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Environmental, ecological and evolutionary effects of weeds allelopathy

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Abstract
The farmer and researcher are globally comprehending more concentration on allelopathic activities of plants as compare to the times of yore. Allelopathy is alleged for the stumpy production and malfunction of crops due to reseeding, crops alteration and over cropping. Additionally, the researcher and farmer give attention to the inexpensive, biodegradable and eco-friendly substitutes for the control & managing of weeds in crops rather than to use the costly and ecosystems degrading herbicides. Even though from the interference of chemical from other means is cumbersome to separate, also the advance research studies have generated compatible and convincing information in this field of study. This review study also explains the ways through biochemical affected the environment and ecosystem.

Keywords: environment, ecology, weed, allelopathy, biocompounds

1. Introduction

From the beginning, it has been reported and proved by experimental work that some plant species have the potential to have an effect on nearby plants. Theophrastus (ca. 300B.C) Aristotle successor was the first person who wrote about this subject matter, he observed the negative effects on the vine by cabbage plants species and supposed that "odours" from the cabbage plants was the main reason of such effects (Albuquerque *et al*. 2010; Willis, 1985) [1, 119]. This observable fact called allelopathy (from the Greek al-lelon = of each other, pathós = to suffer). In 1937 first time this terminology was introduced by a German plant physiologist Hans Molisch by defining the terrifying effects of one plant upon another. Now comprehensively it can be stated that the an influence upon the agricultural and biological ecosystems advancement by the optimistic and pessimistic effects of chemical compounds produced mainly from the secondary metabolism of plants, micro-organisms, viruses and fungi (Albuquerque *et al*. 2010; Kruse *et al*. 2000; Olofsdotter *et al*. 2002; Rice, 2012; Seigler, 1996; Taveira *et al*. 2013, Jabran, 2017; Muzell *et al*. 2017) [1, 63, 84, 97, 99, 106, 54, 55, 56, 76]. Practically it is examined that the allelopathic plants release the active biomolecules generally called "allelochemicals into the environment cause such effects (Bertin *et al*. 2003; Kruse *et al*. 2000; Seigler, 1996; Shinwari *et al*. 2013; Qasem, 2017) [10, 63, 99, 100, 91]. The chemical interaction of plant-herbivore, plant-insect, and plant-plant may be due to allelochemicals complex (Weir *et al*. 2004) [117] in addition the allelochemicals released by microorganisms that can create the communication among microbe-microbe or microbe-plant e.g. colonization development into the new ecosystem (Singh *et al*. 2003) [101].

The extensive demanding approach for green economy and green environment by using those technologies which are cheaper, coefficient and eco-friendly for weed management has been aggravated research studies on crops and weeds allelopathy (Dudai *et al*. 1999; Om *et al*. 2002) [29, 85]. The possibilities of getting low yields using reseeding, over seeding, cover crops and crop rotation like agricultural techniques also need attention to the crop involvement in allelopathic activity (Chon *et al*. 2006; Oueslati, 2003) [20, 86]. The herbicidal properties of plants which have potential to produce allelochemicals are considered as a major source for the chemical industry, as the weeds become resistant to synthetic chemical compound the importance of new molecules are increased (Rawat *et al*. 2017; Bhowmik, 2003; Duke, 2003; Einhellig, 1996; Kruse *et al*. 2000) [94, 11, 30, 34, 63]. The plants and crops are genetically modified which can be introduced as allelopathic cover groups are the time needed development of their application (Duke, 2003; Duke *et al*. 2000; Duke *et al*. 2009; Taiz & Zeiger, 2006) [30, 31, 32, 33, 105].

Considering that in the biological invasion, allelopathy can play vital and significance job in ecological point of view. Practically and from recorded evidence, it has been proved that invasive species becomes more dominant on indigenous species in the invaded areas, but remain suppressive in native regions (Fabbro & Prati, 2015) [25]. Through the "novel" weapons theory tried to explain this phenomenon, which suggest that different allelochemicals or biochemical compounds released to the invaded ecosystem by some exotic plants which are comparatively inefficient against their espoused natural regions (Sangeetha & Baskar, 2015; Callaway & Ridenour, 2004; Namkeleja *et al*. 2014; Rabotnov, 1981; Vivanco *et al*. 2004) [98, 17, 78, 93, 113, 117].

