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Goat weed (*Ageratum conyzoides* L.)- potential as biopesticide and bioherbicide

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ABSTRACT

Goat weed (*Ageratum conyzoides* L.) possesses several phytochemicals, which can be used environment friendly alternatives to synthetic chemical pesticides and herbicides. The major chemicals can serve as natural herbicides and pesticides to expand the range of the green biosphere. This paper: (i) overviews *A. conyzoides* L.; (ii) classification of *A. conyzoides* L.; (iii) botanical characteristics; (iv) invasiveness of *A. conyzoides.* (v) bioactivity of major compounds identified in *Ageratum conyzoides* L. and (vi) effects of *A. conyzoides* on different pathogens as biopesticide.

Keywords: *Ageratum conyzoides,* allelopathy, allelochemicals, bioherbicide, biopesticide, goat weed, green biosphere, natural herbicide, phytochemicals.

1. INTRODUCTION

The non-judicious and excessive use of synthetic herbicides and pesticides causes hazardous effects on the health of soil, water, air, humans and animals (28). It has necessitated the search for a sustainable weed control alternative, resulting utilising the natural herbicidal potential of plants (66). Bioherbicides are prepared from biological materials (plants, animals, microorganisms, and certain minerals) to control pests; whereas, biopesticides are prepared from biological materials to destroy, or control pests (34,72). The

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organic farming system addresses the development of a powerful alternative to synthetic herbicides for use in integrated weed management (19). Weed control studies have recently mainly concentrated on crude extracts from allelopathic species. These species possess the ability to disrupt the growth and functions of neighbouring plants by synthesising and releasing secondary metabolites such as phenolic compounds including terpenols and coumerin. Allelopathy is a biochemical phenomenon in which metabolites are released by one organism and affecting the development, growth, and reproduction of another organism. In 1937, a German plant physiologist Hans Molisch coined the term allelopathy, to refer the type of chemical interactions which can be beneficial or harmful between plants, including microbes (56,67). Allelopathy is a branch of biology that studies the chemicals produced by plants or microorganisms in agricultural or natural populations. To date, numerous secondary metabolites have been isolated from various weed plants. Biotechnological approaches including tissue culture, genomics, and metabolomics can be used to mass-produce them (65).

Interestingly, goat weed (*Ageratum conyzoides* L.) possess several antifungal chemicals, which can be used as safer, more effective, economically, and environmentally friendly alternatives to the fungicides (13). Its essential oil contains a variety of phytoconstituents, such as alkaloids, coumarin, chromene, flavonoids (kaempferol, quercetin, and quercetin-3-rhamnopiranoside), and benzofurans (precocene I, precocene II, and ageratochromene dimer) (66,69). Despite all these facts, *A. conyzoides* L. has been least explored and discussed for its role in sustainable control of devastating pests and noxious weeds.

Figure 1. Single plant of *Ageratum conyzoides* in Aligarh (India)

The invasion of exotic alien species has generated a notable global shift in the composition and structure of vegetation and homogenising the flora. As a result of increased globalisation and an increase in the human population, there has been a remarkable increase in the migration of species outside of their typical biogeographic range and into new habitats. In actuality, the expansion of invasive plants is occurring at an extraordinarily rapid rate, and is one of the largest threats to biodiversity worldwide. *A. conyzoides* has spread like a weed in several natural and artificial ecosystems including farmlands, grasslands, and woodlands (Fig. 2). It is one of the weeds that are the most economically devastating in the world (30,62), and this may be because of its unique features favouring its invasiveness.

This review paper aimed to: (i) overview *A. conyzoides* L.; (ii) classification of *A. conyzoides* L.; (iii) its botanical characteristics; (iv) bioactivity of major compounds identified in *Ageratum conyzoides* L.; (v) effects on different pathogens as a biopesticide.

Figure 2. *Ageratum conyzoides* population around cultivated land in Aligarh (India).

