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(REVIEW ARTICLE)

Products of allelopathic plants for organic weed management: Environmentally approach

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Abstract

Allelopathic substances from different crops may have synergistic effects and can be applied in the mixture. In the previous research, several crop plants have been identified as phytotoxic against various weeds like sorghum, brassica, and sunflower. However, the effect of their tank mixture with each other was never studied in cotton before. Furthermore, it was not sure before this study whether the allele chemicals present in these crops viz. sorghum, sunflower and brassica can have synergistic or additive effects when applied in combination. Herbicides account for 42% of global pesticides' use. Therefore, recent emphases have been on biological weed control measures so as to reduce dependence on synthetic herbicides and finding alternative strategies for weed control in agro ecosystems. Allelopathy is one of such strategies that can be explored for biological weed control of cropping systems. The mimosine that occurs in Leucaena has the potential to be used as a bio-herbicide in weed management. Mimosine is the main allelochemicals in Leucaena and is responsible for the strong allelopathic activity of the plant. The allelopathic effects of *L. leucocephala* towards several agricultural crops and forest trees have been reported.

Plant seedlings of various crops possess allelopathic potential or weed-suppressing activity, including cucumber (*Cucumber sativa* L.), oat (*Avena spp.*) and rice (*Oryza sativa* L.). The main barley allelochemicals are the alkaloids gramine and hordenine which play a significant role in barley allelopathic potential and its defense against weeds, insects, or pathogens. In particular, barley allelopathic extracts have the ability to reduce emergence and growth of serious weeds like winter wild oat (*Avena sterilis* L.), hood canary grass (*Phalaris paradoxa* L.), black grass (*Alopecurus myosuroides* Huds.), great brome (*Bromus diandrus* Roth.), and wild mustard (*Sinapis arvensis* L.). This growth reduction has been mainly attributed to lipid peroxidation. Tamarindus contains allelochemicals on roots, leaves, seeds and bark , however, its allelopathic potential has not yet been compared to that of other allelopathic species such as Parthenium. Citharexylum (*Citharexylum spinosum* L) is equally a tree, a tropical plant with numerous usages but also know to have some allelopathic potential. Flower extracts have proved to be extremely potent to lettuce seed germination and seedlings growth and are very little known regarding its leaves phytotoxity. Consequently, the current experiment will provide additional information regarding Citharexylum leave allelopathic potential.

Sunflower (*Helianthus annuus* L.). In Asteraceae members including sunflower, the main allelochemicals are sesquiterpenes, especially heliannuoles, sesquiterpene lactones and bisnorse squiterpenes, in addition to triterpenes and flavonoids Its allelopathic effects have been tested on both other crops and weeds, in field conditions and in vitro bioassays. In recent years, the allelopathic potential of *Cynara cardunculus* L., an herbaceous perennial species belonging to the Mediterranean basin, was assessed on seed germination and seedling growth of some weeds and target crops. Allelochemicals responsible for *C. cardunculus* allelopathy are the sesquiterpene lactones cynaropicrin, deacylcynaropicrin, 11, 13-dihydro-deacylcynaropicrin, aguerin B, grosheimin, 11,13-dihydroxy-8-deoxygrosheimin and cy-naratriol, as well as polyphenols such as caffeoylquinic and dicaffeoylquinic acids, luteolin and apigenin derivatives. Around 800 species of plants produce biologically active substances, but only a few of them are used in

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agricultural practice. However, in recent years, there has been an increase in interest in allelopathy due to the effective use of allelochemicals in plant protection, such as bioherbicides, bio insecticides, biofungicides and growth regulators.