Allelopathic activities exhibited by different chemical groups which have a large number of biomolecules. It is observed that some of the biological molecules are produced from primary metabolism while in their majority released through secondary metabolism. Even though these biomolecules are of a wide range but mainly their originators are four: acetyl coenzyme A, shikimic acid, melavonic acid and deoxyclulose phosphate. Keeping in view these precursors as a base, the biological compound obtained from secondary metabolism are further classified in three core chemical classes: terpenoids, N-containing compounds and phenolic compounds (Albuquerque *et al*. 2010) [1].

The consensus among the researcher and scientists are developed that the growth of the plant which receives biological compound may not be enough to effect from a simple compound in normal conditions but the growth inhibited by the action of other biomolecules (Belz, 2007; Einhellig, 1996; Kruse *et al*. 2000; Seigler, 1996; Tabaglio *et al*. 2008) [7, 34, 63, 99, 104]. This literature review presents the current trend of the allelopathic association and interaction of crops and weeds in view of current studies and research. It also covers the documented weeds having allelopathic properties and their significance for weed management. Additionally, to explore activities of allelopathic plants through different approaches and their introduction to the agricultural system have been considered.

2. Biocompound Release to ecosystem during Allelopathy

The different parts of plant, i.e., leaves, stems, roots, rhizomes, seeds, flowers and even pollen have allelochemicals in specific concentration (Bertin *et al*. 2003; Gatti *et.al.,* 2004; Kruse *et al*. 2000; Wipf *et.al.*,2016; Yang & Kong, 2017) [10, 40, 63, 121, 124]. These biological compounds from different species are releasing to the environment through the following pathways; Allelochemicals exudates from the leaf surface washed out by rainfall, from the green parts the volatile compounds exudates, plant residues decomposition and root exudation (Chon *et al*. 2006; Morikawa *et al*. 2012; Olofsdotter *et al*. 2002) [20, 74, 84]. During research studies, some essential variation is observed in species of chemicals with ecosystem and phytochemicals (Pueyo *et al*. 2017; Callaway & Vivanco, 2006; Evans *et al*. 2011; Weiner, 2001) [90, 14, 36, 116]. Such interactional changes of allelochemicals and environment led to complication in understanding allelopathy during field analysis by giving contradictory ecological results of specified biochemicals (Latif *et al*., 2017; Blair *et al*. 2006; Callaway & Vivanco, 2006; Duke *et al*. 2009; Evans *et al*. 2011; Kaur & Foy, 2001; Kaur *et al*. 2009) [69, 12, 14, 31, 33, 36, 60, 59].

All troughs the plant life cycle, the releasing concentration of allelochemicals is altered by different environmental factors. The amount of the biomolecules releasing from allelopathic plants are increased by the abiotic factors (drought, irradiation, temperature) and biotic factors (nutrient limitation, competitors, pathogenic and insecticidal diseases) (Cseke *et al*. 2006; Albuquerque *et al*. 2010; Einhellig, 1996; Vidal & Bauman, 1997) [21, 1, 34, 112].