2. *AGERATUM CONYZOIDES*

A. conyzoides (Goat weed, Asteraceae family) an annual aromatic invasive herb is found in tropical and subtropical regions. It generally thrives in fertile soils with moisture and often found near waste zones, watercourses, grasslands, forest edges and gardens. It has branched, elongated, erect, hairy stem that grows to a height of 1-2 m, as well as some white hairs on the leaves and stems (88). Leaves are simple, petiolate, ovate, or rhomboid-ovate in shape, and have a length of up to 7.5 cm and the size in the range of 1.0 and 10 cm. The flowers range in colour from white to purple with a close terminal type of inflorescence. The plant produces achene-like fruits (15,38) (Fig. 1). Phytochemicals like alkaloids, terpenoids, flavonoids saponin, and glycosides as well as other nutrients such as certain amino acids, vitamins, and carbohydrates are found in *A. conyzoides* (2,5). Most metabolites of *A. conyzoides* were also reported to possess several pharmacological and insecticidal properties.

2.1. Scientific Classification

Kingdom	Plantae
Division	Phanerogamia
Class	Dicotyledonae
Series	Inferae
Order	Asterales
Family	Asteraceae
Genus	*Ageratum*
Species	*conyzoides*

2.2. Botanical Characteristics

A. conyzoides is a soft, upright, branched and annual aromatic herb with yellowish brown fibrous roots. It can grow to a height of around 1-2 m. In younger stage, the stem is green, cylindrical, covered in tiny white hairs, and weak. However, as it matures, it becomes sturdy and brown in appearance (69). The oval leaves, which can be up to 100 mm long and resemble an egg, have a stalk. It is broad at the base, has a sharp apex, toothed margin and pronounced veins. The terminal inflorescence, which has 4-18 flower heads and a long peduncle with rectangular, green bracts, can be purple, white, or pinkish in colour (Fig. 1). Fruits are tiny, brown, hairy, and achenes with one seed and five to six pappus (15,38). The plant is widely dispersed throughout India, including the Himalayan area, and often grows in barren, cultivable, or devasted areas. The plant develops freely and is problematic to eliminate because of its wide range of ecological adaptations, sustainable reproduction capacity and allelopathic behaviour. The plant is positively photoblastic and needs light to grow (69).

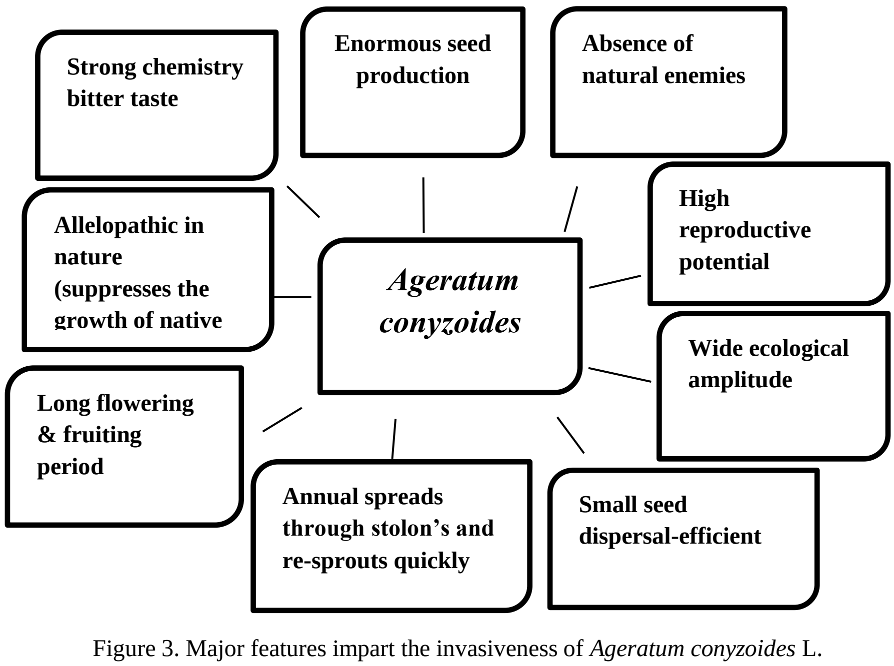

Figure 3. Major features impart the invasiveness of *Ageratum conyzoides* L.

2.3. Invasiveness

The invasive nature of *A. conyzoides* is mainly due to its following attributes:

- The ability of the plant to grow in various environmental conditions (25,45);
- Allelopathic in nature (49);
- Produces a large number of tiny, light seeds (8000-10,000 per plant), that can be dispersed and spread over great distances through wind and water (25,45);
- Wide ecological amplitude (11,74);
- Lack of natural predators (35,74);
- Aromatic odour and bitter taste (43);
- Spreads fast through stolons and re-sprouts quickly (44);
- The capacity of perennial stolons to regenerate after dying down to the ground under unfavourable circumstances.