Keywords: Mimosine; Gramine; Hordenine; Ssquiterpene lactones cynaropicrin; Dacylcynaropicrin; Dicaffeoylquinic acids; Luteolin and Apigenin

1 Introduction

The allelopathic potential of several crop plants like sorghum (*Sorghum bi*color L.), sunflower (*Helianthus annus* L.) and brassica (*Brassica campestris* L.) has been reported in the previous studies (Farooq *et al*., 2013 and Iqbal *et al*., 2009). Naturally occurring allelochemicals from these crops can be easily extracted and sprayed just like herbicides (Razzaq *et al*., 2010). Previous study reported that two POST applications of sorghum water extract (WE) provided total weed biomass reduction of 35% and increased lint yield by 59%. Generally, ACWEs of sorghum, brassica or sunflower educe weed biomass in the range of 40 to 50% with the two to three applications which sometimes is neither practicable nor desirable (Khan *et al*., 2010). Hence, reduced rates of herbicide are necessary to achieve the effective weed control (Cheema *et al*., 2007). In a previous study, mixing sorghum WE ($1Lha^{-1}$) with one third rate of pendimethalin ($667ga.i.ha^{-1}$) reduced the total weed bio-mass by 50–74% and increased lint yield by 25% (Cheema *et al*., 2003).

For centuries, plant biologists have recognized that when some plant species occur together in natural or agricultural communities, they influence each other's growth. Such interactions can be mediated by root exudates in a process referred to asallelopathy. In a more restricted definition of the term (Duke, 2010), to which we will adhere in this article, ''allelopathy'' refers solely to interactions that are detrimental for at least one of the interaction partners. In such a scenario, a donor plant releases allelochemicals that inhibit the growth or development of neighboring plants, often of competitor species. Following these definitions, allelopathy is distinct from general resource competition, although both might result in the same outcome. In resource competition, one plant gains an advantage over another by more efficiently up taking one or several limited re-sources and thus depleting the available pool. In contrast, allelopathy involves the active synthesis and/or release of secondary metabolites by one plant that have a negative influence on the growth of another, regardless of resource availability. Because many crop species, including wheat (*Triticum* sp.), rye (*Secale cereale*), maize (*Zea* mays), barley (*Hordeum vu*lgare), rice (*Oryza* sativa), and sorghum (*Sorghum bicolor*) are allelopathic, targeted exploitation of allelopathy to reduce weed invasion with a simultaneous reduction of herbicide application is an attractive perspective for sustainable agriculture (Belz and Hurle, 2005) However, the applicability of allelochemicals in agricultural settings strongly depends on their stability and chemical fate upon environmental release and presence in biologically active concentrations. Synergism between different allelochemicals released by the same plant has, for example, been described for hordenine and gramine from barley, p-coumaric acid and ferulic acid, and a range of other compounds, indicating that allelopathy may be a complex process. Besides spontaneous post-release chemical breakdown in the soil, conversion and modification of allelochemicals can be accelerated by the activity of soil-dwelling microorganisms. These processes can modify the allelochemicals' chemical and biological properties, potentially rendering them more effective, inactive, or even harmful to other organisms. Hence, the role of the biotic soil environment needs to be understood and taken into account when evaluating allelopathic crop traits for agricultural strategies such as weed management [7–10]. In sweet grasses such as maize, rye, and wheat, allelopathy is often mediated by allelochemicals of the benzoxazinoid (BX) family (Kato-Noguchi *et al*., 2000).

Allelopathic substances from different crops may have synergistic effects and can be applied in the mixture. In the previous research, several crop plants have been identified as phytotoxic against various weeds like sorghum (Uddin *et a*l., 2010), brassica (Al-Sherif *et al.,* 2013), and sunflower (El Marsni *et al*., 2015). However, the effect of their tank mixture with each other was never studied in cotton before. Furthermore, it was not sure before this study whether the allelochemicals present in these crops viz. sorghum, sunflower and brassica can have synergistic or additive effects when applied in combination.

Herbicides account for 42% of global pesticides' use. Therefore, recent emphases have been on biological weed control measures so as to reduce dependence on synthetic herbicides and finding alternative strategies for weed control in agro ecosystems (Farooq *et al*., 2011). Allelopathy is one of such strategies that can be explored for biological weed control of cropping systems.

