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An Effective Approach to Environmentally Friendly Weed Control Through Allelopathy: A Review

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ABSTRACT

The effective approach to environmentally friendly weed control through allelopathy was reviewed. Food security and agricultural sustainability are threatened by the growing world population. In contemporary agriculture, allelopathy has become a practical method for addressing a variety of problems such weed management. The use of allelopathy for weed and other pest management in agricultural production is being investigated using a number of techniques, including as crop rotation, cover cropping, intercropping, mulching, crop residue integration, and water or ethanol extract application. Allelopathic effects for sustainable weed management can be manifested in the form of weed on crop, crop on weed, and weed on weed. Different types of crude extract or ethanol/methanol extracts of either the leaf, stem, rhizomes, or flowers of the concerned species have been shown to have an inhibitory effect on both crop and weed species biomass production as well as seed germination, radicle and plumule elongation. Allelopathy, one of several weed management strategies, may result in lower labor costs and more efficiency without harming the environment. Alternatively, allelopathy can be utilized in the form of extracts of a promising crop or weed species to suppress weed populations with a reduced herbicide rate, thereby broadening the spectrum of control measures.

***Keywords*:** Allelopathy, weed control option, crops, sustainable weed management

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1. INTRODUCTION

According to Dayan *et al*. (2011) and Wang *et al*. (2007), the majority of labor and chemicals utilized in agricultural systems are used to control weeds. Weeds strive for moisture, nutrients, space and light with crops (Zimdahl, 2013). Weeds therefore have a greater negative influence on agricultural production than any other pest (Dayan *et al*., 2011). Uncontrolled weed populations that compete with cash crops for resources have been linked to yield losses of 40% to 80% (Akobundu, 1987; Karlen *et al*., 2002). It is possible to control weeds using a variety of methods, including cultural (hand weeding/hoe weeding, rotation), mechanical and chemical biological, land management, the use of resistant crop varieties, and crop rotation (Griepentrog and Dedousis, 2010; Bergin, 2011; Rueda-Ayala *et al*., 2011; Chauvel *et al*., 2012; Young *et al*., 2014).

Through the use of these weed management techniques, weed infestation levels have been kept below critical levels while crop productivity has increased globally. Even while these weed management techniques significantly increased crop output, some difficulties were also faced. The biggest obstacles to hand weeding include dwindling supply, rising labor costs, and uneven weed management (Carballido *et al*., 2013; Gianessi, 2013). Similar to manual weed control, mechanical weed control necessitates increased soil turnover, which can disrupt soil structure and reduce soil fertility (Smith *et al*., 2011). According to Bond and Grundy (2001), mechanical weed management is not always efficient, can be expensive, and is not very durable. Similarly, the main obstacles to routinely utilizing herbicides for weed control include herbicide-resistant weeds, health impacts, agricultural damage, and environmental concerns (Annett *et al*., 2014; Hoppin, 2014; Starling *et al*., 2014).

According to Heap (2022), herbicide resistance in weeds, soil persistence in herbicides, groundwater contamination, crop damage, and other issues are all brought on by modern agricultural techniques. Plant extracts with allelopathic activity have been recommended as effective, affordable, and secure weed control options in addition to researching potential eco-friendly natural alternatives (Bhadoria, 2011; Farooq *et al*., 2011; Hossain *et al*., 2017). Secondary metabolites include phenolics, terpenoids, and alkaloids are among the most prevalent allelochemicals produced by agricultural plants (Batish *et al*., 2007; Razavi, 2011; Scavo *et al*., 2019). As a result, the objective of this review is to identify the numerous allelopathic elements that can be used as efficient instruments for long-term weed control in crop production.