3. PHYTOCHEMISTRY

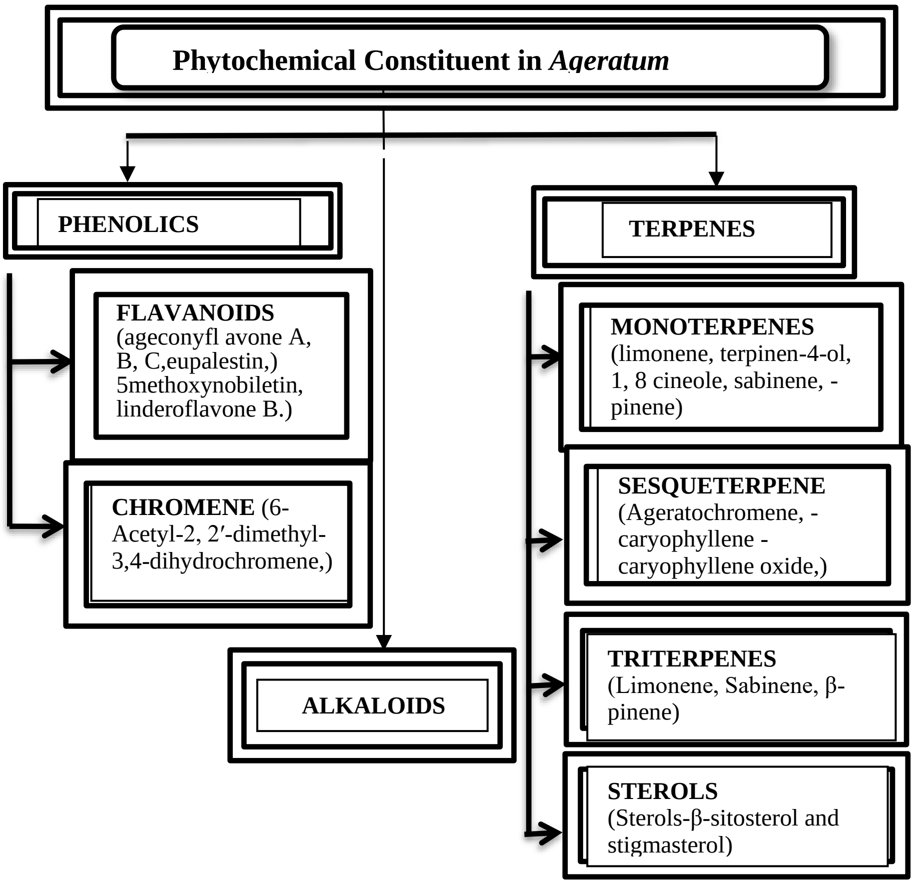

Figure 4. Major phytochemical constituents reported in *Ageratum conyzoides* L.

Numerous phytoconstituents have been identified as active components throughout the entire plant of *A. conyzoides*, and include quercetin, scutellarein, chromene, sitosterol, stigmasterol, fumaric acid, caffeic acid, saponin, pyrrolizidinic alkaloids, ageratochromene derivatives, kaempferol, and glycosides (75) (Fig. 4). These phytoconstituents include both volatile and nonvolatile substances. Among these, sesquiterpenes and monoterpenes are volatile substances; whereas, coumarin, gallic acid, benzoic acid, and protocatecchuic acid,

Table 1. Bioactivity of major identified compounds in *Ageratum conyzoides* L.

