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Assessing the Threat: Parthenium Adverse Effects on Biodiversity, Human Communities, and Environmental Integrity

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Abstract

The pervasive spread of Parthenium hysterophorus, a noxious weed native to the subtropical regions of the Americas, poses significant threats to biodiversity, human health, and environmental stability. Known by various names such as white head weed, congress grass, and Santa Maria feverfew, Parthenium has invaded numerous countries. This review highlights the adverse effects of Parthenium on agricultural productivity, native plant communities, and human and livestock health. The weed's allelopathic properties inhibit the germination and growth of surrounding flora, leading to substantial biodiversity loss and ecosystem disruption. Parthenium's prolific seed production, rapid spread, and adaptability to diverse environmental conditions facilitate its dominance, often resulting in the near-complete displacement of indigenous plant species. The health impacts on humans include allergic reactions such as dermatitis, bronchitis, and hay fever, while livestock consuming the weed suffer from alopecia, dermatitis, and reduced milk and meat quality. Effective management strategies are crucial for mitigating the spread and impact of Parthenium. These include physical removal, chemical herbicides, biological control agents, and the use of allelopathic plants. Despite ongoing efforts, challenges such as herbicide resistance and socio-economic constraints persist, necessitating continued research and integrated weed management approaches. Future directions should focus on understanding herbicide resistance mechanisms, exploring sustainable management practices, and leveraging emerging technologies like remote sensing and genetic engineering for precision management. Community involvement and public awareness campaigns are also essential for successful long-term control. This comprehensive review underscores the urgent need for coordinated efforts to manage Parthenium invasions and protect biodiversity, human health, and environmental integrity.

Keywords: Invasive weed, biodiversity loss, human health hazards, agricultural impact, weed management, ecosystem disruption.

INTRODUCTION

Undesirable plants, known as weeds, pose significant challenges due to their detrimental effects on productivity and human health. They not only compete with agricultural crops and forest plants for essential resources like nutrients, water, and light but also contribute to allergies and skin diseases. Parthenium hysterophorus L., commonly referred to as parthenium weed, is a member of the Asteraceae family. In Pakistan, it is recognized as an invasive weed under the local names 'gajar booti' or 'gajar ghaas' (Shabbir and Bajwa, 2006). This herbaceous plant has a deep taproot system and an erect stem that can grow up to 2 meters in height, gradually developing a woody appearance as it matures. The leaves are bi-pinnate; in the early stages of growth, they resemble rosettes, but as they grow older, they can reach a length of 30 cm and are placed alternately. At the terminals of the branches are terminal panicles containing cream-colored flower-heads, or capitula, that have a diameter of 4-5 mm. According to Navie *et al*., (1996) every capitulum contains four to five wedge-shaped seeds that are two millimeters long and covered in thin, white scales.

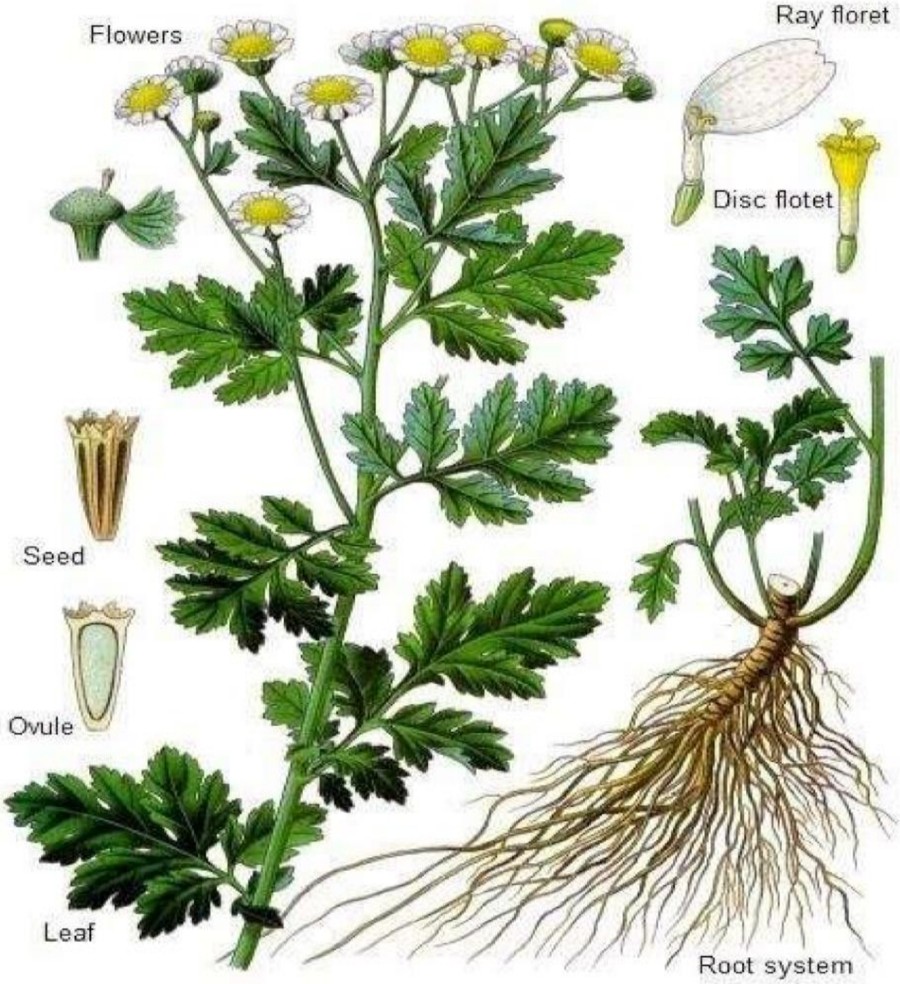

Figure 1: The different plant parts of Parthenium hysterophorus (Masum *et al*., 2013)

Parthenium hysterophorus has emerged as one of the most aggressive weeds in both grazing land and cereal-based agriculture, as well as crop lands (Tamado and Milberg, 2000). It is considered a noxious weed due to its prolific seed production, rapid spread (Haseler, 1976), allelopathic effects on other plants (Adkins, 1996), strong competitiveness with crops (Tamado *et al*., 2002), and health hazards it poses to humans and animals (Chippendale and Panetta, 1994). Its devastating impact often leads to the dominance of Parthenium in affected areas, with little to no presence of other plant species (Shabbir and Swhsana, 2005). In regions infested with this weed, forage productivity can decline by up to 90%, rendering lands infertile and compromising the quality of grazing land, animal health, and agricultural production (Rezene *et al*., 2005; Tahir *et al*., 2024). Additionally, Parthenium poses a serious threat to the environment and biodiversity due to its high invasive potential and allelopathic effects, which can rapidly replace native vegetation (Tamado and Milberg, 2000). Through strong allelopathic interactions, Parthenium inhibits the growth and reproduction of associated crops by releasing phytotoxins from its decomposing biomass and root exudates into the soil. Various studies, including bioassays, pot cultures, and field investigations, have demonstrated the toxic effects of all parts of the plant (shoot, root, inflorescence, and seed) on other plants (Mulatu *et al*., 2009).

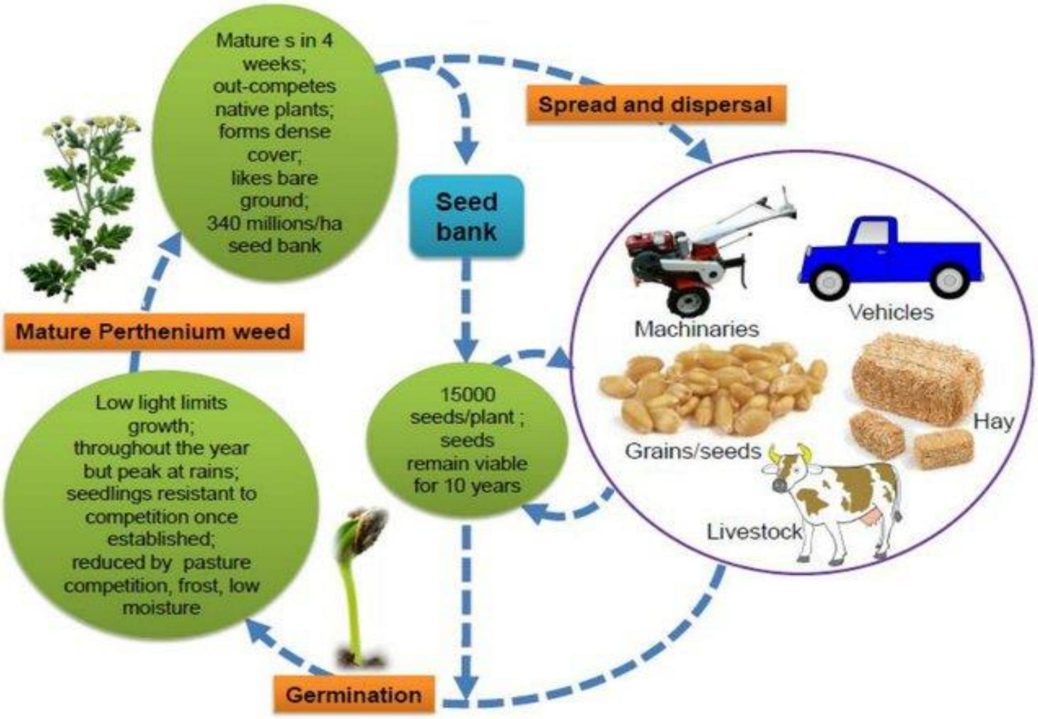

Figure 2: The life cycle of parthenium weed (Masum *et al.*, 2013)

Parthenium poses a significant threat to the integrity of native ecosystems by reducing their biodiversity. It accomplishes this by outcompeting and inhibiting the germination and growth of other flora through the secretion of phytotoxic allelochemicals (Saxena, 1991). As a result, valuable native vegetation with feed, medicinl, or commercial value starts to disappear in regions invaded by this weed globally (Shabbir and Bajwa, 2006; Nigatu *et al*., 2010). Parthenium's competitive and allelopathic abilities can lead to a decline of up to 90% in the herbaceous component of natural plant communities (Mahadevappa *et al*., 2001).

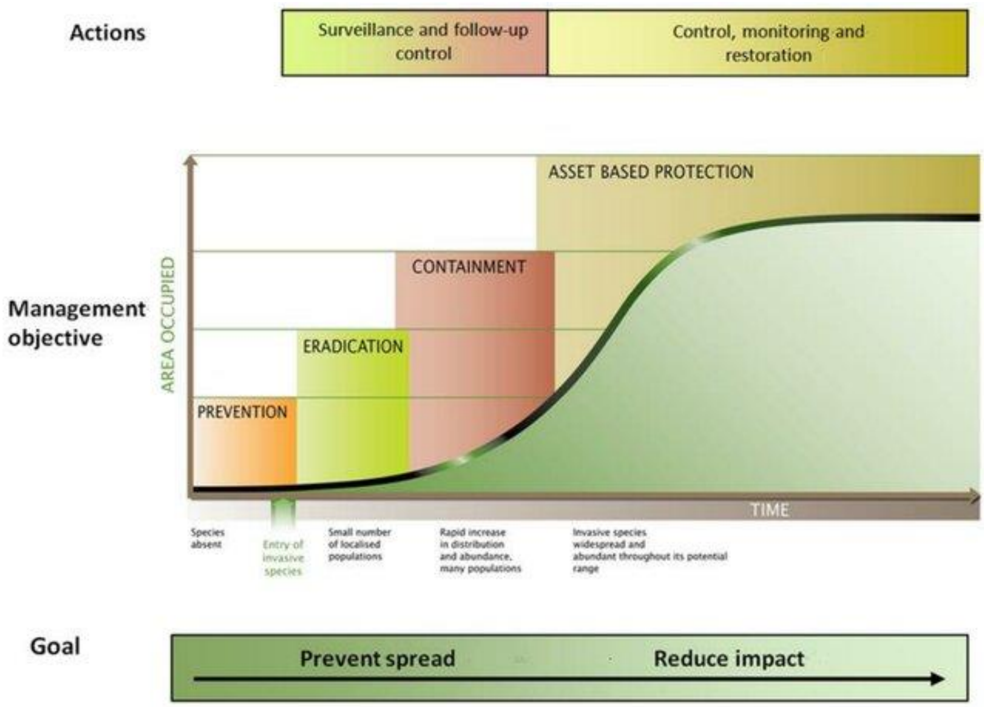

Figure 3: Weed invasion phases, along with the goals, management objectives, and actions associated with each phase (Australian Weeds Committee, 2012)

The ongoing and unchecked spread of parthenium worldwide necessitates a comprehensive understanding of its ecological impact and various management strategies to control this invasive weed. Given the severity of the situation, parthenium has been classified as a noxious weed in numerous countries. This review aims to compile existing knowledge on parthenium's interference in agro-ecosystems and its management, drawing from diverse examples and research findings. This information will aid weed scientists and farm managers in regions affected by parthenium in making informed decisions regarding its management (Arshad *et al*., 2024).