1. 1. Allelopathy and allelochemicals

Allelopathy is a biological phenomenon by which an organism produces one or more biochemicals that influence the germination, growth, survival, and reproduction of other organisms. These biochemicals are known as allelochemicals and can have beneficial (positive allelopathy) or detrimental (negative allelopathy) effects on the target organisms and the community (Meiners *et al*., 2012). Allelopathy is further defined as the direct or indirect impact of a plant on nearby plants or the microflora or microfauna that they are associated with through the generation of allelochemicals that impede the plant's growth (IAS, 2018). In order to protect themselves from microbial invasion, herbivore predation, or competition from other plants, the plants emit allelochemicals (Kong *et al*., 2019). Allelopathic potential for weed management under field conditions has been utilized in various ways, i.e., surface mulch (Khaliq *et al*. 2015), incorporation into the soil (Matloob *et al*. 2010), aqueous extracts, rotation (Narwal 2000), smothering (Samarajeewa *et al*., 2006; Mennan *et al*. 2020).

1. 2. Possible Allelopathic interaction

Allelopathic interactions between crops and weeds in agro ecosystems can be of four types as describes below:

i) Weed on Crop,
ii) Crop on Weed
iii) Weed on weed, and
iv) Crop on crop

(Farooq *et al*., 2011) which can be achieve through crop rotation, cover cropping, mulching (Jabran *et al*., 2015), allelopathic crop water extract. In crop rotation, allelopathic crops release allelochemicals through roots or via decomposition of crop residue to suppress weeds and other pests. Crops such as sudan grass (*Sorghum sudanense* L.), common buckwheat (*Fagopyrum esculentim* Moench), rye, barley, sunflower (*Helianthus annuus* L.), sweet clover, cowpea can effectively smother various weed species (Cheema *et al*., 2012 & 2013).

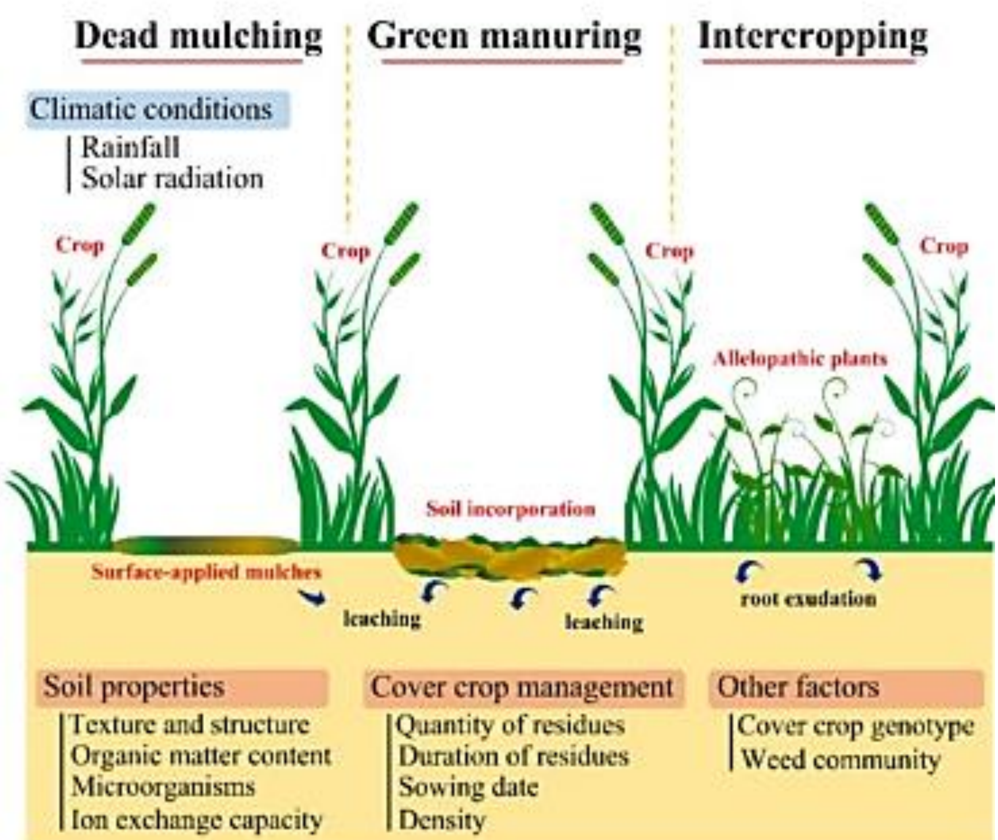

Figure 1. Practical applications of allelopathic cover cropping by intercropping, surface-application (dead mulching) and soil incorporation (green manuring) of crop residues. Allelopathic effects are due to the release of active allelochemicals into the soil through root