The aqueous extracts from genotypes grown under rainfed conditions had higher allelopathic activity than those genotypes grown under irrigated conditions (El-Sadek *et al*. 2017) [35]. It was proved that under severe drought situation the autotoxicity of barley increased during the study for the appearance of autotoxicity of the cultivated barley on seed growth and germination under laboratory conditions (Oueslati *et al*., 2005) [87]. Extorts of barley plant have diverse inhibitory effects on different plant parts and plant growth stages (Ben-Hammouda *et al*. 2001) [8]. Increasing the intensity of ultraviolet-B radiation enhance the allelopathic effects of Houndstongue (*Cynoglossum officinale L.)* on some feeding grasses (Furness *et al*. 2008) [38]. It had been observed that rather than the control plants, extracts of *Helianthus annuus L.* is more effective against the germination of *Amaranthus retroflexus L.* under nutrient deficient condition (Hall *et al*. 1982) [44]. It was found that *Ageratum conyzoides L.* amplified their allelopathic effects on the peanut (*Arachis hypogaea L.),* redroot amaranth (*A. retroflexus*), cucumber *(Cucumis sativus L.)* and ryegrass *(Lolium multiflo- rum Lam.*) under stumpy nutritional situation or in struggle with *Bidens pilosa L.* (Kong *et al*. 2002) [62]. During the studies of *Secale cereale L.* in the context of the yields, phytotoxicity of tissues and biological compounds affected by the three fecundity systems; this study reveals that regardless of the huge amount of its biomass, low fertilization favors the phytotoxic remains and biomolecules (Mwaja *et al*. 1995) [75]. Plants go through multifarious biological changes in reaction to herbivores and infection whenever insect or pathogenic species harasses them, beside it the amount of releasing allelochemicals also increased (Mattner, 2006) [73].

The recent literature shows that allelochemicals production and targeting plants retorts is the result of the processes at cellular and molecular level (Baerson *et al*. 2005; Dayan, 2006; Albuquerque *et al*. 2010; Ding *et al*. 2007; Golisz *et al*. 2008; Song *et al*. 2008) [6, 24, 1, 27, 42, 102]. A gas is known as Reactive Oxygen Species (ROS) which is very toxic and causing biotic and abiotic pester in the cell is produced during the molecular oxygen reduction process (Albuquerque *et al*. 2010; Resende *et al*. 2003; Veronese *et al*. 2003) [1, 96, 111]. The formation of ROS can also be activated by allelochemicals. Weeds during the resistance against other crops/weeds, pest and diseases also release allelochemicals (Belz, 2007) [7].

3. Environmental and Ecological Effects

The environmental, biogeographically and evolutionary research studies develop our knowledge about allelopathy (Evans *et al*. 2011; He *et al*. 2009; Kaur *et al*. 2009; Lankau, 2011; Lankau *et al*. 2009; Pollock *et al*. 2009; Thorpe *et al*. 2009; Wardle *et al*. 2011) [36, 48, 59, 66, 67, 48, 89, 109, 114]. In ecology, the mechanism of communities' formation is an issue of special consideration (Evans *et al*. 2011; Lortie *et al*. 2004) [36, 68]. Rabotnov, the Russian ecologist hypothesized for developing communities' it is important for adaptation with the chemistry of other associated organisms (Evans *et al*. 2011; Rabotnov, 1981) [36, 93]. Biochemical compounds effects and inhibit the plant growth, disintegration, herbivore, ecological interaction and nitrogen cycle (Evans *et al*. 2011; Hättenschwiler *et al*. 2011; Hättenschwiler & Jørgensen, 2010; Hättenschwiler & Vitousek, 2000; Karban *et al*. 2006; Northup *et al*. 1998; Rabotnov, 1981) [36, 45, 46, 47, 58, 83, 93].

In crop production practices the weed management through allelopathy is beneficial and environmental friendly substitute for conventional herbicide; the differences in their chemical structure they have the diverse mood of action (Kruse *et al*. 2000; Macias, 1995; Narwal *et al*. 1998) [63, 71, 79]. To review the development of invasive species in the natural and semi-natural environment by their allelopathic potential comprised. Allelochemicals effects metabolic activities as it hinders totally inhibits and delayed seed germination and seedling growth (Babaahmadi *et al*. 2013; Gomaa *et al*. 2014) [5, 43]. Functioning of the allelochemicals on molecular level influenced the composition and augmentation (Einhellig, 1996) [34]. Studies at the genetic level can give faithful information of allelochemicals about their allelopathic effects (Kruse *et al*. 2000; Amb & Ahluwalia, 2016) [63, 2].

