Evaluation of biopesticidal activity of *Parthenium hysterophorus*

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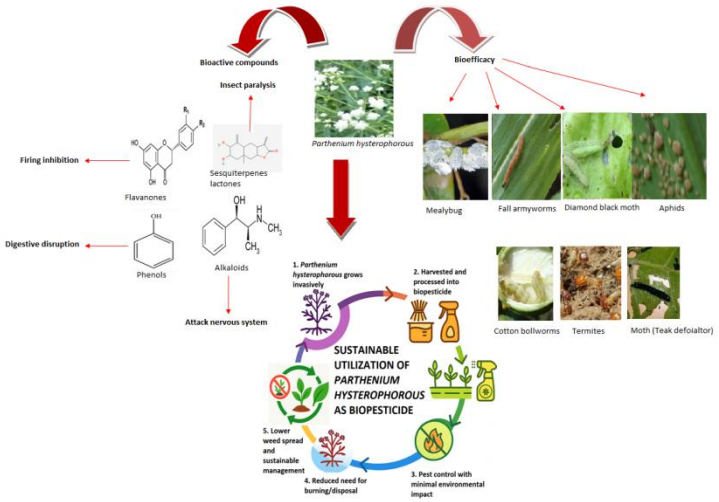
ABSTRACT



In India, *Parthenium hysterophorus* is locally known as carrot grass, congress grass, gajar ghas or dhanura. *Parthenium hysterophorus*, a highly invasive plant species belonging to the family *Asteraceae,* has gained attention due to its potential in controlling pests through biopesticidal properties. This review explores the biopesticidal activity of *P. hysterophorus* extracts against common agricultural pests like aphids, mealy bug, termites, cotton bollworm, moth, fall armyworm etc. The plant contains various bioactive compounds such as flavonoids, phenols, terpenoids and alkaloids, which contribute to its pesticidal effects. Literature has suggested that the methanolic extracts exhibited the highest toxicity, with significant mortality rates in the treated pest populations *Spodoptera litura* and *Aphis gossypii* followed by ethanolic and aqueous extracts. Some bioactive components in Parthenium were identified as key contributors to its pesticidal action, including sesquiterpene lactones and phenols. Additionally, the plant's impact on the pest growth, development, and reproduction was also observed, showing substantial interruption in life cycle processes. The literature has suggested that *P. hysterophorus* can act as a natural bio pesticide and a good alternative for pest management in sustainable agriculture. This review briefly discussed the selected studies from a few past years regarding the biopesticidal activity of *P. hysterophorus* against various pests. It highlights the potential of utilizing plant-derived compounds to reduce reliance on chemical pesticides, thus contributing to integrated pest management strategies and promoting eco-friendly farming practices.

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INTRODUCTION

Parthenium hysterophorus L. is an invasive plant species that has gained remarkable recognition in recent years due to its wide-ranging impacts. It has spread to numerous parts of the world, including Asia, Africa, and Australia, and is now a invasive weed in many regions (Chaudhary *et al.*, , 2020). Its aggressive growth, coupled with its allelopathic effects, has shown drastic biodiversity loss and disruption in native ecosystems. (Gunaseelan *et al.*, 1998) The recent studies have indicated that *P. hysterophorus* possesses various bioactive compounds that could be leveraged for biopesticidal purposes, making it a potential candidate for integrated pest management (IPM) strategies in sustainable agriculture.

The exploration of plant-derived compounds as biopesticides has become an intense area of research, driven by the increasing concerns over the environmental and health hazards caused by synthetic chemical pesticides (Isman, 2020). Biopesticides, which are derived from natural materials like fungi, bacteria or plants, are less toxic, more environmentally friendly, and frequently exhibit target-specificity (Schroder *et al.*, , 2022). *Parthenium hysterophorus*, is one such plant that has shown promise in pest control due to its rich phytochemical outline. This plant accommodates a sea of bioactive substances, including sesquiterpene lactones, flavonoids, alkaloids, and phenolic compounds, all of which have indicated its biopesticidal effects (Meena *et al.*, , 2022; Khan *et al.*, , 2014).