exudation from living mulches and leaching from decomposing residues. The level of phytotoxicity is closely influenced by climatic conditions (rainfall, solar radiation), soil properties (texture, structure, organic matter content, pH, cation exchange capacity and microorganisms), characteristics of the weed community, cover crop genotype and management (quantity and duration of residues, sowing date and density).

1. 3. Allelopathic compounds

The secondary products could be classified in the following categories but it is impossible to enumerate each and every chemical identified as an allelochemicals. Rice (1984 & 2008) and Putnam and Tang (1986) divided allelochemicals into various major chemical groups. Among which are:

- Phenolic acids
- Coumarins- block mitosis in onions by forming multinucleate cells.
- Terpinoids
- Flavonoids
- Scopulatene-inhibits photosynthesis without significant effect on respiration
- Alkaloids

2. DISCUSSION

2. 1. Allelopathic effects of Weed on Arable and Horticultural Crops

Findings from Stef *et al*. (2015) revealed that extracts from roots of Johnson grass significantly inhibits germination, plant height and dry matter of maize and soybeans (Table 1). This finding further corroborated those of Sunar and Agar (2017) who affirmed the germination inhibiting ability of methanol extracts of *Convovulus arvensis* L., *Cyperus rotundus* L. and *Sorghum halepense* L. on maize seeds.

The inhibitory effect of aqueous root extracts of Johnson grass on seed germination of soybean, peas and vetch was reported to be between 28.8 and 86.3% (Kalinova *et al*., 2012). They further reported the suppressive effect of the aqueous extracts from the roots of Johnson grass on the seedling growth (from 17.1% to 86.1%) and the fresh biomass of seedlings (from 8.3% to 97.9%) of soybean, pea and vetch.

In their studies using water and methanol extracts from the dry matter of *Xanthium strumarium* and *Abutilon theophrasti*, Konstantinovic et al. (2013) found that the plants had a germination-inhibiting and seedling growth effect on maize (14.8-26.83%) and soybean (18.5-35.82%) in comparison to controls, which stands at 95 and 92%, respectively. According to Tian et al. (2022), water extract of velvetleaf strongly inhibited the development of maize, wheat, and soybean, and the inhibitory impact became noticeably more pronounced with increasing extract concentration. Similar to this, the impact of velvetleaf powder was evaluated on the development and yield of the three studied crops in both pot and field studies. The findings indicated that in soybean and maize seedlings, the below-ground dry weight was more significantly impacted than the above-ground weight, however in wheat, the opposite is true.

The growth of primary seedlings of several leguminous crops (*Glycine max*, *Pisum sativum*, and *Vicia sativa*) was researched by Marinov-Serafimov (2010) to determine the allelopathic ability of weed extracts of some weed biotypes to have depressive effect. Findings demonstrate that primary seedling growth in all examined plants decreased significantly with increasing extract concentration as compared to the control treatment. The seed germination of *G.max*, *P. sativum*, and *V. sativa* was inhibited by water extracts from fresh and dry biomass of *Amaranthus retroflexus, Chinepodium album, Erigeron canadensis,* and *Solanum nigrum*. The inhibition rate for the extracts from fresh biomass ranged from 28.8 to 81.5% and for the extracts from dry weed biomass from 26.8 to 89.2%. Mohanty et al. (2021) reported the allelopathic effect of aqueous extract of *Ageratum conyzoides* L. on seed germination and seedling growth of *Vigna radiata*. Findings revealed a significant reduction in seed germination, growth of root and height of seedlings as concentration increased from 20-100 mg/ml.

