2020 **Accepted:** 18-09-2020 **Published:** 26-11-2020

Releasing allelopathic compounds into the environment

Allelochemicals can be found in different concentrations in several parts of plants *viz.,* leaves, stems, roots, rhizomes, seeds, flowers and even pollen (Bertin *et al.,* 2003) and their pathway of release into the environment varies among species. The following are known pathways: (1) exudation and deposition on the leaf surface with subsequent washing off by rainfall; (2) exudation of volatile compounds from living green parts of the plant; (3) decay of plant residues (*e.g*. litterfall or dead roots) and (4) root exudation (Chon *et al.,* 2006). Different types of abiotic and biotic stress can alter the production and release of allelochemicals during the vital cycle of plants. Drought, irradiation, temperature, nutrient limitation, competitors, disease and damage from insects have been pointed out as factors that can cause an increased release of allelochemicals from allelopathic plants (Cseke and Kaufman, 2006).

Allelopathy and weed management

Weeds are the most stubborn competitors of crops causing substantial reduction in yield by sharing light, air, water, nutrients and space. Allelopathic water extracts have been successfully used for organic weed management. Allelochemicals are diverse in nature and structure and thus lack common mode of action. When applied at high concentrations, these allelochemicals interfere with the cell division, hormone biosynthesis and mineral uptake and transport (Rizvi *et al.*, 1992), membrane permeability (Harper and Balke, 1981), stomatal oscillations, photosynthesis (Einhellig and Rasmussen, 1979), respiration and protein metabolism (Kruse *et al.,* 2000) and plant water relations (Rice, 1984), which may cause substantial growth reduction. This phytotoxic activity of allelochemicals is responsible for growth suppression of weeds. Flavonoids and phenolics suppressed the germination and growth of several plants (Sadeghi *et al*., 2010). Allelochemicals reduce water and nutrients uptake by roots and inhibit photosynthesis, respiration, protein synthesis, cell division and thickness of seminal roots as well as cause slow maturation and delay or failure of reproduction (Jafariehyazdi and Javidfar, 2011).

Crops with allelopathic potential for weed control

sorghum

Allelopathic crops offer strong potential for the development of cultivars that are highly weed-suppressive. Allelopathic plants such as sorghum (Weston, 1996) and sunflower (Anjum and Bajwa, 2008) are inhibitory to weeds. Sorghum is one of the most widely used crop water extracts as natural herbicide. Sorghum contains several phytotoxins, namely gallic acid, protocateuic acid, syringic acid, vanillic acid, p-hydroxybenzoic acid, p-coumaric acid, benzoic acid, ferulic acid, m-coumaric acid, caffeic acids, p-hydroxybenzalde hyde and sorgoleone (Weston, 1996). 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 per cent or more of the root exudates (Netzly *et al.,* 1988). Sorgoleone is primarily an inhibitor of plant growth through inhibition of photosynthesis and respiration (Duke *et al*., 2007).

Mulches of sorghum or Sudan grass (Putnam and DeFrank, 1979) applied to apple orchards in early spring reduced weed biomass by 90 and 85 per cent, respectively. Sorgaab (Sorghum water extract) sprays and sorghum mulch treatments suppressed the total weed density by 13-54 per cent and 23-62 per cent, respectively. Forney *et al.* (1985) indicated sorghum as annual cover crop because of its rapid growth and ability to suppress weeds. 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 per cent and increased wheat yields by 7-8 per cent. Sorghum allelochemicals are species specific and concentration dependent in their effect (Cheema and Ahmad, 1992).

Two foliar sprays of sorgaab (Sorghum water extract) inhibited weed dry weight by 15-53 per cent and improved wheat yield by 14 per cent. The allelopathic potential of water extract of sorghum and sunflower against weeds in the field of wheat crop revealed that spray of 100 per cent water extracts of sorghum and sunflower at 30 DAS significantly reduced the total weed density up to 48 and 32 per cent and weed dry weight up to 51 per cent (Cheema *et al.,* 1997). Allelopathic properties of sorghum have been successfully used in suppressing weed growth and improving yield of crops such as wheat, maize and soybean with less cost (Ahmad, 1998; Khaliq *et al*., 1999). Concentrated sorgaab (sorghum water extract) controlled *Chenopodium album, Phalaris minor, Fumaria indica* and *Rumex dentatus* in wheat crop. It offered 15-47 per cent and 19-49 per cent reduction in weed density and dry weight, respectively. Soil incorporation of sorghum mulch suppressed the *Phalaris minor, Chenopodium album* and reduced the weed dry weight (48-56%) and increased the yield (16-17%) of wheat over the control (Cheema and Khaliq, 2000). Spray of sorgaab (sorghum water extract) on cotton crop suppressed weed density by 13-54 per cent and weed dry weight by 87%. The weed biomass was suppressed in sorgaab (sorghum water extract), sorghum mulch and in herbicidal treatments by 40, 56 and 87 per cent, respectively. The seed cotton yield increased by 69 per cent (over control) in two sorgaab foliar sprays and 59 per cent in sorghum mulching (Cheema *et al.,* 2000).