An extensive range of activities have been shown by a number of allelochemicals e.g. a good number of alkaloids are noxious or inhibitory to diverse species belonging from different groups including plants, microorganisms specially bacteria & fungi, pests and mammal (Jabran *et al*. 2015; Kruse *et al*. 2000; Wink *et al*. 1998) [57, 63, 120]. Phenolic compounds released during allelopathic activities are toxic for microflora and soil animals (Jabran, 2017; Gallet & Pellissier, 1997) [54, 55, 56, 39]. Terpenoids as allelochemicals in crops of temperate weather are not commonly found but conifers, mints, and euphorbias have in abundant quantity. Terpenoids released to the environment by plants play an important role by inhibiting seed germination, control herbivorous (specific and general), against vectored and pathogenic fungi enhancing defense, attract the pollination agents and also restrain the soil bacteria (Kruse *et al*. 2000; Langenheim, 1994) [63, 65]. Multiple effects are shown by mono-terpenoids individually, but its quantity to effects different species or population is specified known as dosage factor (Langenheim, 1994) [65].

Biological compound resulted from allelopathic activity harms the plants by inhibiting their microsymbionts like nitrifying bacteria and mycorrhiza. Certain ectomycorrhizal fungi allied with *P. mariana* growth affected by the *K. angustifolia* extorts have been evidenced through natural processes and laboratory experiments (Yamasaki *et al*. 1998) [23]. It is proved by experimental work that *Pinus sylvestris* spreading seedling mycorrhizal infection is reduced by the *Empetrum hermaphroditum* aqueous remains (Nilsson *et al*. 1993) [82]. The symbiosis process between *Rhizobium* and legume species actually inhibited by allelochemicals released from living plants and plants extracts damaged or killed by herbicide (Putnam *et al*. 1986; Weston & Putnam, 1985) [92, 118]. *Carduus nutans* decomposed leaves negatively influence the ability of nitrogen fixation of *Trifolium repens* and show its dominance in the territory with ryegrass (Kruse *et al*. 2000; Wardle *et al*. 2011) [63, 114].

Allelochemicals released to the soil by allelopathic plants alter the soil texture and effects plant-soil relationships through different factors (Blum *et al*. 1999; Inderjit, 1998; Kruse *et al*. 2000) [13, 50, 63]. Soil properties influenced by a violent and brutal evergreen weed plant *Pluchea lanceolata*. Higher concentration of Phenolic acid, pH, electrical conductivity, potassium (K+) and soluble chloride (Cl-) were found in *P. lanceolata* environs affecting seedling growth of different crops (Inderjit, 1998; Inderjit & Dakshini, 1998; Kruse *et al*. 2000; Ullah *et al*. 2013; Jabran, 2017) [50, 51, 63, 110, 54, 55, 56]. Nutrients cycling and their availability in the soil can badly affect by Phenolic acid (Appel, 1993; Kuiters, 1991) [4, 64]. Allelochemicals concentration in soil can be reduced by microbial decomposition (Soil detoxification or producing additional phytotoxic allelochemical) and other physicochemical processes e.g., oxidation (Cseke *et al*. 2006; Albuquerque *et al*. 2010; Kaur & Foy, 2001; Nair *et al*. 1990; Vidal & Bauman, 1997; Weidenhamer, 1996; Weiner, 2001) [21, 1, 60, 77, 112, 115, 116]. To the sandy and silt loam soil some allelochemicals catechin and cosolute of Phenolic acid released by *Centaurea maculosa* Lam., which are vanished through oxidation and sorption (Albuquerque *et al*. 2010; Tharayil *et al*. 2008) [1, 107].

Allelopathy is an appreciating factor of plant invasion and establishing in a new environment. The studies recommended that the aggressive colonizers e.g. *Elytrigia repens* and *Vulpia myuros* release allelochemicals is lead to thriving invasion (An *et al*. 1997; Friebe *et al*. 1995) [3, 37]. The research study proved that the regeneration processes of two indigenous species are interrupted through reducing their germination, growth rate and survival by the allelopathic action of phytotoxin release from *L. Camara* (Gentle & Duggin, 1997) [41]. Research showed that *Bunia orientalis* rapidly spreading in Europe due to allelopathic effect. Lettuce and barley seedling growth is inhibited by *B. orientalis* while week response showed by other two plants species to it (Dietz *et al*. 1996; Kruse *et al*. 2000) [26, 63]. Some plants species e.g. *Empetrum hermaphroditum*, *Kalmia angustifolia*, and *Lantana camara* perennially release active biological compounds for invasion or dominance in an ecosystem (Gentle & Duggin, 1997; Mallik, 1998; Zackrisson & Nilsson, 1992) [41, 72, 125].