Ecological and agricultural significance of *Parthenium hysterophorus*

The spread of *Parthenium hysterophorus* has induced remarkable ecological disparity, particularly in tropical and subtropical regions. The plant reduces light availability for native plants, leading to the degradation of local biodiversity due to its dense growth habit. (Chaudhary *et al.*, 2020; Batish *et al.*, 2002). Furthermore, *P. hysterophorus* fabricates allergenic pollen that is known to induce respiratory disorders in humans and animals (Sandeep *et al.*, 2019). In agricultural contexts, *P. hysterophorus* is an illustrious weed that competes with crops for resources, as a result reducing agricultural yields and increasing the cost of weed control (Sharma *et al.*, , 2017). Additionally, its forays constantly lead to soil erosion, further intensifying agricultural challenges. Regardless of its negative impacts, *P. hysterophorus* is a plant of interest for its potential use in pest management.

Remarkably, while the plant is considered a weed, due to its potential biopesticidal properties it has properties of reducing pest populations. This unique dual role-being both a harmful weed and a potential biopesticide—makes *P. hysterophorus* an extremely seductive subject of study. Bioactive compounds in *P. hysterophorus* have been shown to disrupt the growth and development of pests, specifically in the larval stages. Insects susceptible to these compounds often experience stunted growth, impaired reproductive capacity and reduced survival rates (Bhatt *et al.*, 2020). This disruption in the life cycle eventually leads to a decline in pest populations over time.

Phytochemical composition of *Parthenium hysterophorus*

Parthenium hysterophorus holds potential as a biopesticide due to its rich array of bioactive compounds. It contains various chemicals like terpenoids, phenolic compounds, parthenin, flavonoids, alkaloids, carbohydrates, glycosides, saponins, steroids, quinones, etc. (Kaur *et.al*. 2022). According to past research papers, the components of *Parthenium hysterophorus*, which has shown antifungal, antimicrobial, insecticidal, medicinal and antibacterial properties, are phenolic compounds, flavonoids, alkaloids, terpenoids, etc. (Krishnaveni *et al.*, 2014; Gajendran *et al.*, 1982; Hasan *et al.*, 1984; Datta, 2001; Patel *et al.*, 2008; Jundare *et al.*, 2020). These compounds are synthesized in various parts of the plant, including the leaves, stems, and flowers. The most notable of these compounds are sesquiterpene lactones, which are known for their insecticidal, antifungal, and antimicrobial properties (Bhatt *et al.*, 2020).

Sesquiterpene Lactones

Among various phytochemical compounds presence of sesquiterpene lactones was shown by *Parthenium hysterophorus*. It is a class of naturally occurring compounds found in many plants, specifically in the *Asteraceae* family. These compounds are known for various biological activities, such as anti-inflammatory, insecticidal, antimicrobial and anticancer properties. In their structure, the presence of lactone ring is accountable for many of their bioactive effects, making them eminent for both medicinal and agricultural applications. Sesquiterpene lactones have encouraging anticancer effects. As reported by a research group Zhang *et al.,* 2019 sesquiterpene lactones such as parthenolide derived from *Tanacetum parthenium* restrain the growth of distinct cancer cell lines by including apoptosis and cell cycle arrest, resulting in the generation of reactive oxygen species (ROS) and the modulation of NF-κB signaling, which accord to the anticancer effects.

Sesquiterpene lactones like parthenin, which is isolated from *Parthenium hysterophorus*, have insecticidal activity. A research group Thakur *et al.,* 2016 reported that extracts containing sesquiterpene lactones have exhibited the capability to diminish the population of agricultural pests like beetles, caterpillars and aphids. Further, another research Datta, 2001 determined the pesticidal properties of parthenin in *Parthenium hysterophorus* and associated compounds. A rearranged product of parthenin and compounds like lactones, pyrazoline abduct, propenyl derivative were more active than parthenin in terms of antifeedant, insecticidal, herbicidal and nematicidal activity, respectively. Sesquiterpene lactones, particularly parthenin, are the most studied bioactive compounds in *P. hysterophorus*. Parthenin has been shown to exhibit potent phytotoxicity, which contributes to the plant's allelopathic effects on surrounding vegetation (Meena *et al.,* 2022). Additionally, parthenin has been affecting the nervous system of pests, leading to their eventual mortality due to its insecticidal properties (Sharma *et al.,* 2017).

Other sesquiterpene lactones present in the plant, such as hysterophorin and parthenolide, have similar bioactivities, contributing to the plant's pesticidal efficacy (Chauhan *et al.,* 2020).