Geographical Distribution of Parthenium hysterophorus

Parthenium hysterophorus originates from the subtropical regions of North and South America. It is frequently found in the United States, especially in Texas, as well as in parts of Mexico, the Caribbean, and Central and South America (Navie *et al*., 1996). It has widely spread across Africa, impacting countries including Ethiopia, Kenya, South Africa, Uganda, and Tanzania. The weed flourishes in disturbed areas, agricultural lands, and along roadsides, leading to substantial ecological and economic repercussions (Tamado and Milberg, 2000). In Asia, Parthenium hysterophorus is prevalent in India, Pakistan, Nepal, and China. Initially reported in India in the 1950s, it has since emerged as a significant weed problem, especially in agricultural areas, urban settings, and along transportation routes (Kaur *et al*., 2014; Abbas *et al*., 2021). Parthenium hysterophorus entered Australia in the 1950s, possibly via contaminated agricultural goods. Currently, it is widespread in Queensland and New South Wales, presenting a risk to pastures and agricultural areas (Navie *et al*., 1996).

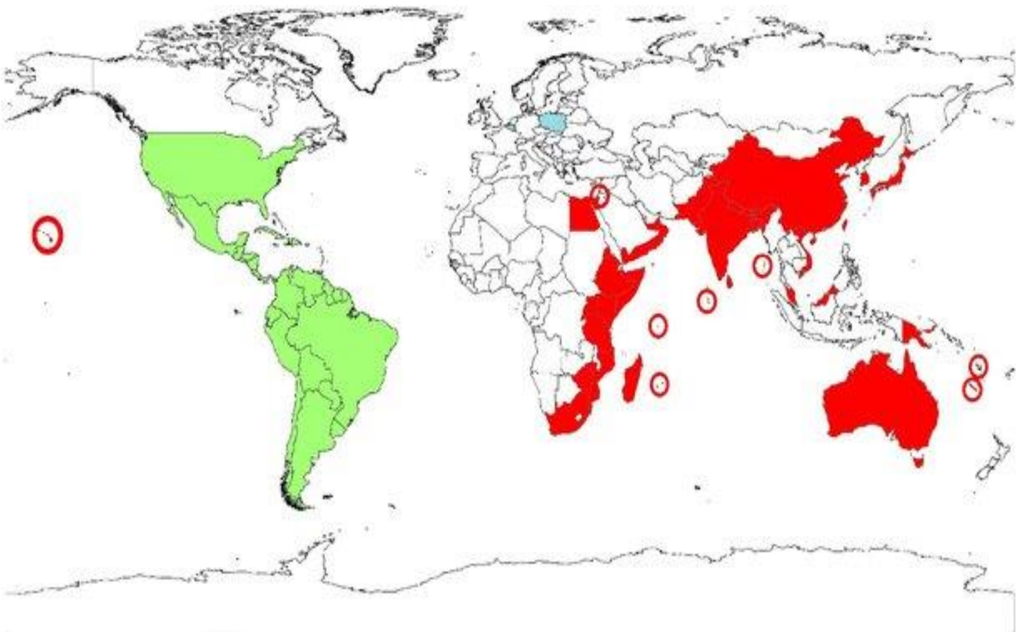

Figure 4: A worldwide map of parthenium weed distribution. Parthenium weed is invasive in the countries shaded or circled in red. Blue-shaded countries represent transient populations of the weed in the Europe. Countries shaded green are considered to be within its native range (Bajwa *et al*., 2016)

The spread of the weed has extended to numerous Pacific Island nations, such as Fiji and Papua New Guinea. Its establishment in these areas jeopardizes indigenous biodiversity and agricultural output (Evans, 1977; Arshad *et al*., 2021). The dissemination of Parthenium hysterophorus is chiefly driven by human activities, encompassing the transport of contaminated agricultural goods, vehicles, and machinery. Moreover, natural dispersal agents like wind, water, and animals play a role in its propagation. Parthenium hysterophorus displays remarkable adaptability to diverse climatic conditions, spanning tropical to temperate regions. Anticipated climate change and the rise in global trade are poised to augment its expansion into novel territories (Shabbir *et al*., 2016).

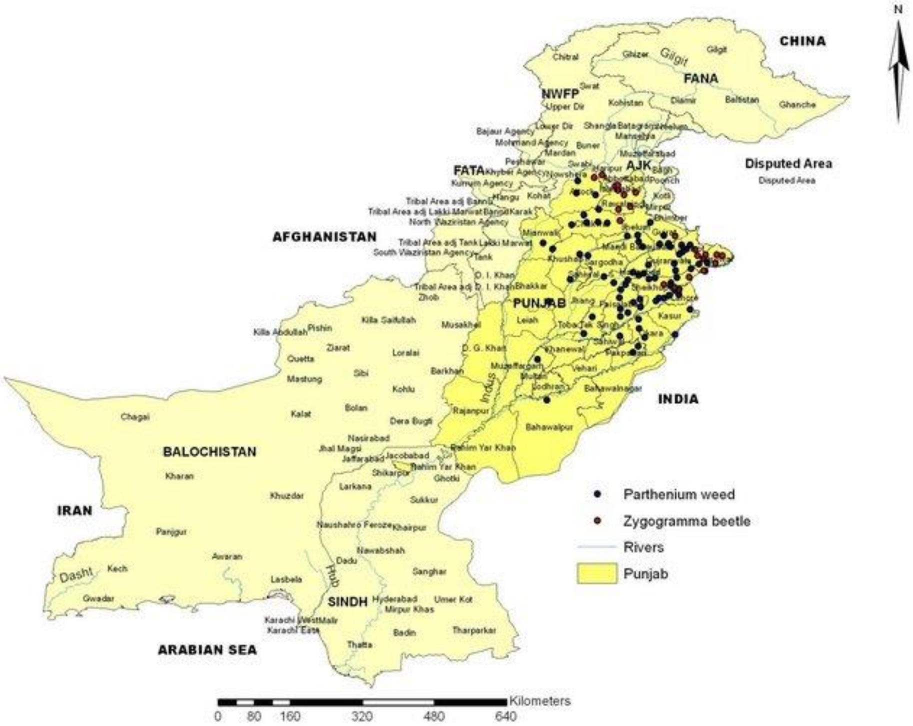

Figure 5: Distribution of Parthenium weed and Zygogramma bicolorata in Punjab, Pakistan as surveyed in 2009. The red circles indicate the sites where both Parthenium weed and Zygogramma beetle were recorded (Shabbir *et al.*, 2012).

Factors contributing to its rapid expansion

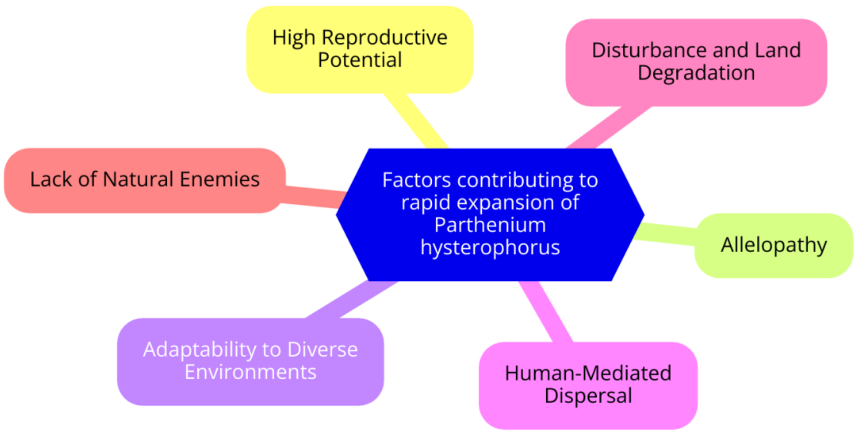

Figure 6: Factors Contributing to the Rapid Expansion of Parthenium hysterophorus

High Reproductive Potential

Parthenium hysterophorus displays abundant seed production, with a single plant capable of yielding thousands of seeds. This heightened reproductive capacity significantly contributes to its rapid spread and establishment in new environments (Shabbir *et al*., 2016). Parthenium also possesses remarkable vigor in growth and establishment. It can thrive in diverse soil types, although it shows less affinity for lateritic soil. Its seeds exhibit year-round germination, independent of photoperiod, temperature fluctuations, or seasonal variations. Given favorable moisture conditions, it forms dense monocultures. When conditions are water-stressed, the plant remains in rosette form until the beginning of rainfall or additional moisture. However, it grows vigorously during the rainy season and in humid climes. Furthermore, it grows quickly from root stumps and leftover components in the soil, like midribs and petioles (Kohli and Rani, 1994). Partheniums flower copiously, producing a large number of seeds (about 25,000 per plant; Navie *et al*., 1996) that build up a large seed bank in the soil. Its lightweight, tiny seeds are easily carried by the wind or water, allowing new regions to be colonized quickly. These seeds may flourish in challenging environmental conditions and last for long periods of time (Williams and Groves, 1980; Abbas *et al*., 2021a). The lack of dormancy and the small weight of its pappus-equipped seeds contribute to its widespread occurrence and establishment (Ramaswami, 1997; Rafeeq *et al*., 2020). The parthenium is a fast-growing annual plant that flowers for several months after usually starting to bloom at 4 to 8 weeks of age. Within four weeks, the weed can sprout, expand, develope, and set seeds even in unfavorable conditions like drought stress. Moreover, it exhibits a high capacity for regeneration (Dagar *et al*., 1976; Akhter *et al*., 2017).

Figure 7: High Reproductive Potential Parthenium hysterophorus displays abundant seed production, with a single plant capable of yielding thousands of seeds

Allelopathy:

Allelopathy is a technique by which weeds successfully establish themselves in an unfamiliar environment. It involves a plant releasing chemicals into the environment that negatively affect the growth of other plants (Bais *et al*., 2003; Heirro and Callaway, 2003). Through the production of phenolic acids and sesquiterpenes from both fresh plant parts and residues, parthenium disturbs the emergence, early growth, and development of crops and allied species (Batish *et al*., 2002; Singh *et al*., 2003). Parthenium hinders the germination and development of other plants by allelopathy. Aqueous extracts of leaves and flowers were found to impede barley, wheat, and pea germination and growth (Srivastava *et al*., 1985).

Singh *et al*., (2005) have describe the phytotoxic results of pathenium remains on Brassica campestris, B. oleracea, and B. rapa in a more recent study. Likewise, the detrimental effects of parthenium residues on Cicer arietinum and Raphanus sativus development were reported by Batish *et al*., (2002). The weed has been shown to contain a number of allelochemicals, including sesquiterpene lactones like parthenin and coronopilin and water-soluble phenolics including caffeic, ferulic, vanillic, anisic, and fumaric acids (Kanchan, 1975; Jarvis *et al*., 1985; Picman and Picman, 1984).