Pre emergence application of sorgabb at 15 L ha^{-1} + metalochlor 717 g a.i. ha^{-1} controlled the 62-92 per cent purple nutsedge and reduced the purple nutsedge dry weight by 75-88 per cent (Javid and Cheema, 2008). Soil incorporation of sorghum stalks at 2, 4 and 6 t ha^{-1} reduced

weed dry weight by 42, 48 and 56 per cent, respectively. Application of sorghum water extract in mungbean controlled *Cyperus rotundus, Chenopodium album, Convolvulusarvensis* and reduced the weed density (17.5-31.6%), weed dry weight (23.7-59.6%) and increased the yield (4.0-17.7%) compared to control (Cheema *et al.,* 2001). Combined application of sorghum water extracts + isoproturon controlled *Phalaris minor, Melilotus parviflora* and reduced the weed density (94.2%), weed dry weight (64.8%) and increased the yield (32.2%) of wheat over the control (Cheema *et al.,* 2002).

Application of sorghum water extract in cotton controlled the *Trianthema portulacastrum, Cynodon dactylon, Cyperus rotundus* and reduced the weed density (47.0 %), weed dry weight (29-40.1%) and increased the yield (17.7- 59.0%) over the control (Cheema *et al.,* 2002). Combined application of sorgaab with sunflower, *Eucalyptus*, sesame, *Brassica* and rice water extracts is more effective for weed management than the sole application of either water extract (Cheema *et al.,* 2003b). Sorghum, sunflower and *Eucalyptus* (Cheema *et al.,* 2003b); sesame, *Brassica* and rice (Rehman *et al.,* 2010) water extracts have effectively controlled the weeds by reducing herbicide dose up to half of recommended one.

Khaliq *et al.* (2002) observed that metolachlor at 1.15 kg ha^{-1}+ sorgaab at 10 L ha^{-1} and pendimethalin at 825 ml ha^{-1} reduced the dry weed biomass by 78 and 75 per cent, respectively. Cheema *et al.* (2003a) showed that sorgaab at 6 L ha^{-1} or 12 L ha^{-1} combined with fenoxaprop - p - ethyl at 375 ml ha^{-1} reduced the dry weed biomass by 87 per cent. The lower weed density, fresh weed biomass dry weed biomass and consequently the highest biological yield (7443 kg ha^{-1}) was observed in plots receiving full dose of pendimethalin at 825 g ha^{-1}. It was followed by sorgaab 18 L ha^{-1} + sunflower 18 L ha^{-1} + pendimethalin 413 ml ha^{-1}, where the biological yield was 7235 kg ha^{-1}. The lowest yield (6025 kg ha^{-1}) was recorded in the weedy check plots (Inayat *et al.,* 2009).

Water extract of sorghum+application of pendimethalin controlled the *Trianthema portulacastrum* and reduced the weed density (51.9%), weed dry weight (50.3%) and increased the yield (3.5%) of cotton compared to control (Iqbal *et al.,* 2009). Water extracts of sorghum+*Brassica*+ application of pendimethalin (Jabran *et al.,* 2010) controlled the *Trianthema portulacastrum, Cyperus rotundus, Chenopodium album, Coronopus didymus* and decreased the weed density (42.8-91.3%), weed dry weight (37.4-94.1%) and increased the yield (39.9%) of canola over the control.

Sorghum reduced the density and biomass of *Trianthema portulacastrum* and *Convolvulus arvensis* (Khalil *et al*., 2010). Application of sorghum water extract in rice controlled *Echinocloa colonum, Cyperus rotundus, Cyperus iria* and decreased the weed dry weight (40.4%) and increased the yield (12.5%) over control (Wazir *et al.*, 2011). It has also been successfully used against weeds of cotton, sunflower and mungbean. It increased the yield of these crops by 3-59 per cent depending upon the type of crop, frequency of application and time of application (Cheema *et al.,* 2012). Application of sorghum shoot water extract at 10 ml kg^{-1} soil significantly reduced the germination per cent, root length, shoot length, fresh biomass and dry biomass of *Trianthema portulacastrum*, *Digera arvensis* and *Convolvulus arvensis* (Kandhro *et al.*, 2015).

Sunflower and Sesame

Sunflower is an annual oleaginous plant native to America has allelopathic activity against weeds (Bogatek *et al.,* 2006). Its use as a natural herbicide for some broadleaf weeds has been suggested (Anjum and Bajwa, 2007 a, b). Several substances with allelopathic properties such as phenolic compounds, diterpenes, triterpenes have been isolated and chemically characterized (Macias *et al.,* 2004b). The properties of sunflower are well recognized; their effects on many weeds and crops have been documented. Macias *et al.* (2004a) isolated 125 natural allelopathic compounds that are phytotoxic towards many plants from different sunflower cultivars. Heliannuols, terpenoids and flavonoids are the most important allelopathic compounds isolated from sunflower (Vyvyan, 2002).