Allelopathic effects are indomitable due to soil chemistry involved in allelopathy caused by allelochemicals concentration & its releasing timing is important for sensitive vulnerable species, availability of nutrients, pH microorganisms and influence in the community through competition (Rice 1984). Allelopathic intrusion among weeds and crops is very much concern with the life cycle of weedy species (Zohaib *et al*. 2016; Dakshini & Dakshini, 1996; Dakshini, 1995; Inderjit & Dakshini, 1998; Inderjit & Dakshini, 1995) [128, 22, 23, 51, 52]. Field experiments show that the perennial weed, *Pluchea lanceolata* have allelopathic effects on numerous crop species (Dakshini & Dakshini, 1996; Inderjit *et al*. 1996; Kruse *et al*. 2000) [22, 53, 63]. Wheat is allelopathically affected by *Stellaria media* which is a policarpic annual weed (Inderjit & Dakshini, 1998) [51]. During growth season the *Polypogon monspeliensis* (monocarpic weed) showed allelopathic interference by releasing phenolic compounds in large quantities towards crops species i.e. radish and cluster bean (Inderjit & Dakshini, 1995) [52].

The allelopathic effect of inhibiting one another found more effectively and consistently in those communities which have a meager number of species than in species affluent. For dominance in the diverse plant community, plants need to release a sufficient quantity of biocompounds in soil (Wardle *et al*. 2011) [114]. The uptake abilities of some vulnerable species reduced, as there is large diversity in plants among the species to species to uptake allelochemicals (Kruse *et al*. 2000; Perez, 1990; Thijs *et al*. 1994) [63, 88, 108]. In communities with those plants which have allelopathic effects (may be more severe in presence of phytotoxic invasive species) turn out to be dominant in low species diversity (Kruse *et al*. 2000) [63]. For allelopathic expression measurement, it is recommended that the relative density of contributor and recipient is an important factor. Susceptible species endurance and augmentation show positive association with density of non-susceptible species e.g. high density of *Lantana camara* negatively affects the seedling growth of two vulnerable and sensitive species while when the densities of affected plants are increased they show average seedling growth (Gentle & Duggin, 1997; Thijs *et al*. 1994; Weidenhamer, 1996) [41, 108, 115].

The tolerance of species to the allelopathic effect is not due to their coexistence; however some of their characters like roots deepness, the thickness of cuticle, metabolic pathway, and properties of the cell membrane (Kruse *et al*. 2000; Newman, 1978) [63, 80]. Physical aspects and microbial activities along with allelochemicals effects can play an important role in coadaptation (Inderjit *et al*. 1996; Rice, 2012) [53, 97]. Significantly in many cases, the species use allelopathy as a strategic tool for adaptation not for competition rather than in determination for environmental interaction. Species use allelopathic phytotoxin as a weapon against other species for resources competition such as nutrient, water, light etc. for their surveillance in an ecosystem (Kruse *et al*. 2000; Lankau *et al*. 2009) [63, 67].