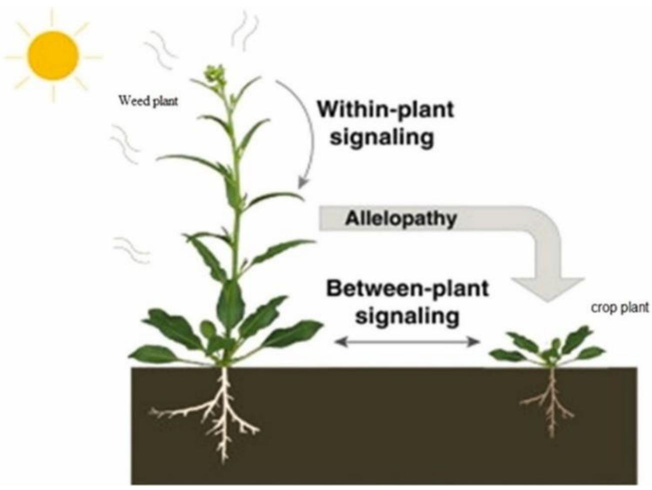

Figure 8: Presents the picture-wise competition and allelopathic war between weed and crop plants for different available resources in the shape below ground such as minerals, nutrient and basic foods, and above ground like sunlight, space, air (Zareen *et al*., 2022)

Adaptability to Diverse Environments

Parthenium weed demonstrates extensive ecological resilience and can flourish across a spectrum of environmental settings, encompassing arid, semi-arid, and humid climates. Its versatility facilitates rapid invasion and establishment in various ecosystems (Singh *et al*., 2002).

Human-Mediated Dispersal

The dispersal of parthenium weed seeds over considerable distances is largely influenced by human activities, including trade, transportation, and agricultural practices. Contaminated agricultural produce, machinery, and vehicles act as carriers for seed dissemination (Singh *et al*., 2003).

Disturbance and Land Degradation

Parthenium weed frequently establishes itself in disturbed habitats and degraded lands, such as roadsides, wastelands, and agricultural fields. Human activities that result in soil disturbance and land degradation provide conducive environments for its proliferation and dissemination (Singh *et al*., 2005; Arshad *et al*., 2024c).

Lack of Natural Enemies

In areas outside its native habitat, Parthenium hysterophorus frequently encounters a dearth of natural predators capable of effectively managing its population. This deficiency in biological regulation fosters its unrestrained proliferation and supremacy in invaded ecosystems (Dhileepan and Strathie, 2009; Pervaiz *et al*., 2024).

Biodiversity Loss Due to Parthenium Invasion

Invasive alien plants pose a significant threat to biodiversity comparable to habitat destruction. They can result in the loss of biodiversity, potentially leading to species extinctions. These plants have also been implicated in the decline of 42% of endangered and threatened species in the U.S. (Wilcove *et al*., 1998). Additionally, the allelopathic properties of these weeds have the potential to disrupt the growth and distribution of natural vegetation, consequently affecting animal diversity (Ayele, 2007). Moreover, these weeds can diminish species richness and abundance in natural ecosystems by inhibiting the physiological processes of other plant species (Nguyen *et al*., 2010).

The region's biodiversity is seriously threatened by the presence of this plant. It has been extensively shown to have a significant effect on natural populations, displacing them and creating imbalances in agricultural and natural ecosystems (Sakai *et al*., 2001). This weed, alongside rubber vine, is identified as one of the two most threatening weeds to biodiversity in the Einasleigh uplands bioregion (Sattler and Williams, 1999). Reports indicate that it has induced complete habitat transformations in native Australian grasslands, open woodlands, riverbanks, and floodplains (McFadyen, 1992; Chippendale and Panetta, 1994). Recent observations in Southern India have also revealed similar invasions in national wildlife parks (Evans, 1997; Aleem *et al*., 2024). Preliminary surveys have highlighted extensive infestations of this weed in the Jessore district, particularly along roadsides near the BARI sub-station (Karim, 2008; Karim and Nag, 2008). Additionally, other districts including as Faridpur, Norail, Magura, Rajshahi, Natore, Sirajgonj, Manikgonj, Dhaka, and Mymensingh have all been shown to have the weed (Karim and Farzwa, 2010).

Impact on native plant communities

The intrusion of non-native exotic species into unfamiliar environments presents a significant menace to indigenous plant communities, leading to profound modifications in the fundamental structures and operations of ecosystems. This intrusion represents one of the gravest perils to biodiversity, instigating substantial alterations in vegetation on a global scale (Vitousek *et al*., 1996; Mack *et al*., 2000). Several research findings have highlighted the disruptive impact of parthenium weed on the structural integrity of natural ecosystems, leading to the displacement of numerous native plant species (Shabbir and Bajwa 2006). This weed has emerged as a major threat to various protected areas, forest reserves, and national parks worldwide. For instance, it has encroached upon the Kruger National Park in South Africa (Strathie *et al*., 2011) the Chitwan National Park in Nepal (communication with Bharat BS, private), and the Masai Mara/Serengeti ecosystem in Kenya and Tanzania, a critical habitat for approximately 2 million wildebeest that rely on this ecosystem for their survival. In Australia, the presence of this weed has been documented in Carnarvon National Park (Vogler, 2002; Rasheed *et al*., 2024) and 22 other reserves, along with two listed wetlands. It is identified as a significant threat to the native grasslands of Queensland and the Einasleigh uplands bioregion (Sattler and Walliam, 1999).

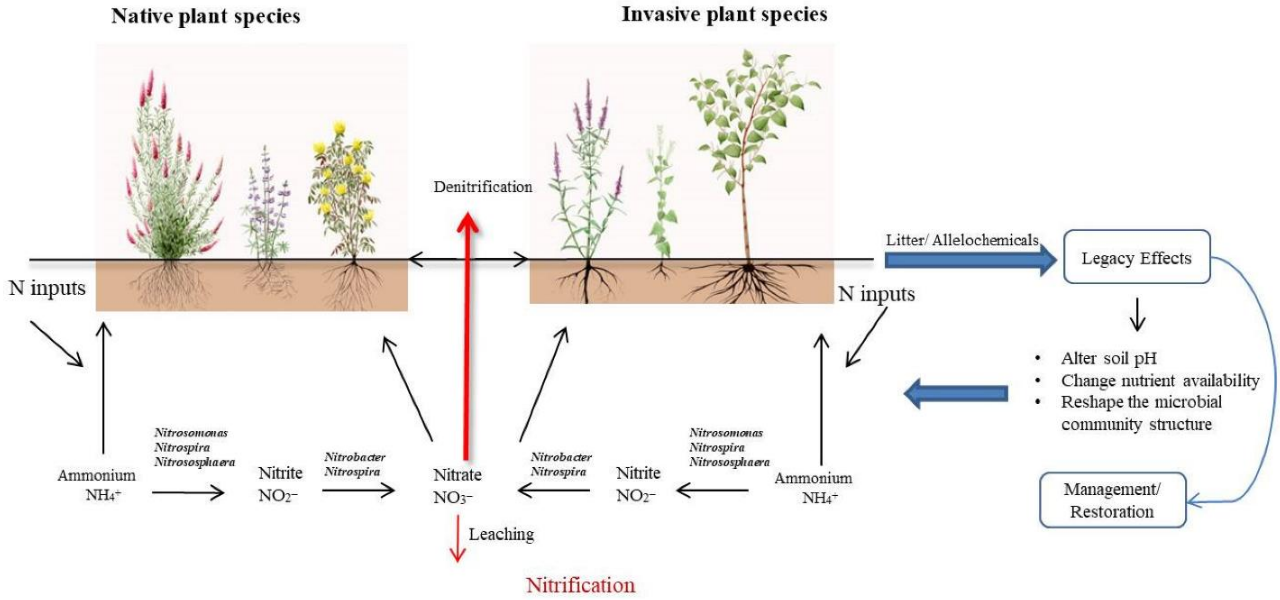

Figure 9: The figure shows the effects of invasive plants on the native plants (Afzal *et al*., 2023)

Disruption of natural ecosystems

The invasion of P. hysterophorus induces notable changes in soil nutrient levels, pH, and organic material, consequently impacting the composition and diversity of plant species (Timsina *et al*., 2011). Livestock grazing patterns are influenced by the toxicity and poor palatability of P. hysterophorus, resulting in alterations to vegetation composition (Narasimhan *et al*., 1977).

Case studies highlighting biodiversity loss in various regions

1. India: Impact on Grassland Ecosystems

In India, Parthenium hysterophorus has invaded vast areas of grasslands, severely affecting biodiversity by displacing native vegetation and altering ecosystem functions. This invasion has led to the decline of native plant species, with cascading effects on herbivores and pollinators. Parthenium has reduced the abundance of native grasses by 60% and lowered the diversity of herbaceous plants by 70%. It has also been found to significantly reduce native herbivore populations that rely on indigenous grasses (Khosla and Sobti, 1981).

2. Ethiopia: Displacement of Native Flora

In Ethiopia, Parthenium hysterophorus has caused severe biodiversity loss, particularly in agricultural and pastoral lands. The weed's aggressive spread has led to the displacement of native plants, reducing the diversity of forage species essential for livestock. In rangelands, Parthenium invasion has resulted in a 90% reduction in native herbaceous species and a 50% decline in the richness of forage plants, leading to reduced grazing capacity (Tamado and Milberg 2000).

3. Australia: Impact on Native Grasslands

In Australia, Parthenium hysterophorus has severely impacted biodiversity, particularly in native grasslands and pastures. The invasive species has outcompeted native plants and led to ecosystem degradation. In heavily infested areas, Parthenium has been found to reduce native grass species richness by over 90%. Its proliferation also negatively affects insects, birds, and small mammals that depend on the native flora (Adkins and Shabbir, 2014).

4. Kenya: Biodiversity Loss in National Parks

In Kenya, Parthenium hysterophorus has invaded protected areas, including national parks, leading to significant biodiversity loss. The weed outcompetes native plant species, posing a serious threat to wildlife and the overall ecosystem health. In affected areas of Nairobi National Park, Parthenium has reduced the population of native herbaceous species by 65% and caused a marked decline in wildlife that depends on these plants for food, particularly herbivorous mammals (Maina and Brown, 2013).

5. South Africa: Effects on Wildlife and Habitat

In South Africa, Parthenium invasion has been linked to the degradation of savanna ecosystems, leading to habitat loss for wildlife. The weed's dominance in disturbed areas has been shown to reduce the availability of native forage plants. Studies show that in Parthenium-infested areas, native plant species richness has decreased by over 40%, with significant reductions in the populations of native grazers like impala and other herbivores (Witt and Luke, 2017).

6. Nepal: Agricultural Biodiversity Loss

In Nepal, Parthenium hysterophorus has invaded agricultural fields, leading to significant biodiversity loss in cropping systems. The weed affects crop yields and reduces the diversity of other weed species, which are important for soil health and ecosystem balance. Parthenium infestations have led to a reduction of crop yields by up to 40%, with native weed diversity in croplands decreasing by 75% in severely affected areas. This has further impacted soil fauna and beneficial insects (Shrestha, 2019).

Human Health Hazards Associated with Parthenium

The presence of this weed presents health risks to both humans and livestock, resulting in allergic reactions such as eye inflammation, skin dermatitis, and allergic dermatitis (Karki, 2009). Concerns among agriculturists arise from the potential impact of parthenium on ediables and forage crops, as its fine particles and dust can induce allergic contact dermatitis in humans (Gunaseelan, 1987; Morin *et al*., 2009). Exposure to P. hysterophorus pollen is known to trigger allergic bronchitis (Towers and Subba Rao, 1992). Ecological and Socio-Economic Impact of Parthenium hysterophorus L. Invasion in Two Urban Cities of South-Central Nepal. MSc thesis, Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

Figure 10: Result of Parthenium in human (Ataei *et al*., 2021)

Parthenium contains many harmful components, such as chlorogenic acid, anisic acid, p-anisic acid, caffeic acid, and benzoic acids, which pose significant health risks to both humans and cattle. Prolonged exposure to Parthenium can lead to respiratory conditions like asthma and allergic bronchitis, often manifesting after years of continual contact, along with symptoms such as rising fever and respiratory illness. In animals, consumption of Parthenium has been linked to reduced food intake, leading to weight loss and other health issues (Ataei *et al*., 2021). Studies on animals have shown that Parthenium adversely affects reproductive functions, and excessive ingestion can lead to fertility problems, including infertility, abortions, and miscarriages (Jayakrishna *et al*., 2023).