The use of sunflower as green manure (Om *et al.*, 2002) reduced the population of *Phlaris minor* by 42 and 100 percent under field and laboratory conditions, respectively. Annuionone isolated from aqueous extract of sunflower (cv. Suncross-42 leaves) reduced the growth of *Phlaris minor*, *Chenopodiun album*, *Coronopsis didymus*, *Medicago polymorpha*, Rumex dentatus (Anjum and Bajwa, 2005). Sunflower extracts completely inhibited seed germination of white mustard (Bogatek *et al.*, 2006).However, the phytotoxins did not affect the seed viability (Kupidlowska *et al.,* 2006). Allelopathic chemicals from sunflower could influence the antioxidant system in target plants, causing cell-membrane permeability and cellular damage, reducing the ability of the target plants to germinate and causing a gradual loss of seed vigour (Oracz *et al.,* 2007).

Emulsive water concentrate (EW) formulation of allelocompounds obtained from root exudates of sesame plants (Lalit and Varshney, 2008) applied on tubers of purple nut sedge caused significant delay and inhibition in germination. Emulsive water concentrate formulation at 240 µg g^{-1} concentration in soil inhibited shoot length, shoot and root biomass by 89, 81.3 and 91.9 per cent, respectively over the control. Results of Awan *et al.* (2009) revealed that combined application of sorghum + sunflower water extracts + pendimethalin inhibited the *Chenopodium album, Melitotus indica* and reduced the weed density (84.0%), weed dry weight (67.3%) and increased the yield (16.4%) of sunflower compared to control. Application of water extract of sunflower controlled *Avena fatua, Phalaris minor* and reduced the weed dry weight (10-62.0%) and increased the yield (18.55-62.0%) of sunflower compared to control (Jamil *et al.,* 2009).

Sunflower inhibited seed germination, growth and biomass of *Trianthema portulacastrum* (Mahmood *et al*., 2010) and *Digera arvensis* (Asgharipour, 2011). Soil

incorporation of sunflower + rice + *Brassica* in maize field (Khaliq *et al.*, 2010) inhibited the *Trianthema portulacastrum* and reduced the weed dry weight (60.1%) and increased the yield (41.0%) compared to control. Water extracts of sorghum + sunflower + rice in combination with butachlor in rice (Rehman *et al.,* 2010) controlled *Echinocloa crusgalli, Cyperus iria* and *Dactyloctenum aegyptium*, decreased the weed density (74-97%), weed dry weight (66-76%) and increased the yield (61%) of rice over the control.

Application of sunflower water extract in wheat controlled *Avena fatua, Melilotus officinalis, Phalaris minor* and *Rumex obtusifolius*, reduced the weed density (10.6-33.6%), weed dry weight (2.2-16.5%) and increased the yield (1.6-10.7%) over the control (Naseem *et al.,* 2010). Combined application of sorghum and sunflower water extracts (Mubeen *et al.*, 2012) drastically reduced the root length, shoot lenth, root dry weight and shoot dry weight of three weed species *viz., Trianthema portulacastrum, Dactyloctenium aegyptium* and *Eleusine indica*. Aqueous extracts from the leaf, stem and root of the sunflower at 100 per cent significantly reduced the germination percentage, plumule length and radical length of *Parthenium* and *Amaranthus* (Monika and Satsangi, 2013).

Trees with allelopathic potential for weed control

Through allelopathy, trees can regulate the germination, growth and development of weeds. Ethanolic extracts of seeds of *Annona squamosa*, *Carica papaya*, *Coffea arabica* and *Tamarindus indica* were found to inhibit germination of *Amaranthus spinosus* by 13, 58, 100 and 36 per cent, respectively (Rizvi *et al.,* 1980). *Eucalyptus* species released volatile compound such as benzoic, cinnamic and phenolic acids which (Putnam, 1984) inhibit the growth of some crops and weeds near to it.

Eucalyptus leaf leachate and oil showed differential effects on the growth of weeds. The leaf leachate of 20 per cent concentration suppressed the biomass production of *Cynodon dactylon* by about 50 per cent, whereas 1.0 per cent oil caused 68 per cent reduction. Application of 1.0 per cent oil significantly inhibited shoot and root length, leaf chlorophyll and total biomass production of *Cyperus rotundus* (Babu *et al.,* 1996). *Eucalyptus spp.,* because of high allelopathic activity, is expected to control weeds (Kohli *et al.,* 1998a). Aqueous extracts of its bark, leaves and oil inhibited *Parthenium hysterophorus* (Kohli *et al.,* 1998b).