There had been studies on the potential of extracts of allelopathic plants in biological weed control in some part of the world, however past studies in Nigeria have been limited to laboratory and non-field experiments. Allelopathy is a phenomenon by which some plants influence the germination, growth and development of neighboring plants by secreting chemical substances known as allelochemicals. The influence may be inhibitory or stimulatory (Farooq *et al*., 2011). Laboratory and non-field experiments represent a too-simplified reality and the result obtained cannot be fully applied by local farmers. More so, one of the arguments of the earliest critics of the field of allelopathy is lack of adequate field studies as most of the studies reported are based on laboratory and non -field experiments (Singh *et al*., 2001). Farooq et al. (2013) also reported that allelopathy application in the field is still lacking practical evidences. Moreover, it is not possible to expect the same effects as allelopathy is a dynamic process that involves more than just donor and target plants (Jabran *et al*., 2008). Variation in the type of soil, water and nutrients availability and climatic conditions are also determinants of the occurrence of effective allelopathic activity. Consequently, past researchers in allelopathy had recommended the possibility of adopting it as a method of weed control that may be environment friendly (Khaliq, 2000; Sisodia and Siddiqui, 2010; Farooq *et al*., 2011; Jafariehya and Javidfar, 2011; Marzieh *et al*., 2013; Awodoyin and Akande, 2014).

The mimosine that occurs in Leucaena has the potential to be used as a bio-herbicide in weed management. Mimosine is the main allelochemical in Leucaena and is responsible for the strong allelopathic activity of the plant (Hong *et al*., 2003). The allelopathic effects of L. leucocephala towards several agricultural crops and forest trees have been reported (Xuan *et al*., 2006).

There is a close relationship between weeds and agricultural activities. Weeds are best defined as plants that grow and occur naturally in a given environment and continuously evolve to disrupt crop growth and agricultural activities. Therefore, the function of allelopathy in weed management is vital for the prevention of weed disturbance in crop growth and yields as well as in decreasing plant loss problems resulting from the weed interference. Allelopathy has been recognized in weed-crop interaction and its beneficial effects are being applied for obtaining better crops and yields in agricultural production (Ahmed *et al*., 2008).

Plant seedlings of various crops possess allelopathic potential or weed-suppressing activity, including cucumber (*Cucumber sativa* L.), oat (*Avena spp*.) and rice (*Oryza sativa* L.). The main barley allelochemicals are the alkaloids gramine and hordenine which play a significant role in barley allelopathic potential and its defense against weeds, insects, or pathogens. In particular, barley allelopathic extracts have the ability to reduce emergence and growth of serious weeds like winter wild oat (*Avena sterilis* L.), hood canary grass (*Phalaris paradoxa* L.), black grass (*Alopecurus myosuroides* Huds.), great brome (*Bromus diandrus* Roth.), and wild mustard (*Sinapis arvensis* L.) (Farhoudi *et al*., 2012 and Farhoudi and Lee, 2013). This growth reduction has been mainly attributed to lipid peroxidation (Lebecque *et al*., 2018 and Ben-Hammouda *et al*., 2001).

However, because of this allelopathic potential, some barley varieties could cause essential adverse effects in crop rotations (Bouhaouel *et al*., 2015), as barley allelopathic potential varied between varieties. Barley has been rated as one of the most important cereals because of its great adaptability to a marginal environment such as dry or saline soils (Rehman *et al*., 2019).

Cover crop residues such as *Avena fatwa*, *Brassica nigra*, *Fagopyrum esculentum, Secale cereale*, *Sorghum bicolor*, *Triticum aestivum*, *Vicia vilosa* and others have been used in weed management on a limited basis. Crop residues from existing crop or rotational crops can provide selective weed control through their physical presence on the soil surface and through the release of allelochemicals (Barker and Bhowmik 2001 and Jabran *et al*., 2015). The allelochemicals are concentrated and exuded through roots or are released during decomposition of plant litter (Bonanomi *et al*., 2006).