Chemical compounds	**Class of compounds**	**IUPAC name**	**Bioactivity**	**Ref**
Ageratochromene / Precocene II	Polyphenol	6,7-dimethoxy-2,2-dimethyl chromene	Allelopathic and insecticidal effects	88
Kaempferol	Flavonols	3,5,7-trihydroxy-2-(4-hydroxyphenyl) chromen-4-one	Anticancer	37,86
Eugenol	Phenolic compounds	2-methoxy-4-prop-2-enylphenol	Antiviral, Antibacte rial and Antifungal	78
Gallic Acid	Phenolic Acid	3,4,5-trihydroxy benzoic acid	Herbicidal effect	9,10,87
5-hydroxy tryptamine	Alkaloid	3-(2-aminoethyl)-1H-indol-5-ol	Inhibit cell proliferation	62,86
Precocene I	Polyphenol flavonoids	7-methoxy2,2-dimethyl chromene	Insecticidal	6,62
β-caryophyllene	Sesquiterpene	4,11,11-trimethyl-8-methylidenebicyclo [7.2.0] undec-4-ene	Herbicidal and Antibacterial	3,90
Caffeic acid	Secondary metabolite	(E)-3-(3,4-dihydroxy phenyl) prop-2-enoic acid	Reactive oxygen species (ROS) production	16, 18
Limonene	Monoterpene	1-methyl-4-prop-1-en-2-ylcyclohexene	Herbicidal activity	14
Fumaric acid	Secondary metabolites	(E)-but-2-enedioic acid	Allelopathic activity	62
Quercetin	Flavonoids	2-(3,4-dihydroxy phenyl)-3,5,7-trihydroxychromen-4-one	Allelopathic effect	3,92
Sabinene	Monoterpene	4-methylidene-1-propane-2-ylbicyclo [3.1.0] hexane	Antibacterial activity	55,62
β-pinene	Monoterpene	6,6-dimethyl-2-methylidenebicyclo [3.1.1] heptane	Antiviral	7
Coumalic Acid	Phenolic acid	6-oxopyran-3-carboxylic acid	Herbicidal effect	9,10,87
Protocatechuic acid	Phenolic acid	3,4-dihydroxybenzoic acid	Herbicidal effect	9,10,87
Catechin/ Catechuic acid	Phenolic acid	(2R,3S)-2-(3,4-dihydroxy phenyl)-3,4-dihydro-2H-chromene-3,5,7-triol	Herbicidal effect	9,10,87
Para-hydroxybenzoic acid	Phenolic acid	4-hydroxybenzoic acid	Herbicidal effect	9,10,87
-coumaric acid	Phenolic acid	2-Propenoic acid, 3-(4-hydroxyphenyl)	Herbicidal effect	87

are non-volatile substances (49,88). *A. conyzoides* has been reported to have significant antifungal, insecticidal, herbicidal, antiviral and antibacterial properties. The bioactivity and chemical structure of various phytochemicals isolated from this plant are shown in Table 1.

3.1. Phenolic compounds

A. conyzoides is rich in various phenolic compounds like flavonoids, chromene, chromone, benzofuran, and coumarin (Fig. 4). Essential oil of *A. conyzoides* contains about 21 polyoxygenated flavonoids. The most prevalent constituent of *A. conyzoides* essential oil is Precocene I (7 methoxy 2, 2 dimethyl chromene), which ranges from 30 % (Vietnamese oil) to 93 % (Congo oil). The major associated substances include hydrodemethoxyencecalin (42), 2,2'- dimethyl-3,4-dihydro chromene and 2-(1'-oxo-2'-methylpropyl)-2-methyl-6,7-dimethoxychromene. Besides 3-(2′-methyl propyl)-methyl-6,8-dimethoxychrom-4-one and 2-(2′-methylethyl)-5, 6- dimethoxybenzofuran also exist (62).

3.2. Terpenes

The GC-MS study of essential oils has revealed a complex mixture of chemicals containing various terpene types, including sterols, monoterpenes (10C), sesquiterpenes (15C), and triterpenes (30C). The most common forms of monoterpenes found in *A. conyzoides* are terpinen-4-ol 0.6 %, methyl eugenol 1.8 %, β-pinene 1.6 %, linalool 0.5 %, eugenol 4.4 %, α-terpineolα-pinene 6.6, limonene 2.9 %, sabinene and β-phellandrene. Additionally, the oxygenated sesquiterpene contains 6-methoxy quinoline-1-oxide (20.77 %), β-caryophyllene oxide (7.29 %), β-sinensal, and ageratochromene (32.90 %) (67). Moreover, Friedelin is one of the common triterpenes extracted from the plant, and the main sterols were stigmasterol (59.9 %) and β-sitosterol (26.7 %). Interestingly, spinasterol (5.2 %), dihydrobrassicasterol (2.7 %), dihydrospinasterol (5.7 %), and brassicasterol (0.3 %) were also extracted. An uncommon sterol named stigmast-7-en-3β-ol was also identified in the foliage of *A. conyzoides.*

3.3. Alkaloids

The only alkaloid compounds recovered from this plant are lycopsamine and echinatine, which are isomeric pyrrolizidines in chemical nature. Other than this, leaves and flowers contain amino acids (arginine, serine, tyrosine, valine, phenylalanine, leucine, histidine, alanine, threonine, glycine and cysteine). The seed oil is rich in stearic acid, hexadecenoic acids, palmitic, linoleic and oleic acid (25.52 %).