Table 1. Allelopathic effects of Weed biotype on some arable and horticultural crop species.

Weeds	Effects on	Cause/source	Resultant effect	Reference
Johnson Grass (*Sorghum halepense* (L.) Pers.	Maize, soybean	Aqueous and alcoholic extract of fresh rhizomes, dried rhizomes, leaf and seeds	Reduced seed germination, growth and dry biomass production	Ștef *et al*., 2015
Johnson Grass (*Sorghum halepense* (L.) Pers.	Soybean, pea and vetch, Egg plant	Aqueous extracts of roots	Reduced seed germination, growth rate and the accumulation of fresh biomass	Kalinova *et al*., 2012
Convulvulus arvensis L., *Cyperus rotundus* L. and *Sorghum halepense* L.	Maize	Methanol extract	Germination and growth inhibitory effect	Sunar and Agar, 2017
Aesculus hippocastanum	Maize	etheric extracts	Inhibits germination, cellular division e.g root elongation,	Ștef *et al*., 2015
Xanthium strumarium L. and	Maize and soybean	Water, hexane, ethyl acetate, and methanol	Inhibits seed germination of maize and soybean	Konstantinovic *et al*., 2013

Abutilon theophrasti Med		extracts at different conc.		
Abuthilon theophrasti Med	Maize, wheat and soybean	Cold aqueous water and powder extracts	Germination and seedling growth inhibition	Tian *et al.* 2022
Amaranthus retroflexus, *Chenopodium album*, *Erigeron canadensis* and *Solanum nigrum*.	*Glycine max* L., *Pisum sativum* L. and *Vicia sativa* L	cold water extracts of fresh and dry biomass	Germination and growth inhibition;	Marinov-Serafimov, 2010
Ageratum conyzoides	*Vigna radiate* L. (Mung bean)	Aqueous extract	seed germination, seedling length and dry weight inhibition	Mohanty *et al.*, 2021
-Ditto-	*Raphanus sativus* (Radish) and *Cucumis sativus* (Cucumber)	Aqueous root extract	Decreased seed germination, seedling growth, fresh weight, dry weight, vigor index, total chlorophyll and carotenoid	Akter Pervin and Islam Maksuda, 2019
-Ditto-	Rice	Leaf and root extract	seed germination, seedling length and dry weigh inhibition	Negi *et al.*, 2020
-Ditto-	Vicia faba	Leaf and flower extract	Germination inhibition and seedling survival	Kumari and Kumar, 2022
Chromolaena odorata, *Ageratum conyzoides* and *Cyperus esculentus*	Tomato	Exudates from vegetative parts	Seed germination	Martina & Onyebuchi, 2022

Akter Pervin and Islam Maksuda (2019) highlighted the allelopathic effect of *Ageratum conyzoides* root extract on *Raphanus sativus* and *Cucumis sativus* to significantly decreased seed germination, seedling growth, fresh weight, dry weight, vigor index, total chlorophyll and carotenoid of both tested crops. In a related discovery, Negi *et al*. (2020) examined the allelopathic impact of fresh and air-dried plant parts (leaves and roots) of *A. conyzoides* on two rice varieties.

The results showed that the effects of leaf extracts were more inhibiting than those of root extracts, and that overall, dry aqueous extracts of leaf and root were more inhibiting than fresh aqueous extracts. According to Kumari and Kumar (2022), *A. conyzoides* has an allelopathic impact on the characteristics of Vicia faba seeds and seedlings.

Findings revealed that, flower extract considerably suppresses growth traits more than leaf extract does, regardless of concentration, changing the plant's ability to develop and survive. Martina & Onyebuchi (2022) found that *Ageratum conyzoides* exudates closely followed C. odorata exudates in terms of their ability to inhibit tomato seed germination on filter paper. Compared to *C. odorata* and *A. conyzoides*, *C. esculentus* inhibited tomato seed growth the least.