Earlier reports have shown that weed control could be achieved by growing cover crop of rye, barley, wheat or sorghum to a height of 40–50 cm, then desiccating the crop by either contact herbicides or winter freezing, and allowing their residues to remain on the soil surface (Barker and Bhowmik, 2001). Barker and Bhowmik, (2001) reported that *Secale cereale* residue used as mulch reduced total weed biomass by 63%. It was found that disappearance of rye allelochemicals was more closely related to weed suppression than to the disappearance of rye residues. Duration of cover crops residue on the soil surface often determines the extent of an effective weed control period. They also studied the disappearance of *Secale cereal* residue and allelochemicals, DIBOA (2, 4-dihydroxy-1, 4-benzoxazin-3-one), DIBOA-glycoside and BOA from *Secale cereal* residues. These authors found that 50% of the initial content of *Secale cereal* residue disappeared by 105 days after clipping. However, the combined active compound concentrations of DIBOA-glucoside, DIBOA, and BOA disappeared 168 days after clipping.

Allelopathic compounds are a suitable substitute for synthetic herbicides because they do not have residual or toxic effects, however, so far only 3% of the approximately 400,000 known compounds in plants that show allelopathic activity have been recognized as acting as bioherbicides, although more than 2000 plant species (39 families) have strong allelopathic effects (Li *et al*., 2019). The deployment of allelopathic cover crops, intercropping, the inclusion of allelopathic plants in crop rotation, and the use of their residues as mulch are important for ecological, sustainable, and integrated weed control systems (Jabran *et al*., 2015).The most significant challenge to sustainable modern crop protection is the limited availability of bioherbicides. For current researchers, allelopathic plants can be a source for identifying and isolating new allelopathic substances. After examining their bioactivity under laboratory and feld conditions, promising compounds can be recommended for novel natural herbicide development for sustainable agriculture (Motmainna *et al*., 2021).

Allelopathy is an inherent feature of a number of plant species, Parthenium (*Parthenium hysterophorus* L.) being among the most significant especially in Australia (Belgeri & Adkins 2015). Due to its allelopathic potential, Parthenium is renowned for its impact on food production (Nigatu *et al*., 2010; Adkins and Shabbir, 2014) and in reducing biodiversity by rapidly invading ecosystems (Nigatu *et al*., 2010). Allelopathic effects of Parthenium onsome plant species at early stages of development is documented, some of them being onion (Wakjira 2009), *Cassia* spp and lettuce (Wakjira *et al*., 2005). Although allochemicals are found on various organs of Parthenium, leave residues, due to their high allelopathic potential are commonly used to carry out allelopthic bioassays (Rahman, 2006) .

Tamarindus (*Tamarindus indica*) is a multi-purpose tree in some parts of the world which is also known for its allelopathic interactions with neighboring plants (Syed et al. 2014). Although less thoroughly studied as Parthenium, Tamarindus' allelochemical compounds are beginning to be identified and investigated (Syed *et al*., 2014). It is acknowledged that Tamarindus contains allelochemicals on roots (Shahnaz Parvez *et al*., 2003), leaves (Parvez *et al*., 2003), seeds (Parvez et al. 2004) and bark (Parvez *et al*., 2004), however, its allelopathic potential has not yet been compared to that of other allelopathic species such as Parthenium.

Similarly, very little is known regarding Litchi (*Litchi chinensis*) allelopathic activity. Though a few studies seem to indicate that Litchi is allelopathic (Wang *et al*., 2013 and 2015), an exploratory research which tested the possible allelopathic potential of twenty Asian plant leave species was inconclusive (Fujii, 2004). Therefore, another experiment could either ascertain or rule out the current assumptions.

Citharexylum (*Citharexylum spinosum* L) is equally a tree, a tropical plant with numerous usages but also know to have some allelopathic potential (Fujii *et al*., 2004; Ayeb-Zakhama *et al*., 2015). Flower extracts have proved to be extremely potent to lettuce seed germination and seedlings growth (Ayeb-Zakhama *et al*., 2015) and are very little known regarding its leaves phytotoxity. Consequently, the current experiment will provide additional information regarding Citharexylum leave allelopathic potential.