Dried mango leaf powder completely inhibited sprouting of purple nutsedge tubers (James and Bala, 2003). According to Khan *et al.* (2004), *Prosopis, Eucalyptus* and *Acacia* retarded the growth and development of several weeds. Application of 5 ml of aqueous extract of *Eucalyptus camaldulensis* leaves (Khan *et al.,* 2008) significantly lowered fresh and dry weight of *Convolvulus arvensis* and other weeds in contrast to water application. Aqueous leachates of fresh leaves of *Eucalyptus* significantly reduced the initiation of propagules and early growth of *Cyperus rotundus* seedlings (Ranganathan and Kandasamy, 2008). El-Rokiek and Eid (2009) documented that aqueous extracts of fresh and dry leaves of *Eucalyptus citriodora* reduced the germination and seedling growth of wild Oat (*Avena fatua* L.). Studies on the allelopathic effects of *Eucalyptus camaldulensis* on seed germination and seedling growth of *Acroptilon repens*, *Plantago lanceolata* and *Portulaca oleracea* (Dadkhah and Assadi, 2010) revealed that maximum inhibition of germination percentage, rate of germination and seedling growth were recorded when using the higher concentration of the aqueous extract (20 g L^{-1}) of *Eucalyptus* leaves.

El-Rokiek *et al.* (2010) observed that application of mango leaf extract at 25 per cent or leaf powder at 100gkg^{-1} of soil reduced the number of mother shoots tuber^{-1}, number of leaves of mother shoots tuber^{-1}, length of mother leaves, number of daughter shoots tuber^{-1} and number of leaves of daughter shoots tuber^{-1}, number of basal bulbs and tubers, number of rhizomes tuber^{-1}, length of rhizomes, dry weight of foliage, dry weight of underground, total dry weight and increased the total phenol contents in foliage and underground parts of purple nutsedge compared to control. Shoot aqueous extract of *Eucalyptus*, sunflower and sugerbeet (Dadkhah, 2012) caused inhibition in germination, growth and photosynthesis of the *Amaranthus retroflexus.* Aqueous extracts of old mango leaves reduced the germination, shoot length, root length and dry weight by 95, 96, 93 and 95 per cent, respectively (Kamran *et al.,* 2013). Volatile essential oil of *Eucalyptus* possess strong inhibitory potential against *Cyndon dactylon* and A*maranthus blitoides* that could be exploited for weed management and can be recommended as a biological herbicide with the aim of weed control (Rassaeifar *et al.,* 2013). Aqueous leaf extracts of *Eucalyptus camaldulensis* inhibited the germination and growth of *Datura spp., Sonchus spp. and Sinapis spp*. (Saeed *et al.,* 2013). Leaf extract of *Eucalyptus globules* significantly decreased the germination percentage, root and shoot length and fresh and dry weight of *Solanum nigrum* (Reza *et al.,* 2014). *Eucalyptus* powder at 30 g kg^{-1} soil + *Eucalyptus* water extract at 30 ml kg^{-1} soil significantly reduced the root length, shoot length, fresh and dry weight of *Cyperus rotundus* and *Convolvulus arvensis* (Kandhro *et al.,* 2016).

CONCLUSION

From this review it can be concluded that, application of allelochemicals through water extract, intercropping, cover cropping and mulching is promising method to control weeds and enhance crop production. However, more work is needed to test the allelochemicals present in the crops and trees.

REFERENCES

Ahmad, R. (1998). Response of maize (*Zea mays* L.) and some kharif weeds to folair application of sorgaab (Sorghum water extract). M.Sc., Thesis, University of Agriculture, Faisalabad.

Anjum, T. and Bajwa, R. (2005). A bioactive annuionone from sunflower leaves. Phytochemistry. 66: 1919-1921.

Anjum, T. and Bajwa, R. (2008). Screening of sunflower varieties for their herbicidal potential against common weeds of wheat. Journal of Sustainable Agriculture. 32 (2): 213-229.

Anjum, T. and Bajwa, R. (2007a). Field appraisal of herbicide potential of sunflower leaf extract against Rumex dentatus. Field Crops Research. 100: 139-142.

Anjum, T. and Bajwa, R. (2007b). The effect of sunflower leaf extracts on *Chinopodium album* in wheat fields in Pakistan. Crop Protection Journal. 26: 1390-1394.

Asgharipour, M.R. (2011). Inhibitory effects of sunflower root and leaf extracts on germination and early seedling growth of amaranth and purple nutsedge. Advances in Environmental Biology. 5(11): 3550-3555.

Awan, I.U., Khan, M.A., Zareef, M. and. Khan, E.A. (2009). Weed management in sunflower with allelopathic water extract and reduced doses of a herbicide. Pakistan Journal of Weed Science Research. Pak. 15: 19-30.