2. 2. Allelopathic effects Weeds on Weeds of Arable and Horticultural

The rhizomes of *Imperata cylindrica* significantly ($P < 0.05$) inhibits the emergence and growth of *Borreria hispada* (Dahiya *et al.*, 2017) (Table 2). According to Koger *et al*. (2004), Cogon grass has an allelopathic effect on some grasses and broadleaf weeds, stunting their germination and seedling growth. Cogon grass residue (foliage and root) extracts at concentrations as low as 0.5 % inhibited germination and seedling growth of Bermuda grass (62 %) and Italian rye grass (96 %).

According to Dahiya *et al.* (2017), Johnson grass living and decaying rhizomes have an allelopathic effect on Giant foxtail (*Setaria faberi*), Large crabgrass, and other plants by inhibiting the growth of their roots and shoots. Studies on the allelopathic action of *Sorghum halepense* on a few noxious weeds were undertaken by Sakran *et al*. (2020).

Table 2. Allelopathic effects weeds on weeds of arable and horticultural farmlands.

Weeds	Effects on	Cause/source	Resultant effect	Reference
Cogon grass (*Imperata cylindrica* L.)	Button weed (*Borreria hisppada*)	Exudates of inhibitory substances through rhizomes	Inhibits emergence and seedling growth	Dahiya *et al*, 2017
Imperata cylindrica L	*Sida spinosa* L., *Brachiaria ramosa* (L.) Stapf., *Echinochloa crus-galli* (L.) Beauv., *Cynodon dactylon* (L.) Pers. and *Lolium multiflorum* Lam.	Aqueous extracts of foliage and below ground parts, leachates, root exudates	Germination and seedling inhibition	Koger *et al*., 2004
Johnson grass	Giant foxtail (*Setaria faberi*), Large crabgrass	Living and decaying rhizomes and leaves	Inhibits root and shoot growth	Dahiya *et al*, 2017

Sorghum halepense (L.) Pers	*Cuscuta campestris*, *Lolium temulentum*, *Amaranthus blitoides*, *Amaranthus retroflexus* and *Portulaca oleracea*	Arial portion of the plant	Germination inhibition, fresh and dry biomass of weed seedlings	Sakran *et al*., 2020
Tithonia diversifolia	*Phalaris minor; Chenopodium album* L.; *Amaranthus viridis*; *Tridax procumbens* L. *Talinum triangulare*; *Chromolaena odoratata* (siam weed),	Root, stem and leaf extract	Reduction in weed density, weed dry weight and increased weed control efficiency (WCE)	Ajayi, 2017
Senna siamea Lam. and *Pinus carribaea* (Jacq.) ex. Walp	*Euphorbia heterophylla* L	Aqueous leaf extracts	Germination and seedling inhibition	Ayeni, 2017
Chenopodium album, *Convolvulus arvensis*	Avena fatua	Water extract	weed density, weed fresh weight, weed dry weight, weed control index	Mengal *et al*. 2015; Arafat *et al*. 2015
Trianthema portulacastrum	*Amaranthus tenuifolius* and *Chenopodium arvensis*	aqueous extract of shoot and root	Root length, shoot length and seedling dry weight reduction	Muhammad Shahid Hassan *et al*., 2023
Ageratina adenopnora (Mexican Devil)	*A. conyzoides, B. pilosa, C. rotundus and G. parviflora*	Aqueous extract Compost extract, stem and leaf extract	Seed germination inhibition, seedling growth	Das *et al*., 2018