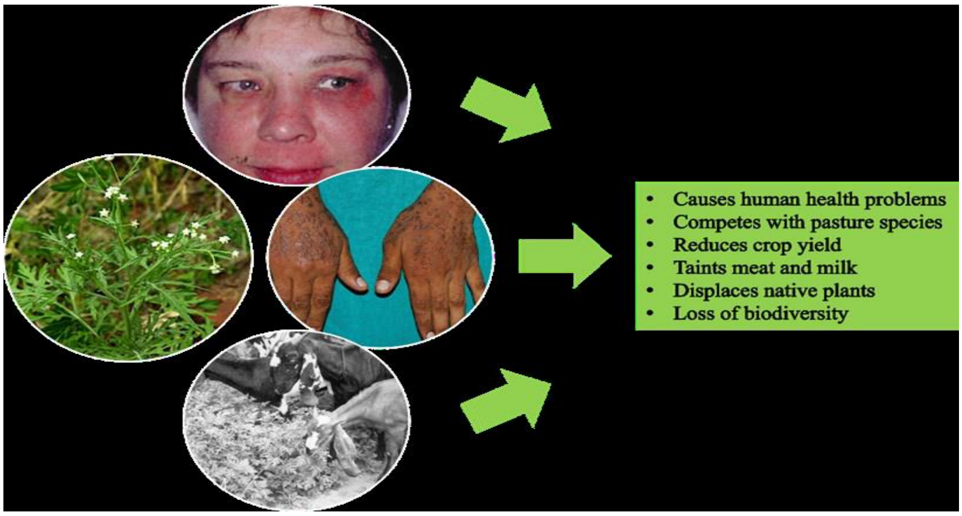

Fig 11: Harmful aspects of Parthenium (Khanal, 2014)

Carrot-weed has been documented to cause various health issues in humans, including asthma, bronchitis, dermatitis, and hay fever upon exposure (Sriramarao *et al*., 1991; Kololgi *et al*., 1997). Additionally, it has been linked to allergic eczematous reactions and mental depression (Sharma *et al*., 2005). Moreover, contact with carrot-weed can result in general illness, skin irritations, pustules on the hands, skin irritation, and stomach pains (Wiesner *et al*., 2007). Exposure to sunlight after contact with carrot-weed may lead to health effects such as violaceous papulae and plaques on exposed areas like the ears, forehead, cheeks, and upper chest. Furthermore, exposure to carrot-weed has been associated with health effects such as hyperkeratotic papules and prurigo nodules (Jayaramiah *et al*., 2017).

The health impacts on livestock and milk quality have led farmers to abandon techniques like utilizing P. hysterophorus as animal bedding (Karki, 2009). Adkins and Navie (2006) have recognized this weed as a significant danger to the sustainability of natural agro-ecosystems worldwide, as it poses a health hazard to both humans and livestock. Exposure to P. hysterophorus also induces systemic toxicity in livestock (Gunaseelan, 1987). Animals feeding on P. hysterophorus have reported symptoms such as alopecia, loss of skin pigmentation, dermatitis, and diarrhea. (In addition, degenerative alterations in sheep and buffalo have been reported, along with inhibition of liver dehydrogenases and liver and kidney abnormalities (Rajkumar *et al*., 1988). It has been discovered that sheep, cattle, and buffalo that consume this herb have lower-quality milk and meat (Lakshmi and Srinivas, 2007).

Environmental Integrity and Ecological Consequences

The presence of Parthenium can induce alterations in soil nutrient dynamics. Research indicates that Parthenium infestation has the potential to elevate soil nitrogen levels, attributed to its high nitrogen absorption and subsequent release via leaf litter. Nonetheless, this may disrupt the equilibrium of other crucial nutrients such as phosphorus and potassium, consequently affecting overall soil fertility. Parthenium invasion exerts significant effects on soil microbial communities and their activity. Depending on the specific circumstances, it can either bolster or suppress microbial populations. For instance, an upsurge in microbial biomass might temporarily enhance nutrient availability; however, sustained decreases in nitrifier abundance could result in diminished soil nitrification rates, thereby adversely impacting plant growth. Parthenium exerts an influence on soil organic carbon (SOC) levels. Invasive species like Parthenium have been found to modify the decomposition rates of organic matter, thereby influencing SOC concentrations. Maintaining high SOC levels is vital for preserving soil structure, fertility, and overall soil health. Parthenium-induced alterations in SOC can contribute to soil degradation and a decline in agricultural productivity. The extensive root systems of Parthenium plants have the potential to compact soil, reducing its porosity and water infiltration rates. This physical alteration can exacerbate soil erosion and diminish water availability for both crops and native vegetation, further deteriorating soil quality.

Economic Implications and Social Consequences

Parthenium weed presents a major threat to both pastures and crops. Aqueous extracts from various parts of Parthenium, such as shoots, leaves, flowers, and roots, have been shown to exhibit allelopathic effects on seed sprouting, sprouting rate, shoot and root growth, and dry weight production in soybean and haricot bean seedlings (Netsere and Mendesil, 2011). Maharjan *et al*., (2007) reported notable obstructive effects on seed sprouting and sapling growth of several grain crops, cruciferous vegetables, and Asteraceae species when exposed to Parthenium hysterophorus leaf extracts. Similarly, Khan *et al*., (2012) observed marked suppression of wheat seed germination and seedling growth caused by extracts from Parthenium roots, stems, and leaves. Devi and Dutta (2012) also found that aqueous extracts of Parthenium inhibited seed sprouting and sapling vigor in Zea mays. The allelopathic effects of Parthenium microspores and other plant section have been shown to impede seed germination and fruit development in crops like chili, tomato, and brinjal, leading to significant crop losses (Jarvis *et al*., 1985). Parthenium is recognized as a major weed in upland rice, responsible for yield reductions exceeding 40% in rice and other crops in India (Oudhia, 1998). Its aggressive nature can lead to pasture production losses of up to 90% (Anonymous, 2011). Parthenin, a compound found in Parthenium, has been reported to inhibit germination and radicle growth in both dicot and monocot plants by entering the soil through decomposing leaf litter (Gunaseelan, 1998). Burning P. hysterophorus in fields has been found to reduce seed sprouting, wood chips, and plumule and total length in Phaseolus mungo (Kumar and Kumar, 2010). Moreover, infestations of P. hysterophorus have been linked to reduced fruiting in leguminous crops and decreased chlorophyll content in crop plants (Lakshmi and Srinivas, 2007).

Management Strategies and Control Measures

A range of management approaches, encompassing chemical, cultural, mechanical, and biological methods, have been employed worldwide in weed control efforts (Melander *et al*., 2017; Korres, 2018). While these strategies prove highly effective on a small scale, their cost-effectiveness diminishes considerably when applied at larger scales (Zimdahl, 2018). Singh (1997) regarded the utilization of biocontrol agents such as insects and fungal pathogens, along with the exploitation of competitive plants through allelopathy, as the most economically viable and practical approach to managing Parthenium. However, despite these efforts, the weed persists above threshold levels, threatening biodiversity and posing health risks to humans and animals. Several processes, including physical, chemical, bioherbicidal, and integrated approaches, are currently being implemented globally to combat this weed and are under discussion.

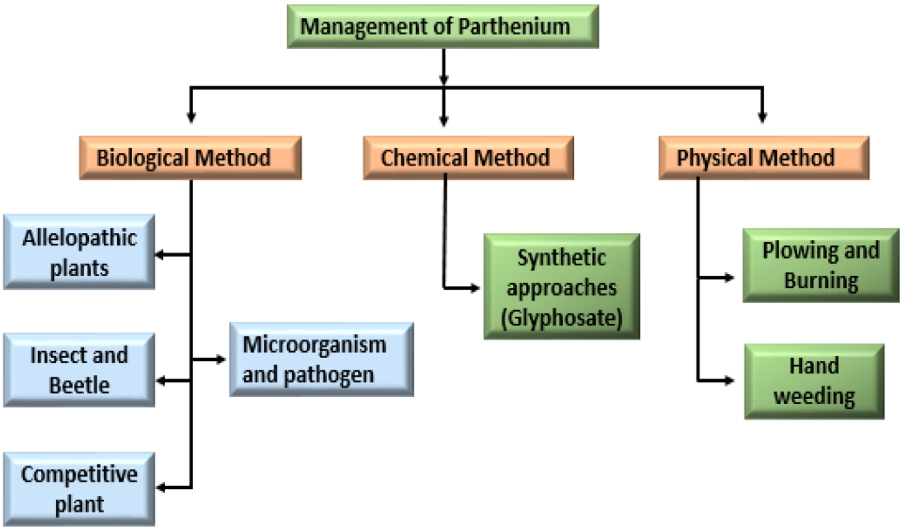

Figure 12: Schematic presentation of the management of *Parthenium hysterophorus* (Dukpa *et al*., 2020)

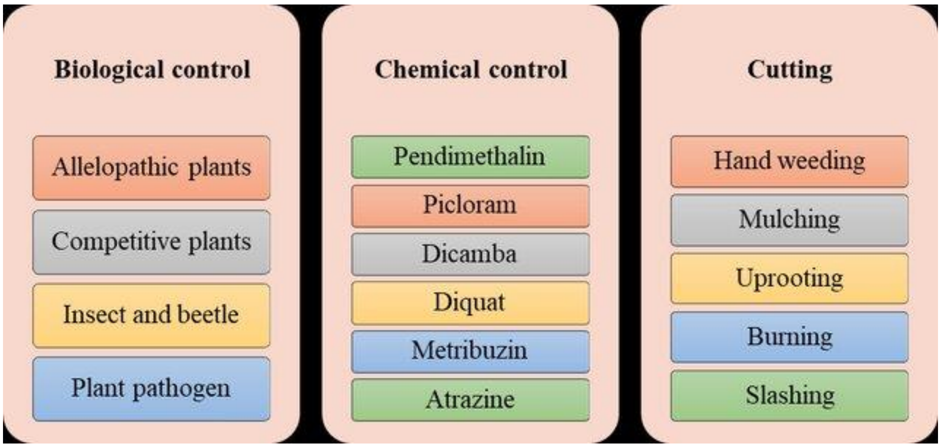

Fig 13: Biological, chemical and physical control of Parthenium hysterophorus (Lalita *et al*., 2018)

Physical Control

1. Manual Removal (Hand Weeding)

Manual removal is one of the most widely used physical methods, especially in small and localized infestations. It involves pulling out the Parthenium plants before they mature and set seed. Hand weeding is effective but labor-intensive. A study conducted in India demonstrated that repeated manual removal of Parthenium (before flowering) reduced the soil seed bank by 70% over two years. Regular removal prevented seed dispersal, leading to a significant decline in infestation density (Sharma and Chauhan 2004).

2. Mowing/Cutting

Mowing is commonly used for controlling Parthenium along roadsides, urban areas, and parks. Cutting the plants before flowering reduces seed production, although repeated mowing is necessary due to the weed's ability to regrow. Research conducted in Australia found that mowing Parthenium before flowering reduced seed production by over 90%, but regrowth from the base of the plant required mowing every 3-4 weeks to prevent full re-establishment (Navie *et al*., 1996).

3. Tillage

Tillage, particularly deep plowing, has been found to reduce Parthenium populations by burying seeds deep in the soil, where they are less likely to germinate. However, shallow tillage can sometimes stimulate seed germination by bringing dormant seeds to the surface. A study in Ethiopia demonstrated that deep plowing reduced Parthenium seedling emergence by 80% compared to no-tillage plots. However, shallow tillage resulted in increased germination due to exposure of buried seeds to sunlight and favorable conditions (Tamado *et al*., 2002).