4. Evolutionary and Genetical Effects of Allelopathy

Allelopathic effects depend on evolutionarily developed interaction. It's time needed to understand the mechanisms in which alien species are very aggressive in invaded area while not too much in their native lands. The evolutionary developed indigenous species suppressed by allelopathic effects of exotic species due to the interaction developed as a result of allelopathy and biochemically, it's necessary to investigate how communities affected by evolutionary history (Callaway, 2003; Evans *et al*. 2011) [15, 36]. In assessing the invasion mechanism the comparative application of ecological and biochemical traits of species show significance in the native ranges (Hierro *et al*. 2005) [49]. The assessment of assembling and amassing of allelopathic compounds in the novel and local ecosystem, and sensitivity of indigenous species to new chemicals released by invasive species, may be helpful in understanding these mechanisms (Evans *et al*. 2011; Sujeeun & Thomas, 2017) [36, 103]. A biogeographic prototype of communications among species in various ecosystems can be justified potentially by the Novel Weapons Hypothesis (NWH). The NHW theory was first anticipated for allelopathic mechanism of invasion *Centaurea diffusa* in North Americaon *C. stoebe* and this supported by recent studies on biogeographic comparisons of alien species in indigenous and novel ranges (Callaway & Aschehoug, 2000; Callaway & Ridenour, 2004; Evans *et al*. 2011; Kim & Lee, 2011; Ni *et al*. 2010; Thorpe *et al*. 2009; Zhang *et al*. 2010) [16, 17, 36, 61, 81, 109, 126]. The introduced plant species develop a response to new ecosystem while the native species adapting with novel organisms. This type of evolutionary response is noticed in coadaptation with a native rival of *Trifolium repens* and the indigenous *Leptocoris tegalicus* co-adapted with introduced plants (Carroll *et al*. 2005) [19].

The researcher suggested to genetical modification of allelopathic crops can enhance the ability to suppress weeds and overcome the autotoxicity while traditional plant breeding to overcoming this problem get less attention (Bertin *et al*. 2003; Albuquerque *et al*. 2010; Kruse *et al*. 2000; Weston & Putnam, 1985) [10, 1, 63, 118]. The main significance of breeding in non-edible crops to overcome the nearby species while in edible crops to increase yields and to improve resistance against diseases as they have a low potential of allelopathy (Bertholdsson, 2004; Albuquerque *et al*. 2010) [9, 1]. Allelopathic traits between the same or different species can be transmitted through molecular and transgenic methods (Belz, 2007; Rice, 2012) [7, 97]. Inhibition of weeds and reducing herbicides use can be achieved by the transduction of allopathic gene to rice (Zhou *et al*. 2008) [127]. For removal, the environmental hazardous contamination like agrochemical residue, industrial pollution, and pesticides through genetically modified species in future and it can be achieved through calibration of researcher from different field and research labs (Macek *et al*. 2008; Olofsdotter *et al*. 2002) [70, 84].

In an analysis, the gene expression resulted by *A. thaliana* in response when introducing to allelochemicals i.e. fagomine, gallic acid, and rutin in the same way as responded to biotic and abiotic stress (Golisz *et al*. 2008) [42]. The some complication and difficulties are facing during utilization of biotechnological technique and tools for the augmentation of the allelopathic perspective of some crops, particularly when the concerned genes belong to very established and known metabolic pathways and encompass cyclic, tissue and genotype differences in the assembling of their metabolic (Cambier *et al*. 2000; Albuquerque *et al*. 2010; Reberg-Horton *et al*. 2005; Wu *et al*. 2000) [18, 1, 95, 122].

Researcher of the University of Arizona finds during an evolutionary research study that the extracellular secretion from many microorganisms released which transform environment auspiciously. Dependability on Social evolution theory, for sustaining such traits a significant role can be played by structured habitats, by restricting the resettlement and extrication strains that endow in these products from 'cheater' strains that do well to exclusive of paying the charge. It is thus astonishing that a lot of unicellular, well-mixed microalgal populations endow in extracellular toxins that bestow ecological remuneration upon the whole population, for example, by abolishing nutrient competitors (allelopathy) (Driscoll, 2013) [28].

5. Conclusion

From the past few decades the trend to understand the myth of allelopathy get more attention among researcher and hence research studies in this regard proved the allelopathic behavior of crops and weeds by crop rotation, cover crops, green manure, intercropping, etc. Research studies prevail to explain the effects (positive and negative) of plants on their communities. Abilities and chemistry of allelopathic plants (crops and weeds) depend on the composition of soil, nutritional availability, community of neighboring plants, ecological and environmental conditions and genetic makeup etc. Modern techniques, methods have helped in recognizing latent biological compounds, make easy to know that how the allelochemicals synthesis, releases to soil, mode of action and how effects the environment. Genetical and evolutionary studies in this field are introductory. Manipulation and identification of allelopathic genes are the revolutionary achievements of researchers for control and weed management. Importantly in future research allelochemicals formulation into a commercial weed control product.

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