Babu, R.C., Kandsamy, O.S., Nagarajan, M., Palaniappan, S.P. and Sankaran, S. (1996). Effects of Eucalyptus leaf leachates and oil on growth of *Cyperus rotundus* and Cynodon dactylon. In: Allelopathy in Pest Management for Sustainable Agriculture. pp. 169-174.

Bertin, C., Yang, X. and Wetson, L.A. (2003). The role of root exudates and allelochemicals in the rhizosphere. Plant and Soil. 256: 67-83.

Bhadoria, P.B.S. (2011). Allelopathy: a natural way towards weed management. American Journal of Experimental Agriculture. 1: 7-20.

Bogatek, R., Gniazdowska, A., Zakrzewska, W., Orac, K. and Gawronski, S.W. (2006). Allelopathic effects of sunflower extracts on mustard seed germination and seedling growth. Journal of Plant Biology. 50: 156-158.

Cheema, Z.A., Khaliq, A. and Farooq, R. (2003a). Efficacy of concentrated sorgaab alone and in combination with herbicides and a surfactant in wheat. Journal of Animal and Plant Sciences. 13(1): 10-13.

Cheema, Z.A. (1988). Weed control in wheat through sorghum allelochemicals. Ph.D., Thesis, Agronomy Department, University of Agriculture, Faisalabad, Pakistan.

Cheema, Z.A. and Khaliq, A. (2000). Use of sorghum allelopathic properties to control weeds in irrigated wheat in semi arid region of Punjab. Agriculture, Ecosystems and Environment. 79: 105-112.

Cheema, Z.A. and Ahmad, S. (1992). Allelopathy a potential tool for weed management In: Proc. Nat. Sem. on Role of Plant Health and Care in Agriculture, held on 28-29 Dec, 1988 at University of Agriculture, Faisalabad.

Cheema, Z.A., Khaliq, A. and Mubeen, M. (2003b). Response of wheat and winter weeds to foliar application of different plant water extracts of sorghum (*Sorghum bicolor*). Pakistan Journal of Weed Science Research. 9: 89-97.

Cheema, Z.A., Khaliq, A. and Tariq, M. (2002). Evaluation of concentrated sorghum water extract alone and in combination with reduced rates of three pre-emergence herbicides for weed control in cotton (*Gossypium hirsutum* L.). International Journal of Agriculture and Biology. 4: 549-552.

Cheema, Z.A., Khaliq, A. and Akhtar, S. (2001). Use of sorghum water extract as a natural weed inhibitor in spring mungbean. International Journal of Agriculture and Biology. 3: 515-518.

Cheema, Z.A., Luqman and Khaliq., A. (1997). Use of allelopathic extracts of sorghum and sunflower herbage for weed control in wheat. Journal of Animal and Plant Sciences. 7: 91-93.

Cheema, Z.A., Asim, M. and Khaliq, A. (2000). Sorghum allelopathy for weed control in cotton (*Gossypium arboreum* L.). International Journal of Agriculture and Biology. 2: 37-41.

Cheema, Z.A., Farooq, M. and Khaliq, A. (2012). Application of allelopathy in crop production: success story from Pakistan. In: Allelopathy: Current Trends and Future Applications, [Cheema, Z.A., M. Farooq and A. Wahid (eds.)]. Springer: Verlag Berlin Heidelberg, Germany. pp: 113-143.

Chon, S.U. and Nelson C.J. (2012). Allelopathic dynamics in resource plants. In: Allelopathy: Current Trends and Future Applications. pp: 81-110.

Chon, S.U., Jennings, J.A. and Nelson, C.J. (2006). Alfalfa (*Medicago sativa* L.) autotoxicity: Current status. Allelopathy Journal. 95: 1063-1070.

Cseke, L.J. and Kaufman, P.B. (2006). Regulation of metabolites synthesis in plants. Nat. Prod. Plants. Pp. 101-104.

Dadkhah, A. (2012). Phytotoxic effects of aqueous extracts of *Eucalyptus*, sunflower and sugar beet on seed germination, growth and photosynthesis of *Amaranthus retroflexus*. Allelopathy Journal. 29: 287-296.

Dadkhah, A. and Assadi, M. (2010). Allelopatic effects of *Eucalyptus camaldulensis* on germination and growth seedlings of *Acroption repens*, *Plantago lanceolata* and *portulaca oleracea* research. Journal of Biological Sciences. 5: 430-434.

Duke, S.O., Baerson, S.R., Rimando, A.M., Pan, Z., Dayan, F.E. and Belz, R.G. (2007). Biocontrol of weeds with allelopathy: conventional and transgenic approaches. Outlooks on Pest Management. 18: 54-58.

Einhellig, F.A. (1986). Mechanisms and modes of action of allelochemicals. In: The Science of Allelopathy, [Putnam, A.R. and C.S. Tang (eds.)]. Wiley, New York, USA. pp: 171-187.