4. ALLELOPATHIC ACTIVITY

Allelopathic effects of *A. conyzoides* extract and essential oils have been observed on many crops: mung bean, radish, ryegrass and tomato. The major constituents of these volatile oils include precocenes, β-caryophyllene, β-farnesene and β-bisabolene (46). The allelopathic potential of this plant varies in different habitats and environments. Its volatile oils are inhibitory to other plants. The application of volatile compounds on test plants resulted in the production of reactive oxygen species (ROS), a reduction in growth parameters and photosynthetic activity, peroxidation of cytosol and cell organelles, and affected mitosis and meiosis. Table 2 shows the effect of volatile compounds extracted from *A. conyzoides* on various target plants.

Table 2. Selected reports on the allelopathic potential in *Ageratum conyzoides* L.

Target Plant	**Effects observed**	**Ref**
Triticum aestivum	Reduced seedling weight and elongation of the radicle and coleoptile.	74
Cicer arietinum	Reduction in root length, plant height, biomass, nodulation and leg-hemoglobin content.	12
Oryza sativa	Rice seedlings were substantially shorter and lighter when dry	10
Glycine max	Excessive levels of ROS, lipid component of the cell membrane and cytoplasm peroxidation, fatty acid reductions and DNA damage.	26,82
Lens culinaris	Reduction in photosynthetic rate, reduced ascorbate and glutathione contents.	76
Sesamum indicum	Plumule length decreases, number of root hair decreases.	35
Lathyrus sativus	Chromosome breakage, a propensity for sticky metaphase, multipolarity, chromosomes that aren't orientated correctly, and the creation of gaps and bridges during both mitosis and meiosis. Also, reduced photosynthetic growth.	76
Microcystis aeruginosa	Inhibitory effects by a decrease in photosynthetic pigments (chlorophyll-a & carotenoids).	77
Oryza sativa	Rice seedling germination and length were considerably impacted by aqueous extracts of both the leaf and the root.	58
Phytophthora megakarya	Ethanol crude extract suppresses mycelial growth.	59
Parthenium hysterophorus	Leaf extract was found as the most herbicidal preventing *Parthenium* from germination and development.	38
Pisum sativum	Root and shoot length, as well as seed germination rate, are inhibited.	72

5. *A. CONYZOIDES* : ROLE AS BIOPESTICIDE

Plant pathogen invasion or any other abiotic or biotic stress results in the development of plant diseases. Since plant infections are parasitic in nature, they absorb the nutrients of plants and cause significant and harvest losses. Bacteria, viruses, fungi and nematodes are the primary vigilance agents for diseases that are transmitted through seeds and soil. In natural and agricultural ecosystems, chemical control mostly causes ecological disruptions in food chains and food webs. Allelochemicals, which include aqueous extracts, oil extracts, residues, etc., effectively prevent plant diseases. *A. conyzoides* has a long history of being used for its antimicrobial, antifungal, antibacterial, anthelminthic, and antinematicidal properties.