4. Burning

Burning of Parthenium hysterophorus is sometimes practiced to destroy standing plants and seeds on the soil surface. Controlled burning, though not always feasible, can help reduce the seed bank if performed carefully. A study in India demonstrated that controlled burning of Parthenium-infested fields after the plants had matured reduced the seed bank by 60-70%. The method, however, must be followed by other control measures to prevent recolonization from adjacent areas (Joshi, 1991).

5. Mulching

Mulching involves covering the soil with organic or inorganic materials to suppress weed germination and growth. Organic mulches, such as straw or plant residues, have been shown to be effective in reducing Parthenium emergence. A study in Kenya showed that applying a 10 cm thick layer of organic mulch (e.g., straw) reduced Parthenium seedling emergence by 85%. The mulch created a physical barrier that prevented sunlight from reaching the soil, thereby inhibiting seed germination (Maina and Mathenge 2006).

6. Flooding

Flooding is a less common physical control method but has been used in areas where water management is possible. Prolonged submergence of Parthenium plants and seeds in water can reduce their survival and prevent seedling emergence. Research in India found that flooding Parthenium-infested fields for 10 days led to a 90% reduction in seedling emergence. Submergence deprived the seeds of oxygen and light, inhibiting germination (Patel, 2011).

Chemical Control

1. Glyphosate (Non-selective Herbicide)

Glyphosate is a systemic, non-selective herbicide that is commonly used to control Parthenium hysterophorus. It is particularly effective when applied to young plants, as it inhibits essential plant enzyme pathways. A study conducted in Australia found that glyphosate (1.0 kg a.i. ha^{-1}) controlled Parthenium seedlings by up to 90% when applied during the early growth stages (2-4 leaf stage). However, mature plants were less susceptible and required higher dosages ((Navie *et al*., 1996).

2. Metribuzin (Selective Herbicide)

Metribuzin is a selective herbicide commonly used in crops such as wheat, soybeans, and potatoes. It acts as a photosynthesis inhibitor and is effective against broadleaf weeds like Parthenium. In a study conducted in India, metribuzin (0.35 kg a.i. ha^{-1}) was found to control Parthenium hysterophorus in wheat fields, reducing weed biomass by 80%. The herbicide provided effective control for up to 4 weeks post-application (Sharma and Singh 2004).

3. Atrazine (Photosynthesis Inhibitor)

Atrazine, a triazine herbicide, is used for pre-emergence and post-emergence control of broadleaf and grassy weeds. It is particularly effective in crops like maize and sorghum. Research conducted in South Africa demonstrated that atrazine (2.0 kg a.i. ha^{-1}) applied as a pre-emergence treatment significantly reduced Parthenium seedling emergence by 90%. Atrazine's long residual activity prevented the re-establishment of Parthenium for up to 3 months (Chikoye and Ekeleme 2001).

4. 2,4-D (Growth Regulator Herbicide)

2,4-D is a selective herbicide that mimics plant growth hormones (auxins), leading to uncontrolled growth and eventual death in broadleaf weeds like Parthenium hysterophorus. A field trial in India found that 2,4-D (1.5 kg a.i. ha^{-1}) applied at the pre-flowering stage of Parthenium reduced plant density by 85%. The best results were achieved when 2,4-D was applied to young plants before they reached the reproductive stage (Tewari and Shukla 2006).

5. Imazapyr (ALS Inhibitor)

Imazapyr is a broad-spectrum herbicide used for both pre- and post-emergence control. It inhibits the enzyme acetolactate synthase (ALS), which is crucial for amino acid synthesis in plants. A study conducted in Australia found that imazapyr (0.75 kg a.i. ha^{-1}) provided excellent control of Parthenium when applied as a pre-emergence herbicide. It reduced seedling emergence by over 90% and provided long-lasting control for up to 6 months (Adkins and Shabbir 2014).

6. Paraquat (Contact Herbicide)

Paraquat is a fast-acting contact herbicide that destroys green plant tissue on contact. It is often used for the immediate suppression of Parthenium infestations, particularly in non-crop areas. In a study conducted in Ethiopia, paraquat (0.75 kg a.i. ha^{-1}) applied to young Parthenium plants reduced weed biomass by 85%. However, because paraquat only affects the plant tissue it contacts, regrowth from the root system was observed within 3-4 weeks, necessitating repeated applications (Taye *et al*., 2007).

7. Pre-emergence Herbicides

Pre-emergence herbicides such as oxyfluorfen and pendimethalin have been used to control Parthenium in non-crop areas by inhibiting seedling establishment. In an experiment conducted in Kenya, the application of pendimethalin (1.0 kg a.i. ha^{-1}) as a pre-emergence treatment reduced Parthenium seedling emergence by 75-80%, with effects lasting for up to 8 weeks (Kanchan and Jayachandra 1980).

8. Integrated Chemical Control

Combining herbicides with other control methods, such as mechanical removal or cultural practices, has shown improved results in managing Parthenium hysterophorus over time. A study in India combined the application of 2,4-D with manual removal and mulching, which reduced Parthenium density by over 90% after two growing seasons. The integrated approach provided more sustainable and long-term control than herbicides alone (Pandey and Joshi 2003).

Management through allelopathic plants:

1. Cassia tora and Cassia sericea

Allelopathic Effect: These plants release secondary metabolites through root exudates and leaf litter that inhibit Parthenium seed germination and seedling growth. A field study reported that intercropping Cassia tora reduced Parthenium emergence by 45% and biomass by 40% after one season. The chemical compounds in Cassia tora were found to inhibit Parthenium growth by interfering with nutrient uptake (Kohli *et al*., 2006).

2. Sorghum bicolor (Sorghum)

Sorghum produces a natural compound called sorgoleone, which is exuded by its roots and inhibits seed germination of surrounding plants, including Parthenium hysterophorus. A greenhouse study found that Sorghum bicolor extracts reduced the germination of Parthenium by 50% and its seedling growth by 60%. This is due to sorgoleone's inhibitory effect on root elongation and cell division (Cheema and Khaliq 2000).

3. Helianthus annuus (Sunflower)

Allelopathic Effect: Sunflower extracts contain phenolic compounds such as p-coumaric and chlorogenic acids, which inhibit seed germination and root growth in competing plants like Parthenium. In a study testing the aqueous extracts of Helianthus annuus on Parthenium, seed germination was inhibited by 70%, and root growth was reduced by 80%. This indicates that sunflower residues can significantly suppress Parthenium growth (Batish *et al*., 2007).

4. Tagetes minuta (Mexican Marigold)

Allelopathic Effect: Tagetes minuta is known to produce compounds like thiophenes, which have herbicidal properties that can suppress the growth of invasive weeds. In a controlled experiment, soil incorporated with Tagetes minuta residues reduced Parthenium seed germination by 60%. Furthermore, the application of Tagetes minuta leaf extracts inhibited Parthenium seedling growth by 55% (Kumar and Kaushik 2005).

5. Eucalyptus species

Allelopathic Effect: Eucalyptus species are known for producing allelochemicals such as eucalyptol and cineole, which inhibit the growth of neighboring plants by reducing their seed germination rate and root elongation. A study using Eucalyptus leaf extracts showed that Parthenium hysterophorus seed germination was reduced by 50-60%, and its seedling growth was inhibited by 65%. The chemicals in Eucalyptus affect cell division and nutrient uptake in Parthenium (Singh *et al*., 2003).

6. Azadirachta indica (Neem)

Allelopathic Effect: Neem produces several bioactive compounds, including azadirachtin, which suppresses the germination and growth of weeds like Parthenium. In an experiment, neem leaf and bark extracts reduced the germination of Parthenium seeds by 55% and 68%, respectively. The bioactive compounds in neem inhibited the root growth and overall biomass production of Parthenium (Javid and Anjum 2006).

Biological management:

1. Use of Biocontrol Agents

Biological management of Parthenium hysterophorus primarily focuses on using natural enemies, including insects, fungi, and competitive plant species. Among the most effective biological agents are the following:

1. Insects:

The Zygogramma bicolorata beetle, a leaf-feeding beetle, has shown significant success in controlling Parthenium. It consumes leaves, reducing plant vigor and seed production. Listronotus setosipennis, a stem-boring weevil, reduces plant growth by feeding on the root system. In a field study conducted in India, the release of Zygogramma bicolorata resulted in a reduction of Parthenium cover by up to 55% after three months (Jayanth, 1987).

2. Pathogens

Puccinia abrupta var. partheniicola is a rust fungus that has been reported to significantly suppress Parthenium populations by attacking leaves, stems, and inflorescences. This fungus weakens the plant and reduces its seed bank, though it requires specific environmental conditions to thrive. Studies in Ethiopia show that rust fungus reduced Parthenium biomass by 65-70% over a growing season (Taye, 2007).

3. Competitive Crops and Cover Crops

Competitive crops like sorghum and cowpea can suppress Parthenium growth due to their aggressive canopy and fast growth, which shades out Parthenium and reduces its ability to thrive. Research in Australia has shown that cultivating sorghum can reduce Parthenium seedling emergence by 80% in the field (Navie *et al*., 2004).

4. Integrated Biological Management

Combining biological agents with other control strategies, such as mechanical removal or herbicides, has shown improved long-term control of Parthenium hysterophorus. For example, combining the use of Zygogramma bicolorata with manual weeding increased the reduction of Parthenium biomass by up to 80% compared to using biological agents alone. In a study in India, integrated biological and mechanical management reduced Parthenium density by over 90% within two growing seasons (Pandey *et al*., 2003).

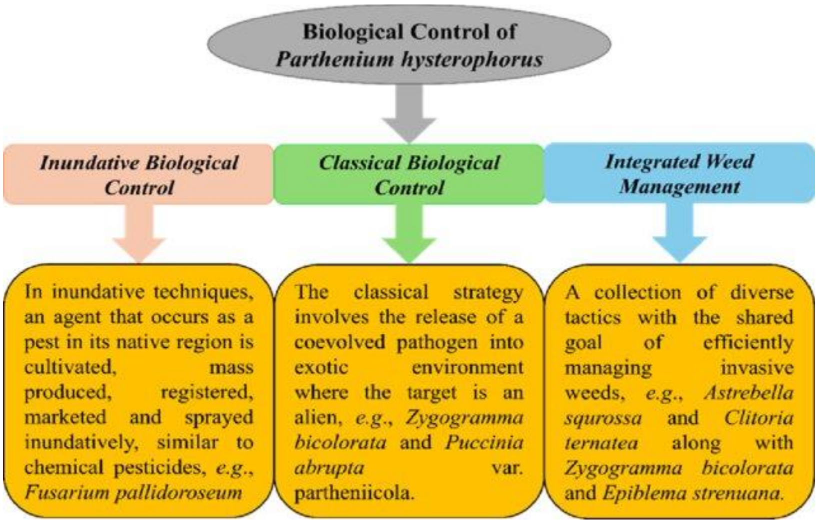

Fig 14: Biological control of Parthenium hysterophorus (Kaur *et al*., 2014)

Table 1: Biological control agents of Parthenium around the world (Weyl *et al*., 2021)

Sr. No.	Biocontrol agent	Country where ntroduced	Year in which reported	Reference
Insects				
1.	Bucculatrix parthenica Bradley	Australia	1983	
2.	Carmenta ithacae (Beutenmüller)	Australia South Africa	1996 2014	
3.	Conotrachelus albocinereus Fiedler	Australia	1992	Cruttwell, 2000
4.	Epiblema strenuana Walker	Australia China India Papua New Guinea South Africa Sri Lanka Vanuatu	1982 1990 1985 2004 2010 & 2018 2003 2014	Strathie and Khan (2018)
5.	Listronotus setosipennis Hustache	Australia Ethiopia Pakistan South Africa Uganda	1981 2007 2019 2003 2018	Weyl *et al.* (2021)
6.	Zygogramma bicolorata Pallister	Australia Ethiopia India Nepal Pakistan South Africa Tanzania Uganda	1980 2007 1983 2009 2003 2005 2013 2018	Strathie and Khan (2018)
7.	Platphalonidia mystica (Razowski & Becker)	Australia	1991	Dhileepan and Strathie (2009)
8.	Smicronyx lutulentus Dietz	Australia Ethiopia India South Africa	1980 2015 1985 & 2018 2010	Weyl *et al.* (2021)
9.	Stobaera concinna (Stål)	Australia	1982	Strathie and Khan (2018)
Fungi				
1.	Puccinia xanthii var. parthenii hysterophorae	Australia South Africa Sri Lanka	1999 2004 2003	Dhileepan and McFadyen (2012)
2.	Puccinia abrupta partheniicola Parmelee	Australia China Ethiopia India Nepal Pakistan South Africa	1991 2007 1997 1980 2011 2019 1995	Weyl *et al.* (2021)

Management by utilization:

A highly effective strategy for managing Parthenium involves its diverse applications. Extensive studies have highlighted its insecticidal properties (Gajendran and Gopalan, 1982) nematicidal activity (Bala *et al*., 1986) and herbicidal potential (Pandey *et al*., 1993). Furthermore, Parthenium is also employed in the production of oxalic acid and biogas (Gunaseelan, 1987; Bhan *et al*., 1997).