The sesquiterpene lactones in *P. hysterophorus* are toxic to many pest species, causing paralysis or death. These compounds interfere with vital biochemical pathways in insects, particularly those involved in the nervous system (Chauhan *et al.,* 2020; Maatooq *et al.,* 1996). Parthenin has been shown to inhibit acetyl cholinesterase activity, leading to the accumulation of acetylcholine and later paralysis, a key enzyme involved in neurotransmission in insects (Prakash *et al.,* 2018). These compounds act as natural repellents or toxins that disrupt the physiological functions of pest species. This makes *Parthenium hysterophorus* a relevant resource for developing biopesticides that target particular pests without causing widespread harm to non-target organisms. Sesquiterpene lactones are thus multifaceted natural compounds with a wide array of biological activities, including insecticidal, antimicrobial, anticancer and anti-inflammatory properties. Their therapeutic potential is enormous, but their toxicity must be cautiously managed. Research is going on to improve their bioavailability, reduce toxicity, and develop them for practical applications in both agriculture and medicine.

Flavonoids and Alkaloids

Flavonoids and alkaloids are two significant classes of secondary metabolites found in *P. hysterophorus* and broadly studied for their biopesticidal properties. Flavonoids and alkaloids are notable for their gigantic range of biological activities, including antibacterial, insecticidal and antifungal effects. (Bezuneh, 2015; Datta, 2001). The polyphenolic compounds i.e. flavonoids exhibit a variety of biological activities due to their antioxidant, anti-inflammatory and antimicrobial properties. Flavonoids have shown insecticidal effects through several mechanisms like change in growth, interference with enzymatic functions and inhibition of insect feeding. Isman *et al.,* 2006 reported that flavonoids such as rutin and

quercetin have shown significant toxicity to a variety of insect pests, including termites, aphids and mosquitoes.

Flavonoids act by inhibiting enzymes involved in energy production, disrupting cell membranes and interfering with cellular signaling pathways. Alkaloids are nitrogen-containing compounds that are found in many plant and often show potent biological activities. Alkaloids, like nicotine, caffeine, and berberine, have shown biopesticidal effects such as nematicidal, larvicidal and insecticidal activities. Apart from sesquiterpene lactones, *Parthenium hysterophorus* contains flavonoids and alkaloids, both of which have been shown to exhibit antimicrobial, antioxidant, and insecticidal activities. Flavonoids, such as quercetin and kaempferol, are known for their ability to deter herbivores through a combination of toxicity and repellent effects (Bhatt *et al.,* 2020). Alkaloids, which are nitrogen-containing compounds, derived from *Parthenium hysterophorus* have also demonstrated insecticidal properties. They interfere with metabolic pathways, thus killing pests (Kumar *et al.,* 2012). The cooperative action of these bioactive compounds reinforces the overall biopesticidal potential of the plant. Flavonoids and alkaloids are favorable natural biopesticides with a wide range of activities against insect pests, microorganisms and plant pathogens. Their antibacterial, insecticidal and antifungal properties make them valuable alternatives to chemical pesticides**.**

Phenolic Compounds

Phenolic compounds, widely distributed in the plant kingdom, are known for their alternative biological activities, including insecticidal, anti-inflammatory, antioxidant, and antimicrobial properties. These compounds are characterized by a hydroxyl group attached to an aromatic ring, and their presence in plants has cause to enhanced interest in their potential as natural biopesticides. Phenolic compounds extracted from *Parthenium hysterophorus* have shown properties similar to synthetic pesticides due to their eco-friendly profile and effectiveness against pests, diseases and pathogens. (Roth *et al.,* 2008).

Phenolic acids, flavonoids and tannins are among the most studied phenolic compounds for their biopesticidal properties (Singh *et al.,* 2002). A study by a research group Rice-Evans *et al.,* 1997 showed that the antioxidant activity of phenolic compounds is linked to their ability to interfere with the oxidative processes in pathogens and insects. Phenolic compounds can show insecticidal activity through several mechanisms, including the disruption of enzyme systems, toxic effects on insect metabolism and interference with the insect nervous system**.**

Zhang *et al.,* 2015 demonstrated that the phenolic acids, like caffeic acid exhibit significant insecticidal effects against *Spodoptera litura* (a common pest of crops). The mode of action of caffeic acid was associated with its ability to lead to starvation and death and restrain key enzymes in the digestive system of the insects. The utilization of phenolic compounds as biopesticides has been investigated in various field trials. The result examined that phenolic extracts could significantly reduce pest infestation in agricultural settings, providing a natural diverse to chemical pesticides. Phenolic compounds are considered to be less toxic than synthetic chemicals. Although, some phenolic compounds can still present toxicity to non-target organisms at high concentrations. Singh *et al.,* 2016 evaluated that the safety profiles of phenolic compounds used in pest control, application to minimize risks to beneficial organisms and the environment and emphasized the need for careful formulation**.**

Phenolic compounds, including tannins and flavonoids, contribute to the plant's ability to counter against both herbivores and pathogens. These compounds influence their insecticidal effects by ultimate mortality and leading to decrease feeding and damaging the digestive system of herbivorous (Meena *et al.,* 2022). In addition, phenolic compounds have antioxidant properties that may play a role in reducing oxidative stress in pests, thereby contributing to their toxicity. Research continues to focus on

improving their efficacy, bioavailability, and safety for use in sustainable agriculture.