5.1. Anti-fungal Activity

The soil-borne fungus *Macrophomina phaseolina*, which largely causes charcoal rot, affects over 500 plant species viz., sunflower, chickpea, maize, soybean and other economically significant crop plants (22,27,90), Methanolic extracts of *A. conyzoides* stem, leaf, root, and inflorescence were reported to significantly reduce *M. phaseolina* fungal biomass. However, leaf extract was followed by stem extract in terms of the amount of fungal biomass that was inhibited. Root, shoot, and leaf extract is ineffective against the *Drechslera australiensis* and *D. holmii* fungus that produce brown spot, leaf blight, root rot, and crown rot in crops. The essential oils of *A. conyzoides* were effective against *Aspergillus niger* (59), and coumarin compounds derived from a leaf acetone fraction demonstrated antagonistic activity against fungal species like *Penicillium notatum* and *Rhizopus stolon* (62), *Puccinia arachidis* (91) and *Fusarium oxysporum* (53). The methanolic stem extract of *A. conyzoides* and its chloroform subfraction were quite effective against the fungus *M. phaseolina.* The 2H-1-benzopyran, 7-methoxy-2, 2-dimethyl, 1, 2-benzene dicarboxylic acid, mono (2-ethylhexyl) ester, and other fatty acid methyl esters may improve the antifungal activity of the chloroform sub-fraction The endomembrane system and mitochondria are repressed by compounds like Precocene II, which is also effective against *Aspergillus flavus*. *Fusarium graminearum* is affected by an increase in the quantity of superoxide in the mitochondria. The creation of pores in the cell wall caused by coumarin in *Candida albicans*, allows cytoplasmic content, necrosis and death (84). Table 3 shows major allelochemicals identified from *Ageratum conyzoides* that possess fungicidal properties.

5.2. Insecticidal Activity

Precocenes I and II have anti-juvenile hormonal effects on many insects, including *S. oryzae*, *T. japonica*, *L. chinensis*, and *D. avidus*. These tests produced sterile, morbid, and dwarfish adults as well as the precocious metamorphosis of the larvae. Green gram seeds were mixed using petroleum ether extracts of the leaves, flowers, and buds, which successfully stopped oviposition and provided reliable protection against the pulse beetle infestation of *C. chinensis.* Raw extract of *A. conyzoides* has insecticidal properties against the mustard aphid *Lipaphis erysimi*. The preservation of *A. conyzoides* in the orchards decreased *Phyllocoptruta oleivora* and *Brevipalpus phoenicis* (33). Upon fumigation, the oil produced by *A. conyizoides* exhibits acute toxicity against adults of the cowpea weevil, *Callosobruchus maculatus* F., inhibiting oviposition and the emergence of adult insects (62). The studies show the larvicidal activity of leaf extract of *Ageratum conyzoides* on *Aedes aegypti*, which is a host of plasmodium causing zika virus and dengue (17).

5.3. Nematicidal Activity

The plant's essential oil displayed anthelmintic efficacy against *T. solium* and *P. posthuma*. *Meloidogyne incognita* second-stage juveniles were sensitive to the nematicidal effects of the stem and leaf extract. Additionally, *C. partellus*, a sorghum pest, produced a juvenile hormone shortage in its fourth instar when fresh leaf methanolic extract was applied. *A. conyzoides* also contains bioactive substances like saponins, flavonoids, and polyphenols that prevent the pest from attacking *Brassica juncea* by preventing larvae from developing into pupae. The results showed that the amount of *A. conyzoides* extract interferes with metamorphosis because it contains alkaloids, which are toxic chemicals that damage neural networks and stop the change from larva to pupa. *Heligmosomoides bakeri's* embryonic development and hatching rate are impacted by the aqueous extract of *A. conyzoides.* The active chemicals that entered the eggshell and halted the segmentation of blastomeres or paralysed the larvae inside the embryonated egg had an impact on the ovicidal activity of the larvae (80).

5.4. Herbicidal Activity

Ageratum conyzoides significantly decreased the growth of *R. sativus*. Compared to herbicide, its leaves extract sprayed on a rice field two days after transplanting decreased weeds by roughly 75 % and boosted yield by 14 %. It could be a natural herbicide that avoided the requirement for synthetic herbicides through weed management in paddy fields (87). One of the major sources of nanoparticle-based biopesticides is plants, which include various types of nanoparticles that can be used as pesticide components in agricultural applications. Silver (Ag), which can be used to cure lice in the hair, is present in the *A. conyzoides* leaf (83). *A. conyzoides* leaf aqueous extract inhibited the seed germination of *C. arietinum* (24). The reduced plant height, fresh weight, dry weight, and total chlorophyll content were shown in *Glycine max* (82). *A. conyzoides* extract was discovered to limit the growth and development of *Cucumis sativus*, *Lolium multiflorum*, *Arachis hypogaea* and *Amaranthus retroflexus* by releasing water-soluble phytochemicals like precocenes, 2H-benzopyran, monoterpenes, and sesquiterpenes. (46).