The results showed that there was a considerable reduction in the fresh and dry biomass of weed seedlings. *Phalaris minor*, *Chenopodium album*, *Amaranthus viridis*, *Tridax procumbens*, *Talinum triangulare*, and *Chromolaena odoratata* were found to be significantly reduced the weed density, weed dry weight and increased weed control efficiency when treated with root, stem, and leaf extracts of *Tithonia diversifolia*, according to Ajayi (2017). According to research conducted by Ayeni in 2017 on the allelopathic effect of *Senna siamea* and *Pinus carribaea* aqueous leaf extracts on *Euphorbia heterophylla* on cowpea accession, there was only a minimal amount of weed germination and seedling inhibition as compared to herbicide and hoe weeding, which served as the control, but it was still preferable to weedy check. Arafat et al. (2015), reported that several weeds were subjected to the allelopathic effects of aqueous extracts of *Salvia moorcroftiana*, *Verbascum thapsus*, and *Chenopodium album*.

The results show that weed germination and radical length were significantly decreased. Mengal et al. (2015) published the results of their experiments on the effects of allelopathic water extracts of *Chenopodium album* and *Convolvulus arvensis* on wheat and its companion weeds. Despite the fact that the results do not indicate a substantial decrease in weed density at 20 DAS, there is a significant difference at crop maturity, where *C. album* and *C. arvensis* produced 12.33 and 11.00 n m^{-2} at maturity as opposed to the 30.33 nm^{-2} seen in weedy check plots. Similarly, weed fresh weight of 60 and 61 (g m^{-2}) was recorded in *C. album* and *C. arvensis* respectively, compared to weedy check (180.3 g m^{-2}) which recorded higher value. Concurrently, this resulted in higher weed control index (%) in that order 60.2%, 40.9% of *C. album* and *C. arvensis* at 60% concentration compared to weedy check (2.15%). The shoot and root aqueous extract of *Trianthema portulacastrum* showed significant reduction on root length, shoot length and seedling dry weight of *Amaranthus retroflexes* and *Chenopodium arvensis* weed biotypes (Muhammad Shahid Hassan *et al*., 2023). The inhibitory effects of aqueous extract, compost extract, stem and leaf extract *Ageratina adenopnora on A. conyzoides, B. pilosa, C. rotundus and G. parviflora* was studied by Das et al. (2018).

2. 3. Allelopathic effects Arable and Horticultural Crops on Weed

Findings from Shen *et al*. (2022) demonstrated the allelopathic effect of different (ether, petroleum, ethyl acetate, and n-butanol alcohol) extracts of sweet potatoes leaves on four invasive weeds, *Bidens pilosa*, *Galinsoga parviflora*, *Lolium multiflorum*, and *Phalaris minor*, were tested for their susceptibility to the allelopathic effects of five main standard compounds (Table 3), including linoleic acid (LA), ethyl linoleate (EL), palmitic acid (PA), and ethyl palmitate (EP). The germination and seedling growth of the five invasive weeds were strongly impacted by all chemicals. Additionally, LA>PA>EP>EL&ELL had largely inhibited weed biomass, root and shoot length of the invasive weeds.

The findings were further supported by those of Ma *et al*. (2020) and Macías *et al*. (2019). In related research, RAVLI *et al*. (2015) showed the allelopathic potential of Fennel, Rue, and Sage on the weed species Hoary Cress (*Lepidium draba*), with fennel seeds having the largest inhibitory effect.

Germination reduction varied from 21.2 to 34.9%. Only the use of fennel significantly reduced shoot length while the use of rue decreased root length by 9.3%. Their findings supported those of Dhima et al. (2009), who demonstrated the efficacy of aromatic and medicinal herbs as well as their varied impacts against weed species. Dhima *et al*. (2009) reported that extracts from dried plant biomass of fennel, coriander, and anise (*Pimpinella anisum*) show significant detrimental impact and reduce of germination, root length, and fresh weight of barnyard grass *(Echinochloa crus-galli*).

Similar to this, Kadiolu and Yanar (2004) and Pirzad *et al*. (2010) showed that sage extract has the ability to suppress common purslane (*Portulaca oleracea* L.), velvetleaf (*Abutilon theophrasti* L.), redroot pigweed, and wild oat (*Avena sterilis*). In another development. Makizadeh et al. (2009) reported the inhibitory efficacy of dried powdered leaf extract of Rue (*Ruta graveolens* L.) on velvet flower (*Amaranthus retroflexus* L.), flixweed (*Descurainia sophia* L.), and purslane (*Portulaca oleracea* L.).