Einhellig, F.A. and Rasmussen, J.A. (1979). Effects of three phenolic acids on chlorophyll content and growth of soybean and grain sorghum seedlings. Journal of Chemical Ecology. 5: 815-824.

El-Rokiek, Kowthar, G., Rafat, R., El-Masry, Nadia, K., Messiha and Ahmed, S.A. (2010). The allelopathic effect of mango leaves on the growth and propagative capacity of purple nutsedge (*Cyperus rotundus* L.). Journal of American Science. 6(9): 151-159.

El-Rokiek, K.G. and Eid, R.A. (2009). Allelopathic effects of *Eucalyptus citriodora* on amaryllis and associated grassy weed. *Planata Daniaha*, 27,887-899.

Farooq, M., Jabran, K., Cheema, Z.A., Wahid, A. and Siddique, K.H.M. (2011a). The role of allelopathy in agricultural pest management. Pest Management Science. 67: 493-506.

Farooq, M., Habib, M., Rehman, A., Wahid, A. and Munir, R. (2011b). Employing aqueous allelopathic extracts of sunflower in improving salinity tolerance in rice. Journal of Agriculture, Forestry and the Social Sciences. 7: 75-80.

Forney, D.R., Foy, C.L. and Wolf, D.D. (1985). Weed suppression in no-till alfalfa (*Medicago sativa*) by prior cropping of summer annual forage grasses. Weed Science. 33: 490-497.

Fujii, Y. (2003). Allelopathy in the natural and agricultural eco systems and isolation of potent allelochemicals from velvet bean (*Mucuna pruriens*) and Hairy vetch (*Vicia villosa*). Biological Science in Space. 17(1): 6-13.

Harper, J.R. and Balke, N.E. (1981). Characterization of the inhibition of K^+ absorption in oat roots by salicylic acid. Plant Physiololoy. 68: 1349-1353.

Inayat U.A, Khan, M.A., Zareef, M. and Khan, E.A. (2009). Weed management in sunflower with allelopathic water extract and reduced doses of a herbicide. Pakistan Journal of Weed Science Research. 15(1): 19-30.

Iqbal, J. and Cheema, Z.A. (2008). Purple nutsedge (*Cyperus rotundus* L.) management in cotton with combined application of sorgaab and S - metolachlor. Pakistan Journal of Botany. 40 (6): 2383-2391.

Iqbal, J., Cheema, Z.A. and Mushtaq, M.N. (2009). Allelopathic crop water extracts reduce the herbicide dose for weed control in cotton (*Gossypium hirsutum*). International Journal of Agriculture and Biology. 11: 360-366.

Jabran, K., Cheema, Z.A., Farooq, M. and Hussain, M. (2010). Lower doses of pendimethalin mixed with allelopathic crop water extracts for weed management in canola (*Brassica napus*). International Journal of Agriculture and Biology. 12: 335-340.

Jafariehyazdi, E. and Javidfar, F. (2011). Comparison of allelopathic effects of some *Brassica* species in two growth stages on germination and growth of sunflower. Plant, Soil and Environment. 57(2): 52-56.

James, J.F. and Bala, R. (2003). Allelopathy: How Plants Suppress Other Plants. The Hort. Sci.Depart. Inst. Food Agric. Sci. Univ. Florida. (Available at: http://edis.ifas.ufl.edu).

Jamil, M., Cheema, Z.A., Mushtaq, M.N., Farooq, M. and Cheema, M.A. (2009). Alternative control of wild oat and canary grass in wheat fields by allelopathic plant water extracts. Agronomy for Sustainable Development. 29: 475-482.

Javaid Iqbal and Cheema, Z.A. (2008). Purple nutsedge (*Cyperus rotundus* L.) management in cotton with combined application of sorgaab and s-metolachlor. Pakistan Journal of Botany. 40(6): 2383-2391.

Kamran Saleem, Shagufta Perveen, Nighat Sarwar, Farooq Latif, Khalid Pervaiz Akhtar and Hafiz Muhammad Imran Arshad. (2013). Identification of phenolics in mango leaves extract and their allelopathic effect on canary grass and wheat. Pakistan Journal of Botany. 45(5): 1527-1535.

Kandhro, M.N., Jogi, Q., Buriro, M., Soomro, A.A., Laghari, G.M. and Khaskheli, A.N. (2016). Germination and seedling growth of *Convolvulus arvensis* L. and *(Cyperus rotundus* L.) under the allelopathic influence of *Eucalyptus camal--dulensis* (L.) leaves. Sarhad Journal of Agriculture. 32(3): 252-257.

Kandhro, M.N., Tunio, S.D., Rajpar, I., Chachar, Q.D. and Gandahi, A.W. (2015). Allelopathic impact of sorghum and sunflower on germination and seedling growth of summer broadleaf weeds. Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences. 31(2): 229-239.