Legal Management:

Legislators need to pass national-level laws and acts aimed at controlling Parthenium. Collaboration between federal and provincial government administrations, along with scientists, is crucial. Public awareness campaigns via radio, TV, videos, posters, and seminars are essential to educate people about the importance of implementing these laws and acts. Previous research indicates that an integrated approach is necessary for effective Parthenium management. This approach should combine minimal use of potent herbicides, biological control agents, and cultural practices.

Challenges in eradication and containment

High Seed Production and Dispersal

Parthenium hysterophorus exhibits extensive seed production, with seeds capable of maintaining viability in the soil for extended periods. This abundant seed production, coupled with the seeds' dispersal through various means such as wind, water, animals, and human activities, presents considerable challenges for eradication efforts (Navie *et al*., 1996). Parthenium weed demonstrates rapid growth and versatility in adapting to a wide range of environmental conditions, spanning from arid to semi-arid regions. This adaptability enables its establishment in various habitats (Shabbir *et al.*, 2006).

Herbicide Resistance

Continuous application of identical herbicides may result in resistance, diminishing the efficacy of chemical control techniques. Hence, there is a need to formulate and rotate various herbicides and implement integrated weed management strategies (Adkins and Shabbir, 2014).

Socio-Economic Constraints

Efficient management of parthenium weed infestations frequently demands significant financial and labor investments, which might not be readily accessible in heavily affected regions. Constraints in funding and resources can impede ongoing control endeavors (Adkins and Navie, 2006).

Future Directions and Research Needs

Additional exploration into the management and consequences of Parthenium hysterophorus is imperative to formulate enhanced control tactics and grasp the comprehensive scope of its impacts. The following outlines crucial domains necessitating further investigation based on recent research:

Mechanisms of Herbicide Resistance

Comprehending the genetic and biochemical mechanisms responsible for herbicide resistance in Parthenium hysterophorus is pivotal for devising approaches to counter resistance and enhance herbicide effectiveness (Sharma and Singh 2019).

Impact on Soil Health and Microbial Communities

Exploring the impact of parthenium infestation on soil health, encompassing alterations in soil microbial communities and nutrient cycling, is crucial for comprehending its wider ecological ramifications and guiding restoration initiatives (Wakjira and Mekuria 2018).

Long-term Efficacy of Biological Control Agents

Assessing the enduring efficacy and ecological repercussions of biological control agents on parthenium populations is imperative to ensure sustainable weed management practices (Dhileepan and Strathie 2009).

Allelopathic Interactions and Natural Herbicides

Additional investigation into the allelopathic characteristics of various plants and the formulation of natural herbicides derived from these sources could offer environmentally sustainable alternatives for managing parthenium (Batish *et al*., 2007).

Climate Change Impacts

Investigating the potential impacts of climate change on the distribution, proliferation, and management of parthenium is essential for devising adaptive approaches to weed control amid evolving environmental dynamics (Kriticos and Leriche 2010).

Integrated Weed Management (IWM) Approaches

Further research into the creation and application of Integrated Weed Management (IWM) strategies, integrating various control techniques adapted to specific regional contexts, is imperative for achieving sustainable management of parthenium (Adkins and Shabbir 2014).

Socio-economic Impacts and Community Involvement

Researching the socio-economic ramifications of parthenium invasion and identifying effective approaches to involve local communities in control endeavors can bolster the adoption and efficacy of management strategies (Mcconnachie *et al*., 2003).

Emerging technologies for Parthenium management

Progress in genetic engineering and biotechnology is offering fresh avenues for parthenium management by facilitating the creation of genetically modified organisms (GMOs) and biotechnological interventions (Belhaj *et al*., 2015). The CRISPR/Cas9 gene-editing technology presents an opportunity for the development of herbicide-resistant crops or for directly targeting specific genes in parthenium to diminish its growth and reproductive capabilities (Belhaj *et al*., 2015). RNAi technology offers a promising approach to silence critical genes in parthenium, thereby decreasing its viability and competitive prowess (Caste and Martienssen 2013).

Remote sensing and Geographic Information Systems (GIS) are increasingly recognized as potent instruments for overseeing and controlling parthenium infestations at a broad scale. Through the utilization of satellite imagery and unmanned aerial vehicles (UAVs), scientists can accurately detect and map parthenium infestations, facilitating precise and targeted interventions (Everitt *et al*., 2005). GIS can be fused with additional data reservoirs to construct decision support systems aiding in the formulation and execution of management strategies. Advanced agricultural technologies like precision agriculture, featuring automated weed identification and robotic weed management, provide accurate and effective approaches to parthenium management. Utilizing machine learning algorithms and image recognition software enables the identification of parthenium plants within crop fields, facilitating targeted herbicide application or mechanical eradication (Lottes *et al*., 2018).

Autonomous robots, outfitted with sensors and actuators, can autonomously traverse fields to mechanically eliminate or administer targeted treatments to parthenium plants. Exploration of bioherbicides and botanical extracts presents eco-friendly substitutes to synthetic herbicides. Specific fungi and bacteria have been recognized for their ability to infect and inhibit the growth of parthenium in a selective manner (Bailey, 2014).

CONCLUSION

Extensive data on the biodiversity impact caused by the invasion of parthenium underscores the urgent necessity for comprehensive management strategies to alleviate its adverse effects. Parthenium, alongside other invasive plant species, presents a significant threat to ecosystems worldwide, comparable to habitat destruction in its ability to disturb natural equilibriums and induce biodiversity decline. The encroachment of parthenium not only displaces indigenous plant communities but also poses significant health risks to humans and livestock, exacerbating socio-economic difficulties in affected areas. Its allelopathic characteristics, coupled with its prolific seed production and adaptable nature, render it a formidable opponent in both agricultural and natural environments. Efforts to address parthenium invasion demand a multifaceted approach, integrating chemical, biological, cultural, and integrated weed management tactics. Nonetheless, obstacles such as herbicide resistance, socio-economic limitations, and the necessity for sustainable, environmentally friendly solutions persist. Future research endeavors should concentrate on comprehending the mechanisms behind herbicide resistance, evaluating the long-term effectiveness of biological control agents, examining allelopathic interactions, and exploring emerging technologies like genetic engineering and remote sensing for efficient parthenium management. Community engagement and awareness campaigns are also pivotal for the successful implementation of control measures. By tackling these challenges and capitalizing on innovative solutions, we can endeavor towards the sustainable management of parthenium and the preservation of biodiversity, human health, and agricultural sustainability for generations to come.

REFERENCES

- Abbas, A., Wang, Y., Muhammad, U., & Fatima, A. (2021a). Efficacy of different insecticides against gram pod borer (Helicoverpa armigera) and their safety to the beneficial fauna. *International Journal of Biosciences, 18*, 82-88.
- Abbas, R. N., Arshad, M. A., Iqbal, A., Iqbal, M. A., Imran, M., Raza, A., & Hefft, D. I. (2021). Weeds spectrum, productivity and land-use efficiency in maize-gram intercropping systems under semi-arid environment. *Agronomy, 11*(8), 1615.
- Adkins SW (1996). The allelopathic potential of parthenium weed (Parthenium hysterophorus L.). Australia Plant Prot. Q. 11:20-23.
- Adkins, S. W., and Navie, S. C. (2006). Parthenium weed, a potential major weed for agroecosystems in Pakistan. Pakistan Journal of Weed Science Research, 12, 19-36.
- Adkins, S.W., and Shabbir, A. (2014). Biology, ecology and management of the invasive parthenium weed (Parthenium hysterophorus) in Australia. Weed Research, 54(4), 306-320.
- Afzal, M. R., Naz, M., Ashraf, W., & Du, D. (2023). The legacy of plant invasion: Impacts on soil nitrification and management implications. Plants, 12(16), 2980.
- Akhter, M. J., Abbas, R. N., Waqas, M. A., Noor, M. A., Arshad, M. A., Mahboob, W. M., & Gull, U. G. (2017). Adjuvant improves the efficacy of herbicide for weed management in maize sown under altered sowing methods.
- Aleem, S. (2024). Advancements in Mutation Breeding in Phalsa (Grewia asiatica L.) Crop Improvement: A Comprehensive Review of Radiation and Chemical Induced Mutagenesis Studies. *Haya Saudi J Life Sci*, *9*(5), 158-171.
- Anonymous. (2011). Parthenium weed (Parthenium hysterophorus L.). Fact sheet. The State of Queensland, Department of Employment, Economic Development and Innovation, 1-4.