Table 3. Allelopathic effects of some arable and horticultural crops on weed biotypes.

Crop specie	Effects on	Cause/source	Resultant effect	Reference
Sweet potato	*Bidens pilosa*., *Galinsoga parviflora*., *Lolium multiflorum*., and *Phalaris minor*.	Petroleum ether extract, ethyl acetate, and n-butanol alcohol extracts	Germination and seedling growth (shoot and root length) inhibition.	Shen *et a*l., 2022; Ma *et al*., 2020; Macías *et al*. (2019).
Fennel, Rue and Sage	Hoary Cress (*Lepidium draba*)	Water extracts	Germination, root and shoot inhibition and fresh weight reduction	Ravlić *et al*., 2015; Dhima *et al*. (2009); Kadiolu and Yanar (2004) and Pirzad *et al*. (2010)

Rue (*Ruta graveolens* L.)	*Chenopodium album, Cyperus rotundus,* common purslane and flixweed (*Descurainia sophia*)	Aqueous extracts of dried powdered leaf	Germination, radicle and plumule inhibition	Makizadeh *et al*., 2009.
Brassica sp.	*Amaranthus retroflexus* L., *Chenopodium album* L.	Shoot and root mulch incorporation	Reduced seedling emergence	Bangarwa and Norsworthy, 2014; Jabran *et al*., 2015
Broccoli, white cabbage and flax	*Orobanche crenata* Fors (Broom rape)	As trap and catch crop	Reduced number of shoots and dry weight.	Aksoy *et al*., 2016
Wheat	*Abutlion theophrasti, Aegilops tauschii, Amaranthus retroflexus, Avena fatua, Digitaria sanguinalis*	Grown in mixed culture adopting the replacement series technique and Soil incubation experiments.	2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA) produced by wheat inhibit the germination and growth of weeds	Yong-Hua *et al*., 2016
Fresh garden rocket plant (*Eruca sativa*)	*Phalaris minor* Retz.; *Beta vulgaris* (T.)	Aqueous extract (80% conc.)	Maximum growth inhibition	El-Wakeel *et al*., 2019
Fresh white cabbage	*Amaranthus retroflexus* L., *Chenopodium album* L.	Aqueous and methanol extract 50% conc.	Germination inhibition by (95-97%)	Kural and Ozkan, 2020
Cruciferous Plants (garden rocket, turnip, white cabbage, broccoli, and finally red cabbage)	Johnson grass	Aqueous extract	Germination inhibition, shoot and radicle length of Seed and rhizome at high conc. of 10 & 20%	Elsekran *et al*., 2023
Leaves of *Eucalyptus camaldulensis* (L.)	*Convolvulus arvensis* L. and *Cyperus rotundus* L	Water extract and powder	inhibition in germination and seedling growth	Kandhro *et al*., 2016
Sun flower and Johnson grass	*Cyperuns rotundus* and *Echinochloa colonum*	Residue powder incorporation, water extract at different conc.	Germination inhibition,	Lalchand *et al*., 2021

According to the results, extracts considerably reduced the germination of seeds from weed species, and the degree of inhibition grew as extract concentration increased (0>1>2.5>5>10>15%). On a side note, results by Bangarwa and Norsworthy (2014) reveal that Brassica sp. has a toxic effect on weeds when absorbed into the soil and can be a substitute herbicide, despite the fact that substantial seed germination was more obvious in extracts of 2.5%.