Khalil, S.K., Mehmood, T., Rehman, A., Wahab, S., Khan, A.Z., Zubair, M., Mohammad, F., Khan, N.U., Amanullah and Khalil, I.H. (2010). Utilization of allelopathy and planting geometry for weed management and dry matter production of maize. Pakistan Journal of Botany. 42(2): 791-803.

Khaliq, A., Aslam, Z. and Cheema, Z. A. (2002). Efficacy of different wheat management strategies in mungbean. International Journal of Agriculture and Biology. 4(2): 237-239.

Khaliq, A., Cheema, Z.A., Mukhtar, M.A. and Basra, S.M.A. (1999). Evaluation of sroghum (*Sorghum bicolor* L.) water extracts for weed control in soybean. International Journal of Agriculture and Biology. 1: 23-6.

Khaliq, A., Matloob, A., Irshad, M.S., Tanveer, A. and Zamir, M.S.I. (2010). Organic weed management in maize through integration of allelopathic crop residues. Pakistan Journal of Weed Science Research. 16: 409-420.

Khan, M.A., Hussain, I. and Khan, E.A. (2008). Suppressing effects of *Eucalyptus camaldulensis* (L.) on germination and seedling growth of six weeds. Pakistan Journal of Weed Science Research. 14(3-4): 201-207.

Khan, M.A., Marwat, K.B. and Hassan, G. (2004). Allelopathic potential of some multipurpose tree species (MPTS) on wheat and some if its associated weeds. International Journal of Biology and Biotechnology. 1(3): 275-278.

Kohli, R.K., Batish, D.R. and Singh, H.P. (1998a). Allelopathy and its implications in agroecosystems. Journal of Crop Production. 1: 169-202.

Kohli, R.K., Batish, D.R. and Singh, H.P. (1998b). Eucalypt oils for the control of parthenium (*Parthenium hysterophorus* L.). Crop Protection. 17: 199-122.

Kruse, M., Strandberg, M. and Strandberg, B. (2000). Ecological Effects of Allelopathic Plants-a Review, National Environmental Research Institute. NERI, Technical Report No. 315, Silkeborg, p: 66. Available online at: http://www2.dmu.dk/1_viden/2_publikationer/3.../rapporter/fr315.pdf (Accessed: 15 February 2013).

Kupidlowska, E., Gniazdowska, A., Stepien, J., Corbineau, F., Vinel, D., Skoczowski, A., Janeczko, A. and Bogatek, R. (2006). impact of sunflower (*Helianthus annuus* L.) extracts upon reserve mobilization and energy metabolism in germinating mustard (*Sinapis alba* L.) seeds. Journal of Chemical Ecology. 32: 2569-2583.

Lalit, K. and Varshney, J.G. (2008). Allelopathic effect of sesame root exudates against purple nut sedge. Indian Journal of Weed Science. 40 (1 and 2): 32-36.

Macias, F.A., Lopez, A., Verala, R.M., Torres, A. and Molinillo, J.M. G. (2004a). Bioactive apocarotenoids annuionones F and G: structural revision of annuionones A, B and E. Phytochemistry. 65: 3057-3063.

Macias, F.A., Molinillo, J.M.G., Chinchilla, D. and Galindo, J.C.G. (2004b). Heliannanes - A structure-activity relationship (SAR) Study, In: Allelopathy: Chemistry and Mode of Action of Allelochemicals. [Macias, F.A., J.C.G. Galindo, J.M.G. Molinillo and H.G. Cuttler (Eds.)]. Chapter: 5 CRC Press Publisher, (pp.103-124).

Mahmood, A., Cheema, Z.A., Khaliq, A. and Hassan, A.U. (2010). Evaluating the potential of allelopathic plant water extracts in suppressing horse purslane growth. International Journal of Agriculture and Biology. 12: 581-585.

Molisch, H. (1937). Der Einfluss einer Pflanze auf die Andere-Allelopathic. Fischer, Jena, Germany. 31: 12-16.

Monika, S. and Satsangi, G.P. (2013). Potential allelopathic influence of sunflower (*Helianthus annuus* L.) on germination and growth behavior of two weeds *in- vitro* condition. International Journal of Biotechnology and Bioengineering Research. 4(5): 421-426.

Mubeen, K., Nadeem, M.A., Tanveer, A. and Zahir, Z.A. (2012). Allelopathic effects of sorghum and sunflower water extracts on germination and seedling growth of rice (*Oryza sativa* L.) and three weed species. Journal of Animal and Plant Sciences. 22 (3): 738-746.

Narwal, S.S. (1994). Allelopathy in Crop Production. Scientific Publishers, Jodhpur, India.

Naseem, M., Aslam, M., Ansar, M. and Azhar, M. (2010). Allelopathic effects of sunflower water extract on weed control and wheat productivity. Pakistan Journal of Weed Science Research. 15: 107-116.