- Arshad, M. A. (2021). A review on wheat management, strategies, current problems, and future perspectives. *Haya: Saudi Journal of Life Sciences, 6*, 14-18.
- Arshad, M. A., Abbas, R. N., Khaliq, A., & Ahmed, Z. (2024a). Assessing herbicide efficacy and susceptibility for weed management and enhancing production of non-GMO soybean cultivation.
- Arshad, M. A., Rouf, S., Abbas, R. N., Aleem, K., Sarwar, A., Shahbaz, Z., Baloch, R., Rehman, H. u., & Masood, M. T. (2024). Environmental benefits and risks of herbicides use in forestry– Review. *Haya: Saudi Journal of Life Sciences, 9*(2), 23-35.
- Arshad, M. A., Rouf, S., Abbas, R. N., Shahbaz, Z., Aleem, K., Shahbaz, H., Pervaiz, R., Sarwar, A., & Rehman, H. U. (2024c). Navigating synergies: A comprehensive review of agroforestry system and agronomy crops. *Haya: Saudi Journal of Life Sciences, 9*(4), 97-112.
- Australian Weeds Committee. 2012. Pathenium (Parthenium hysterophorus L.) strategic plan 2012–17, Weeds of National Significance, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.
- Ayele, S. (2007). The impact of Parthenium (Parthenium hysterophorus L.) on the range ecosystem dynamics of the Jijiga rangeland, Ethiopia (Master's thesis). Department of Animal Sciences, School of Graduate Studies, Haramaya University, Haramaya.
- Bailey, K. L. (2014). The bioherbicide approach to weed control using plant pathogens. *Biocontrol Science and Technology, 24*(8), 801-815.
- Bais, H. P., Vepachedu, R., Gilroy, S., Callaway, R. M., & Vivanco, J. M. (2003). Allelopathy and exotic plant invasion: From molecules and genes to species interactions. *Science*, 301, 1377-1380.
- Bajwa, A. A., Chauhan, B. S., Farooq, M., Shabbir, A., & Adkins, S. W. (2016). What do we really know about alien plant invasion? A review of the invasion mechanism of one of the world's worst weeds. *Planta*, 244, 39-57.
- Bala, S. K., Bhattacharya, P., Mukerjee, K. S., & Sukul, N. C. (1986). Nematicidal properties of the plants Xanthium strumarium and Parthenium hysterophorus. *Environmental Ecology, 4*(2), 139-141.
- Batish, D. R., Lavanya, K., Singh, H. P., & Kohli, R. K. (2007). Root-mediated allelopathic interference of nettles leaved goosefoot (Chenopodium murale) on Phalaris minor and its potential for use as a natural herbicide. *Journal of Agronomy and Crop Science, 193*(1), 37-44.
- Batish, D. R., Singh, H. P., Pandher, J. K., Arora, V., & Kohli, R. K. (2002). Phytotoxic effect of Parthenium residues on the selected soil properties and growth of chickpea and radish. *Weed Biol Manag*, 2, 73–78.
- Belhaj, K., Chaparro-Garcia, A., Kamoun, S., Patron, N. J., & Nekrasov, V. (2015). Editing plant genomes with CRISPR/Cas9. *Current Opinion in Biotechnology*, 32, 76-84.
- Bhan, V. M., Kumar, S., & Raghuwanshi, M. S. (1997). Future strategies for effective Parthenium management. In Proceedings of the First International Conference on Parthenium Management (pp. 90-95).
- Castel, S. E., & Martienssen, R. A. (2013). RNA interference in the nucleus: Roles for small RNAs in transcription, epigenetics and beyond. *Nature Reviews Genetics, 14*(2),
- Cheema, Z. A., & Khaliq, A. (2000). Use of sorgaab (sorghum water extract) as a natural weed inhibitor in irrigated wheat. *International Journal of Pest Management, 46*(2), 105-110.
- Chikoye, D., & Ekeleme, F. (2001). Weed management practices for groundnut production in the northern Guinea savanna of Nigeria. *Crop Protection, 20*(5), 499-504.
- Chippendale, J. F., & Panetta, F. D. (1994). The cost of parthenium weed to the Queensland cattle industry. *Plant Protection Quarterly, 9*(2), 73-76.
- Dagar, J. C., Rao, A. N., & Mall, L. P. (1976). Regeneration of Parthenium hysterophorus. *Geobios*, 3, 202-203.
- Devi, O. I., & Dutta, B. K. (2012). Allelopathic effect of the aqueous extract of Parthenium hysterophorus and Chromolaena odorata on the seed germination and seedling vigour of Zea mays L. In vitro. *Applied Journal of Plant Science, 5*(4), 110-113.
- Dhileepan, K. (2009). Managing Parthenium weed across diverse landscapes: prospects and limitations. In: Inderjit (ed) Management of invasive weeds. Springer Netherlands, Dordrecht, pp 227–259.
- Dhileepan, K., & Strathie, L. (2009). Twenty-five years of classical biological control of Parthenium hysterophorus: Progress and prospects. Biological Control, 26(3), 477-488.
- Dukpa, R., Tiwari, A., & Kapoor, D. (2020). Biological management of allelopathic plant Parthenium sp. *Open Agric*, 5, 252–261.
- Evans, H. C. (1997). Parthenium hysterophorus: A review of its weed status and the possibility of biological control. *Biocontrol News and Information, 18*(3), 89-98.
- Evans, H. C. (1997). Parthenium hysterophorus: A review of its weed status and the possibilities for biological control. *Biocontrol News and Information, 18*(3), 89-98.
- Everitt, J. H., Yang, C., & Deloach, C. J. (2005). Remote sensing of giant reed with QuickBird satellite imagery. *Journal of Aquatic Plant Management, 43*(2), 69-75.
- Gajendran, G., & Gopalan, M. (1982). Notes on the antifeedant activity of Parthenium hysterophorus L.

on Spodoptera litura. *Indian Journal of Agricultural Sciences*, *52*(3), 203-205.

- Gunaseelan, V. N. (1987). Parthenium as an additive with cattle manure in biogas production. *Biological Wastes, 21*(3), 195-203.
- Haseler, W. H. (1976). Parthenium hysterophorus L. in Australia. *PANS*, 22, 515-517
- Heirro, J. L., & Callaway, R. M. (2003). Allelopathy and exotic plant invasion. *Plant and Soil*, 256, 29-39.
- Jarvis, B. B., Pena, N. B., Rao, M. M., Comezoglu, R. S., Comezoglu, T. F., & Mandava, N. B. (1985). Allelopathic agents for Parthenium hysterophorus and Baccharis megapotamica. In The Chemistry of Allelopathy: Biochemical Interactions among the Plants (pp. 149-159). American Chemical Society.
- Javaid, A., & Anjum, T. (2006). Biological Control of Parthenium III: Control of Parthenium hysterophorus L. by aqueous extracts of allelopathic grasses. *Pakistan Journal of Botany, 38*(1), in press.
- Jayakrishna, M., Boddana, P., & Vijay, M. (2023). Assessing The Sustainability of Chemical Control Methods in Pest Management: A Review of Carrying Capacity and Pesticide Use. *Journal of Advanced Zoology, 44*(4).
- Jayanth, K. P. (1987). Introduction and establishment of Zygogramma bicolorata on Parthenium hysterophorus in Bangalore, India. Current Science, 56(6), 310-311.
- Jayaramiah, R., Krishnaprasad, B., Kumar, S., Pramodh, G., Ramkumar, C., & Sheshadri, T. (2017). Harmful effects of Parthenium hysterophorus and management through different approaches-A review. *Annals of Plant Sciences*, *6*(05), 1614-1621.
- Joshi, S. (1991a). Interference effects of Cassia uniflora Mill. on Parthenium hysterophorus L. *Plant and Soil*, 132, 213–218.
- Kanchan, S. D., & Jayachandra. (1980). Allelopathic effects of Parthenium hysterophorus L. IV. Identification of inhibitors. *Plant and Soil*, 55, 67-75.
- Kanchan, S. D. (1975). Growth inhibitors from Parthenium hysterophorus Linn. *Current Science*, 44, 358–359.
- Karim, S. M. R. (2008). Parthenium weed (Parthenium hysterophorus L.): A threat for Bangladesh. Paper presented at the seminar at the Bangladesh Agricultural University, Mymensingh, Bangladesh, October 29, 2008.
- Karim, S. M. R., & Nag, B. L. (2008). A new invader weed, Parthenium hysterophorus: A threat for Bangladesh. Poster session presented at the 1st National Conference and Seminar on Weeds and Food Security, Bangladesh Agricultural Research Council, Dhaka, Bangladesh, November 8, 2008.
- Kaur, M., Aggarwal, N. K., Kumar, V., & Dhiman, R. (2014). Effects and management of Parthenium hysterophorus: A weed of global significance. International Scholarly Research Notices, 2014,
- Kaur, M., Aggarwal, N.K., Kumar, V. & Dhiman, R. (2014). Effects and management of Parthenium hysterophorus: A weed of global significance. International Scholarly Re-search Notices, 2014, 1-12.
- Khan, H., Khan, B.M., Hassan, G., & Khan, M.A. (2012). Chemical control of Parthenium hysterophorus L. at different growth stages in non-cropped area. *Pakistan Journal of Botany, 44*(5), 1721–1726.
- Khanal, S. (2014). Be aware of a new threat Parthenium hysterophorus L: A serious headache.
- Khosla, S. N., & Sobti, S. N. (1981). Parthenium hysterophorus L.—A review. *Agricultural Reviews*, 2(2), 110-117.
- Kohli, R. K., Batish, D. R., Singh, H. P., & Dogra, K. S. (2006). Status, invasiveness and environmental threats of three tropical American invasive weeds (Parthenium hysterophorus, Ageratum conyzoides and Lantana camara) in India. *Biological Invasions*, *8*(7), 1501-1510.
- Kohli, R. K., & Rani, D. (1994). Exhibition of allelopathy by Parthenium hysterophorus L. in agroecosystems. *Trop Ecol*, 35, 295–307.
- Oviedo, P., Herrera, O., & Caluff, M. G. (2012). National list of invasive and potentially invasive plants in the Republic of Cuba-2011. Bissea Boletín sobre Conserv. *Plantas del Jardín Botánico Nac Cuba*, 6, 22–96.
- Kololgi, P., Kololgi, S., & Kololgi, N. (1997). Dermatologic Hazards of Parthenium in Human Beings. Proceedings of the 1st International Conference on Parthenium Management, Dharwad, 18-19.
- Korres, N. E. (2018). Agronomic weed control: A trustworthy approach for sustainable weed management. In Non-Chemical Weed Control (pp. 97-114). Elsevier.
- Kriticos, D. J., & Leriche, A. (2010). The effects of climate change on the distribution of Parthenium hysterophorus. *Weed Research, 50*(2), 146-152.
- Kumar, M., & Kumar, S. (2010). Effect of Parthenium hysterophorus ash on growth and biomass of Phaseolus mungo. *Academic Arena*, *2*(1).
- Kumar, S., & Kaushik, N. (2005). Effect of Tagetes minuta on the germination of Parthenium hysterophorus L. *Journal of Environmental Biology, 26*(2), 209-214.
- Lakshmi, C., & Srinivas, C. R. (2007). Parthenium: A wide angle view. *Indian Journal of Dermatology, Venereology, and Leprology, 73*(5), 296-306.
- Lalita, K. A. (2018). Review on a weed Parthenium hyster-ophorus (L.). *International Journal of Current Research and Review*, 10, 23.