This was further supported by Jabran et al. (2015), who found that fresh white cabbage at a concentration of 50% prevented *Amaranthus retroflexus* and *Chenopodium album* seeds from germinating. According to Yong-Hua et al. (2016), the mixed culture of allelopathic wheat decreased the biomass of weeds via releasing 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA), although the reduction was reliant on the mixing proportions in a replacement series. Further research showed that increasing densities of weeds (*Aegilops tauschii, Amaranthus retroflexus*, and *Avena fatua*) similarly raised the concentration of DIMBOA in wheat roots, preventing weed root extension. The situation was different in a monoculture, though.

According to Aksoy et al. (2016), crops from the Brassicaceae family, when grown as trap and catch crops, have an allelopathic effect on broomrape infestation levels in lentil fields. Similar results were reported by El-Wakeel et al. (2019), who noted the herbicidal potential of an Eruca sativa fresh shoot aqueous extract in controlling weeds related to Pisum sativum. According to Kural and Ozkan, (2020), white cabbage (Brassica oleracea L.) aqueous and methanol extracts (30, 40, and 50%) have an allelopathic effect on plants, inhibiting the germination of *Amaranthus retroflexus* L., *Chenopodium album* L., and *Solanum nigrum* L., with methanol extracts having the most notable effect. Elsekran *et al*. (2023) documented the inhibitory effect of some Cruciferous species (white cabbage, red cabbage, broccoli, turnip, and garden rocket) on seed and rhizome gemination as well as shoot and root elongation of Johnsongrass when the aqueous extracts were prepared in different concentrations of 2%, 5%, 10%, and 20%, respectively.

The results also showed that *Sorghum halepense* L seeds and rhizomes were completely inhibited by garden rocket, indicating that the plant had a stronger phytotoxic effect. Results by Kandhro *et al*. (2016) on the effect of leaves of *Eucalyptus camaldulensis* (L.) allelopathy on weed species' ability to proliferate were consistent with those of the earlier studies. Similar to this, Lalchand et al. (2021) confirms that some noxious weeds (*Cyperus rotundus* L. and *Echinochloa colona* L.) are inhibited from germinating by residual powder incorporation and water extracts of sunflower and Johnson grass.

3. LIMITATIONS AND FUTURE PROSPECTS TO THE USE OF ALLELOPATHY FOR WEED MANAGEMENT

The review makes it very evident that many allelopathic plant and weed species have enormous potential for controlling weeds. Weed management effectiveness and benefits of several allelopathic species have been discussed. Despite recent developments in the study of allelopathy, there is still significant space to investigate new allelochemicals and enhance the ones that are now available. The barrier to its commercial success, however, is the cost of extracting and manufacturing the active component from a promising crop or weed species. The environmental stability, accessibility, and low herbicidal effectiveness of many natural chemicals are only a few more drawbacks. Allelochemicals could be used to control weeds in order to achieve an environmentally friendly and sustainable agricultural production system. It may be possible to efficiently control weeds in farming ecosystems and reduce the use of persistent herbicides by breeding crops cultivars with allelopathic potential. Hence, the most promising use of allelopathy is represented by this. The ability to smother weeds should therefore be combined with high production potential, disease resistance, early maturity, and quality traits. Similar to this, employing crop genotypes with potential allelochemicals may lessen the other measures needed to control weed infestation, with a focus on the administration of herbicide.

4. CONCLUSION

The focus of this review is on several allelopathic species that discharge some types of dynamic allelochemicals obtained from weeds and crops that may be used in conventional or organic agriculture for sustainable weed management. Although conventional methods like intercropping, crop rotation, cover crops, and mulching have been employed for a variety of advantages; the addition of allelopathic crops and/or weeds might improve their capacity to suppress weeds. An alternate approach for a sustainable weed management program would be to use allelopathic plant extracts in conjunction with lower doses of pesticides. Natural herbicides made from weeds and crop plants haven't been used very often up to this point. Therefore, using allelopathic plant extracts along with lower pesticide doses could be a different approach for a long-term weed management program. If these allelochemicals produced by weeds and crops could be effectively used to control weeds, less herbicide would need to be used, production costs would drop, and weed biotypes would become less resistant to herbicide.

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