In calcareous soils, the leaves of *A. conyzoides* decreased the growth of *Echinochloa crus-galli var. formosensis Ohwi*. by 70 % and entirely hindered the appearance of *Monochoria vaginalis* (*Burm.f. Persil var. plantaginea Solms*.) and *Aeschynomene indica L*. (87) The leaves, stem, and root aqueous extract of *A. conyzoides* affects *Phalaris minor* and *Poa annua*, reducing their seed germination (4). The most effective post-emergence herbicidal effects on *A. spinosus* were produced by *A. conyzoides* ethyl acetate extract. The aqueous extract shows herbicidal activity against *Parthenium hysterophorus* (38). Flavones and ageratochromene have been shown to greatly slow the development of weeds, namely *Cyperus difformis, Digitaria sanguinalis* and *Bidens pilosa* (64).

5.5. Antiviral and Antibacterial Activity

The essential oil of *A. conyzoides* contains monoterpenes mainly β-pinene, which has antiviral action against herpes simplex virus type 1 (HSV-1). It is known to have a 100 % reduction in viral infectivity (7). The methanolic extract of *A. conyzoides* causes inhibition of echovirus (60). Also, it is known to show antiviral activity against the leprosy virus (33). Furthermore, eugenol suppresses the herpes virus in vitro as well as against HSV-1 and HSV-2 (Herpes simplex virus 1/2) by preventing viral infection and limiting viral reproduction in a way that works in conjunction with acyclovir (79). Eugenol additionally possesses antibacterial properties. It has been reported to possibly inhibit membrane-bound ATPase activity in *Escherichia coli* and *Listeria monocytogenes* (32). It has been proposed that the eugenol inhibits histidine carboxylase, amylase, and protease in *Enterobacter aerogenes* by binding to them (23). The antibacterial properties of methanolic extract and essential oil were shown against *S. aureus*, *E. coli,* P. *aeruginosa*, *V. cholerae*, *C. diphtheria,* and *S. typhi* (23).

Table 3. List of allelochemicals found in *Ageratum conyzoides* L. with fungicidal activity

Chemical compound	Fungal strain targeted	Method of action	Ref
Eugenol	*Botrytis cinerea*	Cytoplasmic coagulation, hyphal shrivelling, vaculation, and inhibition of conidia formation.	82
Coumarin	*Candida albicans*	The formation of holes in the cell wall injured the fungi, allowing the outflow of cytoplasmic material and death.	84
Precocene II	*Fusarium graminearum*	Trichothecene production was ultimately prevented by rising superoxide levels in mitochondria.	29
Beta-caryophyllene	*Trichoderma reesei and A. niger*	Antifungal effect	20
Eugenol	*Candida albicans*	The SEM data corroborated the eugenol-induced cellular deformation.	1

6. CONCLUSIONS

This study evaluated the literature to show that *A. conyzoides* has nematicidal, fungicidal, bacterial, and herbicidal bio-pesticidal properties. Allelochemicals found in it have demonstrated efficacious inhibitory characteristics against detrimental biotic agents found in soil, including but not limited to nematodes, fungi, bacteria, insects, and other pests. Extracts of *A. conyzoides* plant parts also exhibited herbicidal action. Its essential oil is rich in allelopathic terpenes, flavonoids, saponins, and alkaloids, hence may have bioherbicidal potential. Bioherbicides are crucial in modern agriculture for sustainability, reduced residue impact, herbicide resistance management, and addressing health concerns linked to synthetic herbicides. Serving as a sustainable alternative, they support integrated weed management, encourage eco-friendly farming practices, adapt to organic farming, and drive innovation and research. *A. conyzoides*, an invasive weed, possesses diverse properties that have the potential to contribute significantly to waste-to-wealth research initiatives.

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DECLARATION

We thus affirm that this Ms. has been written by all authors with significant involvement. We did not leave out any authors who contributed significantly to this Ms. We have complied with the ethical standards set out by our work institutions.

CONFLICT OF INTEREST

The authors confirm that there are no known conflicts of interest associated with this study.

ETHICAL APPROVAL

The study, according to the authors, was conducted according to ethical and professional standards for science. However, since there was no use of animals in this investigation, the relevant committee's ethical approval was not required.

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