Biopesticidal activity

Several studies have investigated the biopesticidal potential of *Parthenium hysterophorus* against a wide range of agricultural pests. These studies have manifested that various extracts of the plant are effective against insect pests, such as aphids, beetles, and caterpillars, as well as nematodes and fungal pathogens.

Aphids

One of the most common pests in crops, aphids can be effectively controlled using extracts from *Parthenium hysterophorus*. A study by Rajashekar *et al.,* 2017 demonstrated that an ethanol extract of Parthenium shows remarkable mortality in aphid populations, with the sesquiterpene lactones being the most active components in the extract. The aphids showed signs of paralysis and reduced reproduction rates after exposure to the extract. The toxic effect of *Parthenium hysterophorus* extract/parthenin against larvae of *P. Xylostella* and *A. craccivora* was studied Reddy *et al.,* (2017). Further, Muthukrishnan *et al.,* 2021 investigated that leaf extracts of *Parthenium hysterophorus* had significant insecticidal activity against the aphid species *Aphis craccivora,* which is commonly found on leguminous crops. The ethanol extract was particularly effective, leading to a high percentage of aphid mortality within 24 hours of exposure**.**

Another research group Maqsood *et al.* (2024) demonstrated that the flower extract exhibited remarkable antioxidant and insecticidal activities, specifically against *Brevicoryne brassicae*, which is a widespread sucking pest. The extract's potency is further supported by its LC_{50} values of 1446µgmL^{-1} and 750µgmL^{-1} at 72 and 96 hours, respectively. The strong correlation between antioxidant activity, phenolic/flavonoid content, and extract yield highlights its potential. Chemical analysis displays the presence of various bioactive compounds which are responsible for these activities. *P. hysterophorus* extract exhibits potential for use as a biopesticide and can replace the synthetic chemicals for antioxidant and insecticidal purposes. Therefore, further research is necessary to optimize extraction, purification, and evaluate the biological potential of these compounds against various aphids found in different crops.

Termites

Termites are major pests that damage crops and wood structures. Parthenin has been examined to have antifeedant and toxic effects on termites**.** Gururaja *et al.,* 2016 investigated the termite-control potential of extracts from *Parthenium hysterophorus*. The results indicated that both aqueous and methanolic extracts of the plant significantly decreased the activity and survival of termites, recommended that the active compounds in the plant could act as potential biopesticides against termite infestations**.** Another study by Rajendran 2007 investigated the termite-repellent and toxic properties of *Parthenium hysterophorus* extracts. The study reported that the methanol extract of *Parthenium hysterophorus* showed a high level of toxicity against subterranean termites, with a dose-dependent effect on termite mortality**.** They concluded that the plant's extracts could be an eco-friendly diverse to chemical insecticides in termite management. The mechanisms of insecticidal activity of *Parthenium hysterophorus* suggested that its bioactive compounds disrupt the nervous system of termites. The sesquiterpene lactones, specifically parthenin, are known to possess neurotoxic effects that lead to paralysis and death and interfere with the central nervous system of insects. The presence of flavonoids might also contribute to the insecticidal activity by affecting termite feeding behavior and development.

Cotton Bollworm

Another important pest in agriculture, the cotton bollworm (*Helicoverpa armigera*) is known for its damage to cotton and other crops. According to a study by Koul *et al.,* 2017 both crude and fractionated extracts of *Parthenium hysterophorus* demonstrate significant toxicity against the cotton bollworm. The plant's bioactive compounds impersonated by interference with the digestion

and absorption of nutrients, resulting in delayed growth and high mortality in larvae. These studies suggest that *Parthenium hysterophorus* extracts have appreciable potential as a natural insecticide, with applications in controlling a variety of agricultural pests.