As regards the Asteraceae, the most studied allelopathic crop is sunflower (*Helianthus annuus* L.). In Asteraceae members including sunflower, the main allelochemicals are sesquiterpenes, especially heliannuoles, sesquiterpene lactones and bisnorse squiterpenes, in addition to triterpenes and flavonoids (Macías *et al*., 2006) Its allelopathic effects have been tested on both other crops and weeds, in field conditions and in vitro bioassays (Rawat *et al*., 2017). In recent years, the allelopathic potential of *Cynara cardunculus* L., an herbaceous perennial species belonging to the Mediterranean basin (Pandino and auromicale, 2020), was assessed on seed germination and seedling growth of some weeds and target crops (Scavo *et al*., 2018 and 2019). Allelochemicals responsible for *C. cardunculus* allelopathy are the sesquiterpene lactones cynaropicrin, deacylcynaropicrin, 11,13-dihydro-deacylcynaropicrin, aguerin B, grosheimin,11,13-dihydroxy-8-deoxygrosheimin and cy-naratriol, as well as polyphenols such as caffeoylquinic and dicaffeoylquinic acids, luteolin and apigenin derivatives (Rial *et al*., 2014; Scavo *et al*., 2019 and 2020) Recently, Rial et al. (2020) demonstrated the phytotoxicity of safflower (*Carthamus tinctorius* L.), a thistle-like herbaceous plant cultivated in regions with arid or semiarid climate for industrial applications (oil production, pigments and human consumption), indicating the sesquiterpene lactones dehydrocostuslactone and costunolide and several strigolactones as the main allelochemicals released by root exudation.

Allelopathy in Poaceae plants has been widely described. Rice (*Oryza sativa* L.), rye (*Secale cereale* L.), common (*Triticum* aestivum L.) and durum wheat (*T. durum*), sorghum (*Sorghum spp.*), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) are probably the most studied allelopathic crops. The spectrum of their allelochemicals has been investigated in depth, with benzoxazinoids (DIBOA, HMBOA, BOA, DIMBOA, MBOA), phenolic acids, flavonoids and terpenoids recognized as major allelochemicals (Chon and Kim, 2004 and Weston *et al*., 2013 Stochmal *et al*., 2006). Moreover, the biosynthetic pathways of some of these allelochemicals have been sequenced, such as in the case of sorgoleone (Stochmal *et al*., 2006). Given the considerable knowledge of this family and chemicals involved, the recent research has focused on the utilization of their allelopathic mechanisms for weed control.

The Brassicaceae family comprises more than 3200 species, of which the Brassica genus includes several highly allelopathic crops such as canola (*Brassica napus* L.), Indian mustard (*B. juncea*), black mustard (*B. nigra*) and cabbage (*B. oleracea*). (Rial *et al*., 2020 and Rehman *et al*., 2018) reviewed the use of Brassica allelopathy for weed management and documented that glucosinolates (mainly isothiocyanates and nitriles) and the endogenous steroidal compounds brassi-nosteroids (e.g., brassinolide, 24-epibrassinolide, 28-homobrassinolide) are responsible for their phytotoxicity. Significant evidence of allelopathic effects has been reported in some leguminous crops. The best known example is alfalfa (*Medicago sativa* L.), commonly used as living or dead mulch for weed management, and widely studied also as a plant model in autoallelopathy (Chon and Kim, 2002 and Chon *et al*., 2006). Other examples of allelopathic Fabaceae plants are the common bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.), peanut (*Arachis hy*pogaea L.) and, recently, liquorice (*Glycyrrhiza uralensis* Fisch.) (Li *et al*., 2014; Ren *et al*., 2014)and Asaduzzaman and Asao, 2012) Fabaceae allelopathy is mainly due to phenolic acids such as benzoic, cinnamic, p-hydroxybenzoic, vanillic, coumaric, ferulic, caffeic, salicylic, etc.

The Solanaceae family is gaining in interest for the allelopathic potential shown by some important members. Rial et al. (2018), for example, investigated the allelopathic traits of tomato (*Solanum lycopersicum* L.) and identified its major root allelochemicals as the alkaloid -tomatine, the steroid stigmasterol, the furocoumarin bergapten and the strigolactones solanacol, orobanchol, strigol, etc. Important phytochemical advances were also made in the discovery and identification of tobacco (*Nicotiana tab*acum L.) (Baek *et al*., 2017) and red pepper (*Capsicum annuum* L.) allelochemicals (Sun and Wang, 2015).