- Lottes, P., Behley, J., Milioto, A., & Stachniss, C. (2018). Fully convolutional networks with sequential information for robust crop and weed detection in precision farming. *IEEE Robotics and Automation Letters*, *3*(4), 2870-2877.
- Mack, R., Simberloff, D., Lonsdale, M., Evans, H., Clout, M., & Bazzaz, F. (2000). Biotic invasions: cause, epidemiology, global consequences, control. *Ecological Applications*, 1, 689–710.
- Maharjan, S., Shrestha, B. B., & Jha, P. K. (2007). Allelopathic effects of aqueous extract of leaves of Parthenium hysterophorus L. on seed germination and seedling growth of some cultivated and wild herbaceous species. *Scientific World*, *5*(5), 33-39.
- Maina, G. G., & Mathenge, P. W. (2006). Mulching as an effective control of Parthenium hysterophorus L. in Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, *107*(1), 57-65.
- Maina, G. G., & Brown, J. R. (2013). The influence of invasive Parthenium hysterophorus on plant biodiversity and soil properties in a savanna ecosystem in Kenya. *Applied Ecology and Environmental Research*, *11*(3), 381-390.
- Masum, S. M., Hasanuzzaman, M., & Ali, M. H. (2013). Threats of Parthenium hysterophorus on agro-ecosystems and its management: a review. *International Journal of Agriculture and Crop Sciences*, *6*(11), 684.
- McConnachie, A. J., de Wit, M. P., Hill, M. P., & Byrne, M. J. (2003). Economic evaluation of the successful biological control of Azolla filiculoides in South Africa. *Biological Control*, *28*(1), 25-32.
- McFadyen, R. C. (1992). Biological control against parthenium weed in Australia. *Crop Prot 11*(5), 400–407. https://doi.org/10.1016/0261-2194(92)90021-V
- Melander, B., Matt, L., Adam, S. D., Eric, R. G., Paolo, B., Anna-Camilla, M., Jesper, R., Rommie, W., & Francesco, V. (2017). Non-chemical weed management. In Weed Research (pp. 245-270).
- Morin, L., Reid, A. M., Sims-Chilton, N. M., Buckley, Y. M., Dhileepan, K., Hastwell, G. T., Nordblom, T. L., & Raghu, S. (2009). Review of approaches to evaluate the effectiveness of weed biological control agents. Biological Control, 5(1), 1-15.
- Mulatu W, Gezahegn B, Solomon T (2009). Allelopathic effects of an invasive alien weed Parthenium hysterophorus L. compost on lettuce germination and growth. Afr. J. Agric. Res. 4(11):1325-1330.
- N. V. Gunaseelan, “Impact of anaerobic digestion on inhibition potential of Parthenium solids,” Biomass and Bioenergy, vol. 14, no. 2, pp. 179–184, 1998.
- Narasimhan, T. R., Ananth, M., Swamy, M. N., Babu, M. R., Mangala, A., & Rao, P. V. (1977). Toxicity of Parthenium hysterophorus L. to cattle and buffaloes. Experientia, 33, 1358–1359.
- Navie, S. C., McFadyen, R. E., Panetta, F. D., & Adkins, S. W. (1996). The biology of Australian weeds. 27. Parthenium hysterophorus L. Plant Protection Quarterly, 11(2), 76-88.
- Navie, S. C., McFadyen, R. E., Panetta, F. D., & Adkins, S. W. (2004). The biology of Australian weeds. 37. Parthenium hysterophorus L. Plant Protection Quarterly, 19(2), 76-88
- Netsere, A., & Mendesil, E. (2011). Allelopathic effects of Parthenium hysterophorous L. aqueous extracts on soybean (Glycine max L.) and haricot bean (Phaseolus vulgaris L.) seed germination, shoot and root growth and dry matter production. Journal of Applied Botany and Food Quality, 84, 219-222.
- Nguyen, T. L., Navie, S. C., & Adkins, S. W. (2010). The effect of Parthenium weed (Parthenium hysterophorus L.) on plant diversity in pastures in Queensland, Australia. In Proceedings of the 17th Australasian Weeds Conference, New Frontiers in New Zealand: Together We Can Beat the Weeds* (pp. 26-30). New Zealand Plant Protection Society, Christchurch, New Zealand.
- Nigatu L, Hassen A, Sharma J, Adkins SW (2010) Impact of Parthenium hysterophorus on grazing land communities in north-eastern Ethiopia. Weed Biol Manag 10(3):143–152.
- Noxious Weed Threatens the Biggest Wildlife Migration on the Planet. [Online]. IUCN. Available: http://www.iucn.org/news_homepage/ events/?6511/Noxious-weed-threatens-the-biggest-wildlife-migration-on-the-planet [25 June 2011].
- Oudhia, P. (1998). Parthenium: A curse for the biodiversity of Chhattisgarh Plain. In Abstract National Research Seminar on Biochemical Changes: An Impact on Environment (p. 26). R.D. Govt. P.G. College, Mandla (M.P.), 30-31 July.
- Pandey, A. K., & Joshi, D. C. (2003). Integrated management of Parthenium hysterophorus in central India. Journal of Biological Control, 17(2), 149-152**.**
- Pandey, D. K., Kauraw, L. P., & Bhan, V. M. (1993). Inhibitory effect of Parthenium hysterophorus residue on growth of water hyacinth (Eichhornia crassipes). Journal of Chemical Ecology, 19(12), 2651-2662.
- Patel, S. (2011). Harmful and beneficial aspects of Parthenium hysterophorus: An update. 3 Biotech, 1(1), 1-9.
- Pervaiz, R., Baloch, R., Arshad, M. A., Abbas, R. N., Shahzad, N., Hamid, M., ... & Akbar, M. M. (2024). Herbicide strategies for weed control in rice cultivation: Current practices and future directions. *Haya Saudi J Life Sci*, *9*(4), 114-129.
- Picman, J. and A.K. Picman. 1984. Autotoxicity in Parthenium hysterophorus and its possible role in germination. Biochem. Systemat. Ecol., 12: 287-292.

- Rafeeq, H., Arshad, M. A., Amjad, S. F., Ullah, M. H., Imran, H. M., Khalid, R., & Ajmal, H. (2020). Effect of nickel on different physiological parameters of Raphanus sativus. *International Journal of Scientific Research Publications*, *10*, 9702.
- Rajkumar, E. D. M., Kumar, N. V. N., Haran, N. V. H., & Ram, N. V. S. (1988). Antagonistic effect of P. hysterophorus on succinate dehydrogenase of sheep liver. Journal of Environmental Biology, 9(3), 231-237.
- Ramaswami, P. P. (1997). Potential uses of Parthenium. In Proceedings of the First International Conference on Parthenium Management (pp. 77-80).
- Rasheed, H. U. (2024). Adaptation and Agricultural Significance of Syzygium cumini L. *Saline Environments: A Global Perspective on Jamun Cultivation and Salt Stress Resilience. Haya Saudi J Life Sci*, *9*(5), 172-187.
- Rezene F, Meckasha C, Mengistu H. (2005). Spread and Ecological consequences of Parthenium hysterophorus, in Ethiopia. Arem 6:11- 23.
- Sakai, A. K., Allendorf, F. W., Holt, J. S., Lodge, D. M., Molofsky, J., With, K. A., Baughman, S., Cabin, R. J., Cohen, J. F., Ellstrand, N. C., McCauley, D. E., O'Neil, P., Parker, I. M., Thompson, J. N., & Weller, S. G. (2001). The population biology of invasive species. Annual Review of Ecology and Systematics, 32, 305-332.
- Sattler, P., & Williams, V. (1999). The conservation status of Queensland's bioregional ecosystems. Queensland Environmental Protection Agency.McFadyen RE. 1992. Biological control against Parthenium weed in Australia. Crop Protec., 11:400-407
- Shabbir, A., & Swhsana, R. B. (2005). Parthenium hysterophorus spread and status on its management in Pakistan. pp. 28-35. In: Proceeding of the Second International Conference on Parthenium Management. 5- 7 December. 2005. University of Agricultural Science, Bangalore, India.
- Shabbir, A., & Bajwa, R. (2006). Distribution of Parthenium weed (Parthenium hysterophorus L.), an alien invasive weed species threatening the biodiversity of Islamabad. Weed Biology and Management, 6(2), 89-95.
- Shabbir, A., Bajwa, A. A., & Qasim, M. (2016). Impact of climate change on parthenium weed distribution in Pakistan. Journal of Integrative Agriculture, 15(9), 2034-2044.
- Shabbir, A., Dhileepan, K., & Adkins, S. W. (2012). Spread of parthenium weed and its biological control agent in the Punjab, Pakistan. Pakistan Journal of Weed Science Research, 18(Special Issue), 581-588.
- Sharma, R., & Singh, M. (2004). Evaluation of herbicides for control of Parthenium hysterophorus in wheat. Indian Journal of Weed Science, 36(1-2), 123-126.
- Sharma, S., & Chauhan, S. (2004). Manual uprooting of Parthenium hysterophorus and its effect on soil seed bank. Weed Biology and Management, 4(3), 176-180.
- Sharma, S., & Singh, M. (2019). Mechanisms of Herbicide Resistance in Weeds. Current Opinion in Biotechnology, 64, 134-142.
- Sharma, V. K., Sethuraman, G., & Bhat, R. (2005). Evolution of clinical pattern of parthenium dermatitis: A study of 74 cases. Contact Dermatitis, 53(2), 84-88.
- Shrestha, B.B. (2019). Invasive alien plant species in Nepal. *The Initiation*, 6(1), 70-78.
- Singh, H. P., Batish, D. R., & Kohli, R. K. (2002). Allelopathic interference of Parthenium hysterophorus L. through root-mediated release of allelochemicals. Plant and Soil, 249(1), 193-200.
- Singh, H. P., Batish, D. R., & Kohli, R. K. (2003). Allelopathic interactions and allelochemicals: New possibilities for sustainable weed management. Critical Reviews in Plant Sciences, 22 (3-4), 239-311.
- Singh, H. P., Batish, D. R., Pandher, J. K., & Kohli, R. K. (2005). Phytotoxic effects of Parthenium hysterophorus residues on three Brassica species. Weed Biology and Management, 5, 105-109.
- Singh, H.P., D.R. Batish and R. K. Kohli. 2003. Allelopathic interactions and allelochemicals: New possibilities for sustainable weed management. Cri. Rev. Plant Sci., 22: 239-311.
- Sriramarao, P., Nagpal, S., Subba Rao, B. S., Prakash, O. M., & Subba Rao, P. V. (1991). Immediate hypersensitivity to Parthenium hysterophorus. II. Clinical studies on the prevalence of Parthenium rhinitis. *Clinical & Experimental Allergy*, *21*(1), 55-62.
- Srivastava, J. N., Shukla, J. P., & Srivastava, R. C. (1985). Effect of Parthenium hysterophorus extract on the seed germination and seedling growth of barley, pea, and wheat. Acta Botanica Indica, 13, 194-197.
- Strathie LW, McConnachie AJ and Retief E, Initiation of biological control against Parthenium hysterophorus L. (Asteraceae) in South Africa. Afr Entomol 19:378–392 (2011).
- Tahir, M., Arshad, M. A., Akbar, B. A., Bibi, A., Ain, Q. U., Bilal, A., ... & Pervaiz, R. (2024). Integrated nitrogen and irrigation management strategies for sustainable wheat production: Enhancing yield and environmental efficiency. Journal of Pharmacognosy and Phytochemistry, 13(4), 209-222.
- Tamado T, Schutz W, Milberg P (2002). Germination ecology of the weed Parthenium hysterophorus L. in eastern Ethopia. Ann. Appl. Biol. 140:263-270

- Tamado, T., & Milberg, P. (2000). Weed flora in arable fields of eastern Ethiopia with emphasis on the occurrence of Parthenium hysterophorus. Weed Research, 40 (6), 507-521.
- Taye, T., Strathie, L. W., & Mersie, W. (2007). The distribution and impact of the rust fungus, Puccinia abrupta var. partheniicola on Parthenium hysterophorus in Ethiopia. Biological Control, 45(2), 315-321.
- Tewari, G., & Shukla, R. P. (2006). Management of Parthenium hysterophorus L. by herbicides in India. Weed Biology and Management, 6(3), 197-203.
- Timsina, B., Shrestha, B. B., Rokaya, M. B., & Munzbergova, Z. (2011). Impact of Parthenium hysterophorus L. invasion on plant species composition and soil properties of grassland communities in Nepal. Flora, 206, 233–240.
- Towers, G. H. N., & Subbha Rao, P. V. (1992). Impact of the pan-tropical weed, P. hysteroporus L. on human affairs. In R. G. Richardson (Ed.), Proceedings of the First International Weed Control Congress* (pp. 134-138). Weed Science Society of Victoria.
- Vitousek PM, D'Antonio CM, Loope LL and Westbrooks R (1996) Biological invasions as global environmental change. American Scientist 84: 218–228
- Vogler, W., Navie, S., & Adkins, S. W. (2002). Use of fire to control parthenium weed. A report for the Rural Industries Research and Development Corporation, Australia.
- Wakjira, M., & Mekuria, W. (2018). Impacts of Parthenium hysterophorus on Soil Properties and Soil Microbial Communities. *International Journal of Environmental Studies, 75*(2), 225-237.
- Weyl, P., Ali, K., González-Moreno, P., ul Haq, E., Khan, K., Khan, S. A., Khan, M. H., Stewart, J., Godwin, J., Rehman, A., & Sultan, A. (2021). The biological control of Parthenium hysterophorus L. in Pakistan: Status quo and future prospects. *Management of Biological Invasions, 12*(3), 509.
- Wiesner, M., Tessema, T., Hoffmann, A., Wilfried, P., Büttner, C., Mewis, I., & Ulrichs, C. (2007). Impact of the Pan-Tropical weed Parthenium hysterophorus L. on human health in Ethiopia. *Institute of Horticultural Science, Urban Horticulture, Berlin, Germany*.
- Wilcove, D. S., Rothstein, D., Dubow, J., Philips, A., & Losos, E. (1998). Quantifying threats to imperiled species in the United States. *Bioscience*, 48, 607-615.
- Williams, J. D., & Groves, R. H. (1980). The influence of temperature and photoperiod on growth and development of Parthenium hysterophorus. *Weed Res*, 20, 47-52.
- Witt, A. B. R., & Luke, Q. (2017). Guide to the naturalized and invasive plants of Eastern Africa. *CABI Invasive Species Compendium*.
- Zareen, S., Fawad, M., Haroon, M., Ahmad, I., & Zaman, A. (2022). Allelopathic potential of summer weeds on germination and growth performance of wheat and chickpea. *Journal of Natural Pesticide Research*, 1, 100002.