Netzly, D., Riopel, J.L., Ejeta, G. and Butler, L.G. (1988). Germination stimulants of witchweed (*Striga asiatica*) from hydrophobic root exudates of sorghum (*Sorghum bicolor*). Weed Science. 36: 441-446.

Netzly, D.H. and Butler, L.G. (1986). Roots of sorghum exude hydrophobic droplets containing biologically active components. Crop Science. 26: 775-778.

Om, H., Dhiman, S.D., Kumar, S. and Kumar, H. (2002). Allelopathic response of Phlaris minor to crop and weed plants in rice-wheat system. Crop Protection. 21: 699-705.

Oracz, K., Bailly, C., Gniazdowska, A., Come, D., Corbineau, F. and Bogatek, R. (2007). Induction of oxidative stress by sunflower phytotoxins in germinating mustard seeds. Journal of Chemical Ecology. 33: 251-264.

Oudhia, P., Kolhe, S.S.S. and Tirpathi, R.S. (1998). Allelopathic effect of *Blumea lacera* L. on rice and common Kharif weeds. Oryza. 35: 175-177.

Putnam, A.R. (1984). Allelopathy chemicals. Can natural plant herbicides help control weeds. Weeds Today. 15: 6-8.

Putnam, A.R. and DeFrank, J. (1979). Use of allelopathic cover crops to inhibit weeds. Proceeding IX International Congress of Plant Protection. Burgess Publishing Co., Minneapolis pp. 580-582.

Ranganathan, C. and Kandasamy, O.S. (2008). Allelopathic effect of *Eucalyptus globulus* (L.) on *Cyperus rotundus* (L.) and *Cynodon dactylon* (L.) Pers. Journal of Agronomy and Crop Science. 179(2): 123-126.

Rassaeifar, M., Hosseini, N., Haji Hasani Asl, N., Zandi, P. and Moradi Aghdam, A. (2013). Allelopathic effect of *Eucalyptus globulus* essential oil on seed germination and seedling establishment of *Amaranthus blitoides* and *Cyndon dactylon*. Trakia Journal of Science. 11(1): 73-81.

Rehman, A., Cheema, Z.A., Khaliq, A., Arshad, M. and Mohsan, S. (2010). Application of sorghum, sunflower and rice water extract combinations helps in reducing herbicide dose for weed management in rice. International Journal of Agriculture and Biology. 12: 901-906.

Reza Ataollahi, Mahmood Dejam and Sedighe Sadat Khaleghi (2014). Phytotoxic effects of Eucalyptus globulus leaf extract on *Solanum nigrum.* South Western Journal of Horticulture, Biology and Environment. 5(1): 43-53.

Rice, E.L. (1984). Allelopathy, 2nd edition. Academic Press, New York, USA.

Rizvi, S.J.H., Haque, H., Singh, V.K. and Rizvi, V. (1992). A discipline called allelopathy. In: Allelopathy Basic and Applied Aspects. [Rizvi, S.J.H and V. Rizvi (eds.)]. Chapman and Hall, London. pp: 1-8.

Rizvi, S.J.H., Mukerji, D. and Mathur, S.N. (1980). 1,3,7- Trimethy--lxanthine, a new natural herbicide. Agricultural and Biological Chemistry. 54: 1255-1256.

Sadeghi, S., Rahnavard, A. and Ashrafi, Z.Y. (2010). Allelopathic effect of *Helianthus annuus* (sunflower) on *Solanum nigrum* (black nightshade) seed germination and growth in laboratory condition. Journal of Horticultural Science and Ornamental Plants. 2(1): 32-37.

Saeed, J.A., Al-Rawi, E.R. and Ibraheem, F.K. (2013). The effect of aqueous leaves extracts of *Eucalyptus camaldulensis* on germination and growth of three weed species. Rafidain Journal of Science. 24(2): 1-10.

Tesio, F. and Ferrero, A. (2010). Allelopathy, a chance for sustainable weed management. International Journal of Sustainable Development and World Ecology. 17(5): 377-389.

Vyvyan, J.R. (2002). Allelochemicals as leads for new herbicides and agrochemicals. Tetrahedron. 58: 1631-1646.

Wazir, I., Sadiq, M., Baloch, M.S., Awan, I.U., Khan, E.A., Shah, I.H., Nadim, M.A., Khakwani, A.A. and Bakhsh, I. (2011). Application of bio-herbicide alternatives for chemical weed control in rice. Pakistan Journal of Weed Science Research. 17: 245-252.

Weston, L.A. (1996). Utilization of allelopathy for weed management in agroecosystems: Allelopathy in cropping systems. Agronomy Journal. 88: 860-866.

Weston, L.A. and Duke, S.O. (2003). Weed and crop allelopathy. Critical Reviews in Plant Sciences. 22: 367-389.