Early studies of the effects of barley as a "smother crop" for suppressing weed growth found that substances released from the foliage contained allelopathic activity responsible for severely inhibiting growth of chickweed (*Stellaria media* L.). Several laboratory or growth chamber studies have demonstrated allelopathic effects of extracts of barley plants on seed germination and seedling growth of numerous weed species (Chon and Kim, 2004 and Dhima *et al*., 2006). Although growth reduction of weedy Brassica species under irrigated field conditions was largely due to superior competitiveness of barley for light and nitrogen, allelopathy as a component of overall interference could not be excluded. In field studies under no-tillage, spring barley residues reduced weed densities by ≤90% compared with soils devoid of surface residues. Subsequent studies confirmed the effectiveness of barley residues in reducing plant densities of the weeds portulaca (*Portulaca oleracea* L.) and smooth crabgrass[*Digitaria ischaemum*(Schreb.) Muhl.] 60 days after killing the barley with paraquat. Barley residues added to the soil surface of field plots inhibited emergence of eastern black nightshade (*Solanum ptycanthum* Dun.) by 98% and yellow foxtail [*Setaria glauca* (L.) Beauv.] by 81% 30 days after planting the weed species. Barley grown in rotation with wheat provided an apparent residual weed control observed in the wheat crop for ≤2 years (Legere and Stevenson, 2002).

Muhammad et al. (2011) reported that sunflower plant extract application was found to be reduce the weed population. Parthenium incorporated into soil reduces the growth of Cynodon dactylon. Leachate of dry menthe (cumin) controls most of the weeds. Velvet bean suppress purple nut sedge. Xanthotoxin inhibits germination and growth of Lactuca sativa. AAL Toxin - Alternaria alternate lycopersicii is effective against dicot weeds at low concentration.

Around 800 species of plants produce biologically active substances, but only a few of them are used in agricultural practice. They account for less than 1% of the market for plant protection agents, especially those for weed control. However, in recent years, there has been an increase in interest in allelopathy due to the effective use of allelochemicals in plant protection, such as bioherbicides, bio insecticides, biofungicides and growth regulators (Głab *et al*., 2017 and Grulova *et al*., 2020). This may be a result of the implementation of integrated plant protection and the need to implement sustainable development, including in agriculture. Allelochemicals may be found in different parts of plants, i.e., in the roots, leaves, stems and in the seeds (Alsharekh *et al*., 2022). They may alter a variety of physiological processes, such as cell division and differentiation, water and ion uptake, phytohormone metabolism, photosynthesis, respiration and enzyme function (Amri *et al*., 2013). The production and release of allelocompounds by plants may affect other organisms, including plants, in the way they inhibit or stimulate their growth and development (Scavo and Mauromicale, 2021 and Pytlarz and Gala-Czekaj, 2022). The way in which these compounds found in plants act is similar to that of synthetic herbicides. Due to the high variety of metabolites that they contain, it is possible to generate new and environmentally friendly natural herbicides (Duke *et al*., 2002 and Requesón *et al*., 2022). Allelocompounds of plant origin are in most cases safe for humans and are not toxic to soil or water. Still, synthetic herbicides are very effective, though their overuse has a negative effect on human health and the environment (Alsharekh *et al*., 2022).

2 Conclusion

Allelopathic substances from different crops had significant impact against various weeds like sorghum, brassica, and sunflower. Therefore, recent emphases have been on biological weed control measures so as to reduce dependence on synthetic herbicides and finding alternative strategies for weed control in agro ecosystems. Allelopathy is one of such strategies that can be explored for biological weed control of cropping systems. Mimosine is the main allelochemicals in Leucaena and is responsible for the strong allelopathic activity of the plant. The allelopathic effects of *L. leucocephala* towards several agricultural crops and forest trees approved the most suitable to minimize the chemical herbicides and safe the food products from chemicals and produce organic foos fit for humanity.

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