A study by Rajput *et al.,* 2015 showed the insecticidal activity of *Parthenium hysterophorus* leaf extracts on the cotton bollworm. The research reported that methanolic and aqueous extracts of Parthenium exhibited significant toxic effects on the larvae of *Helicoverpa armigera.* The extracts led to decreased larval growth, inhibited feeding behaviors and enhance mortality. The study concluded that Parthenium could be a potential source for developing eco-friendly pest management strategies. Yadav *et al.,* 2005 demonstrated that the powdered form of *Parthenium* applied to the cotton plants was highly effective in decreasing bollworm infestation. The chemical compounds in the plant acted as the mortality rate of larvae increased significantly and deterrent to feeding. Jadhav *et al.* (2017) investigated the insecticidal potential of different extracts of *Parthenium hysterophorus* such as ethanolic, methanolic and aqueous against the cotton bollworm**.** The results indicated that all the extracts exhibited toxicity to the bollworm larvae**.** Among these, ethanolic extracts exhibited the highest larvicidal activity, leading to high mortality rates**.**

Mealy bug

Mealy bugs are pink, soft bodied insect covered with white, waxy and cottony material. They are common house hold pests. Taswar *et al.* (2021) found that *Parthenium hysterophorus* has an antagonistic potential against mealy bug. A parallel study was carried out by Sayeed *et al.,* 2017 which have shown that aqueous extract of Parthenium have good control with 70.0% mortality of second instar of P. Brassicae after 48 hrs of exposure. The petroleum ether extract and aqueous extract of *Parthenium* have shown 50% and 60% mortality of first instar of *S. Litura,* whereas 10% aqueous extract of *Parthenium hysterophorus* recorded maximum 59.5% growth rate of *Sclerotiumrolfsii.*

Moth (Teak defoliator)

Teak moth, the most virulent pests attacking teak plantation is characterized by their medium to large size, with wingspans ranging from 40 to 100 mm. Their larva cause substantial damage to trees. Durairaj (2010) determined the screening of biopesticidal properties of *Oscimum tenuiflorum* L. and *Parthenium hysterophorus* L. He reported that the aqueous extract of *Parthenium hysterophorus* bring out 20%, 60%, 80% mortality of early insta larva of *Hybleae Puera* in 24 hrs at 1%, 5%, and 2% concentration respectively. At all the concentrations, it showed 100% mortality rate in 48 hrs.

Fall armyworm

Fall Armyworm is a polyphagous insect that feeds on over 300 plant species including maize, wheat, sorghum, millet, sugarcane, vegetable crops and cotton. Various research groups have studied the efficacy of *Parthenium hysterophorus* L against fall army worm (Wasu *et al.,* 2013; Usama, 2024). Plant extracts like *Parthenium hysterophorus*, *A.indica, E.globulus* and *C.sativa* have shown significant toxicity potential against the fall armyworm third instar larvae (*Spodoptera frugiperda*). In lepidopteran larvae, the *Spodoptera frugiperda* is the major pest. Armand *et al.,* (2023) reported on the effectiveness of three selected chemicals and one biological insecticide on lepidopteran larvae in maize field.

Diamond back moth

The diamondback moth (*Plutella xylostella*) is the most destructive insect pest of Brassicaceae species, including cruciferous weeds, across the world. *Parthenium hysterophorus* L. have shown good bioefficacy against this pest. Reddy *et al.,* 2017 investigated that the parthenin isolated from *Parthenium hysterophorus* showed promising toxicity to larvae of *Plutella xylostella* L. and *A. craccivora.* In addition to its insecticidal properties, *Parthenium hysterophorus* has been preventing insects from infesting crops or structures due to its repellent effects. A study by

Jadhav *et al.,* 2018 tested the repellent activity of essential oils extracted from Parthenium against houseflies and mosquitoes. The antimicrobial properties of *Parthenium hysterophorus* have well-authenticated, several studies which has explored its potential as a natural fungicide and bactericide. Studies by Ahmad *et al.* (2019) evaluated the antibacterial activity of various extracts of *Parthenium hysterophorus* against pathogenic bacteria such as *Escherichia coli*, *Salmonella typhi*, and *Staphylococcus aureus*. The ethanol and methanol extracts exhibited strong antibacterial activity, inhibiting bacterial growth at shifting concentrations. The antibacterial effects are attributed to the presence of flavonoids, saponins, and sesquiterpene lactones.

The antifungal properties of *Parthenium hysterophorus* have been studied in relation to plant pathogens. A study by Meena *et al.,* 2020 showed that the methanolic extract of Parthenium demonstrated significant antifungal activity against *Fusarium oxysporum*, a major pathogen in crops like tomato and cotton. The sesquiterpene lactones and flavonoids were identified as the active components responsible for disrupting fungal cell walls and inhibiting spore germination. The antimicrobial and antifungal properties of *Parthenium hysterophorus* provide an added benefit in agricultural pest control, as these properties may help to prevent the spread of diseases that are often transmitted by pests or cause damage to crops directly. Beyond its direct pesticidal activities, *Parthenium hysterophorus* also exhibits allelopathic effects, which can indirectly affect the growth and survival of pests. The inhibition of the growth of other compounds due to the chemical compounds by *P. hysterophorus* into the soil, which may reduce the availability of food sources for herbivores. This reduces the pest population in areas infested with *Parthenium hysterophorus.* A study by Giri *et al.,* (2017) found that allelopathic compounds from *Parthenium hysterophorus* reduced the germination and growth of several crop plants, including maize and wheat and this effect is generally considered a disadvantage for crop production, it suggests that *Parthenium hysterophorus* has a potential role in pest management by creating unfavorable conditions for pest hosts.

Environmental Impact and Safety

Plant-based biopesticides derived from *Parthenium hysterophorus* have shown promising eco-friendly insecticidal activity. In particular, Taswar *et al.,* 2021 demonstrated that aqueous extracts of *Parthenium hysterophorus* achieved high mealybug mortality—up to 80% at 200–500 µg/mL concentrations—making them a cost-effective and environmentally friendly option for sustainable forestry pest control. Moreover, *Parthenium hysterophorus* is a globally invasive and noxious weed with documented negative impacts on biodiversity and land use. A study by Zheng *et al.,* 2024 highlights its aggressive spread and threats to ecosystems like cropland, forests, and grasslands under current and future climate scenarios. Utilizing its biomass as a biopesticide could thus serve a dual purpose—helping control pests while mitigating the spread and disposal issues associated with its invasion. Nevertheless, safety assessments remain incomplete. There is currently no published evidence demonstrating that *Parthenium hysterophorus*-derived biopesticides are less toxic to non-target organisms—such as pollinators and natural predators—or safer than conventional chemical pesticides in field contexts. This knowledge gap underscores the need for comprehensive field trials and long-term ecological monitoring before recommending widespread use.

Potential for Sustainable Agriculture

The growing urgency for sustainable and eco-friendly preference to synthetic chemical pesticides has highlighted the potential of plant-based biopesticides such as *Parthenium hysterophorus*. Biopesticides are considered a safer and more environmentally friendly alternative compared to conventional chemical pesticides, which often have harmful effects on non-target organisms, pollinators, and the

environment. (Khursheed *et al.,* 2022; Daraban *et al.,* 2023)

Reduced Environmental Impact

Unlike synthetic chemical pesticides, which can persist in the environment and accumulate in the food chain, the active compounds in *Parthenium hysterophorus* are biodegradable and break down relatively quickly. This reduces the risk of long-term environmental contamination and non-target effects (Kumar *et al.,* 2017).

Target Specificity

Several studies have reported the pesticidal and herbicidal properties of *Parthenium hysterophorus* extracts due to bioactive compounds such as parthenin. While evidence on their specificity toward target pests is emerging, further research is required to fully establish their safety profile with respect to non-target organisms such as pollinators and natural predators.

Development of Novel Formulations

The use of *Parthenium hysterophorus* in agriculture can be made possible by developing effective formulations that maximize the plant's pesticidal potential and minimize potential phytotoxicity. Advances in extraction techniques and formulation technologies can ensure that biopesticides are both cost-effective and efficacious in field conditions. (Zainuddin *et al.,* 2019)

Parthenium hysterophorus exhibits significant biopesticidal activity, manifesting its potential as a natural option to chemical pesticides. Active compounds such as sesquiterpene lactones and flavonoids contribute to its insecticidal, repellent, and antimicrobial properties. The plant's extracts, particularly from its leaves and flowers, have shown effectiveness in controlling various insect pests and pathogens. *Parthenium hysterophorus* could be a promising candidate for sustainable pest management due to its eco-friendly nature and low toxicity to animals and humans. Despite this, further research is necessary to optimize its application and fully recognize its mechanisms and potential environmental impact and there is a need to purify and characterize pure compounds. Still the bio-efficacy studies of some insects like lace bugs, earwigs, bagworms, squash bugs and gastropods has to be done to confirm its biopesticidal properties.

Author's contribution

Shivani Guleria conceived and designed the manuscript. Zeenat Parveen collected the data and wrote the manuscript. Shivani Guleria contributed significant editorial guidance on the presentation and preparation of the manuscript.

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