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Review Article

Utility Potential of *Parthenium hysterophorus* for Its Strategic Management

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Parthenium hysterophorus, one of the world's most dangerous weeds, is responsible for huge losses to the biodiversity, agriculture, economy, and health of livestock and human beings. High competitive success rate and adaptability of the species enable it to dominate diverse types of habitats. Various weed control strategies are being used globally to reduce its population to manageable levels. But owing to many limitations associated with the conventional methods, management of *Parthenium* still remains a challenge. Recently large scale utilization has been taken up as a holistic approach for the control of weeds. *Parthenium hysterophorus* can be managed by exploiting this weed in diverse fields. In agriculture, it can be used either as green manure or after composting. Industrially it can be used for producing various value added products. The weed also exhibits many environmental applications. Chemical constituents of *Parthenium* show extensive range of pharmacological activities suggesting its role as a chemotherapeutic agent. This review briefly discusses the problem of *Parthenium* and enlists its possible utilities which can open new avenues for effective management of this violent weed.

1. Introduction

Parthenium hysterophorus, enlisted in Global Invasive Species database [1], is a highly prolific and pernicious weed, which originated in northeast of Mexico [2] by natural hybridization between *Parthenium confertum* and *Parthenium bipinnatifidum* [3]. This is also known by several region specific common names such as altamisa, carrot grass, Santa Maria, bitter weed, star weed, white top, wild feverfew, gajar ghas, the "scourge of India," and congress grass. In the last century, it has invaded many countries including Africa, Australia, United States, Central and South America, West Indies, India, Nepal, China, and Vietnam and naturalized them successfully [2, 4, 5]. Thus nowadays it is found infesting almost all parts of the world. Its rapid and extensive spread can be attributed to both human activities during globalization and colonizing potential of the weed plant over wide range of habitats and climatic conditions. *P. hysterophorus* is now considered among the world's top seven most devastating weeds [6] and has attained major weed status in India and Australia [7].

Parthenium hysterophorus L., belonging to the family Asteraceae, is an annual ephemeral herb. Its biological characteristics such as short-life cycle (4 to 6 weeks) (Figure 1), continuous and profuse flowering until senescence [8], high seed productivity (up to 15,000 to 100,000 per plant) [9], light seed weight, seed dormancy in adverse environmental conditions [8], large viable seed bank (subsoil and above soil) [10], and strong regenerative capability [11] make it a highly fecund weed. Seeds are dispersed across large distances by means of machinery, vehicles, livestock, grain, and feedstock, whereas wind and water spread them to shorter distances [11]. *Parthenium* shows remarkable adaptability over wide range of environmental conditions as well as soil types and is therefore found growing in diverse types of habitats [12]. Though seasonal variations significantly affect germination, flowering, and seed setting in *Parthenium* plant, suitable conditions (rain, moisture, mild soil, and optimum temperature

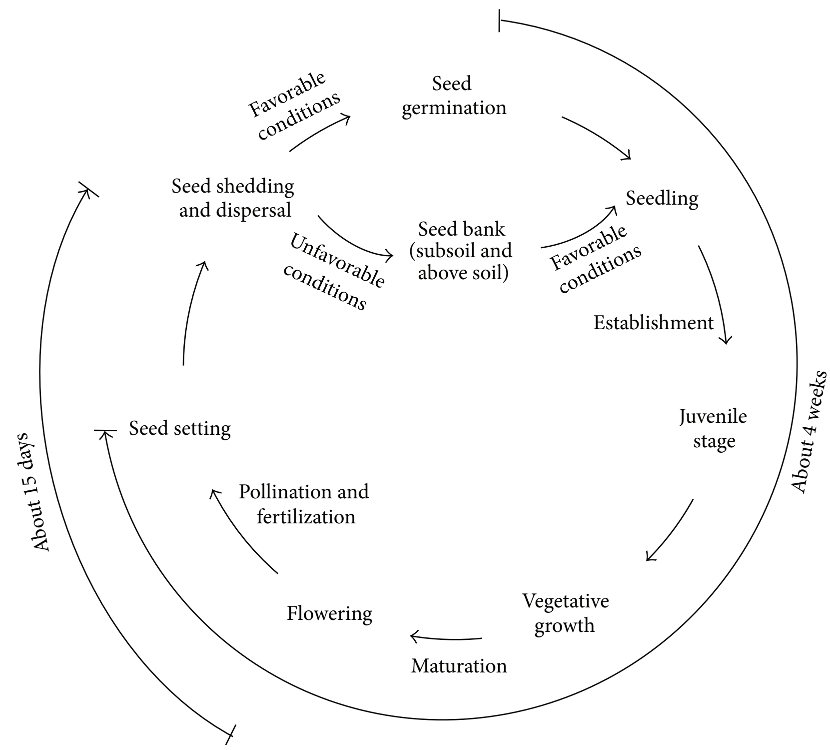

Figure 1: Life cycle of *Parthenium hysterophorus* plant.

between 12 and 27°C) are usually present throughout the year. The weed, therefore, can be seen growing round the year in different stages of its life cycle and can show one to even three generations per year [5].

Parthenium weed is found in both natural and agroecosystems. It shows many adverse effects on agriculture, biodiversity, and health of animals and human beings. In man, *Parthenium* plant or its pollens cause health problems of asthma, hay fever, dermatitis, bronchitis, diarrhoea, and allergies on skin, eyes, nose, and mouth [13]. The weed is allergic and unpalatable to grazers but if consumed by cattle results in losses due to serious concerns of health hazards and tainting of milk and meat [14]. *Parthenium* is found more populated in waste lands, rock crevices, along irrigation canals, road sides, railway tracks, coalfield areas, and developing residential colonies around the towns [2, 13]. Invasion rate is higher in such minimally managed habitats lacking interspecies competition and transforms them to weed monocultures. Establishment of weed is more vigorous in bare land after drought and floods. Extensive vegetation or pasture in undisturbed land remains a second choice for invasion showing an inverse relationship between density of existing vegetation cover and weed abundance. However, invasion by *Parthenium* has been documented to cause enormous loss to the biodiversity [12] by replacing native species in the natural ecosystems, sometimes causing total habitat alteration. Reports have shown negative impact of *Parthenium* on biodiversity in North Western Indian Himalayas [15], Nepal grasslands [13], and Awash National Park in Ethiopia [16]. Effects of *Parthenium* are very prominent in agricultural ecosystems leading to economic losses to the nation due to reduced crop productivity. Many reports have suggested significant losses to the forage [3, 17, 18] due to invasion by harmful *Parthenium*. Similar negative effects have been observed in rice, *sorghum* [19], and other crops [4, 7]. Inhibitory effects of *Parthenium* on wide variety of crops and agricultural plants have been reported in studies using extracts [20–22], residues [23], and ash [24] of the weed, all showing varying degrees of effects on different plants. The reduction in pasture yield and agricultural productivity can be accounted to various reasons such as allelopathic inhibition of useful crop and forage plants [13], contamination of grains and seeds, inhibition of fruit setting in important crop plants, and reduced nodulation in leguminous plants and by providing alternate host for plant viruses and insect pests [9].

Many control measures are being used to manage this obnoxious weed. The chemical methods of control of *Parthenium* rely on the use of chemical herbicides, which lead to the problems of environmental pollution. Physical methods of uprooting and ploughing are labor intensive and relatively ineffective. Burning has damaging effects on the environment. Biological methods, making use of pests, competitive crops, or mycoherbicides against *Parthenium* plant, have their own restrictions. Among all known strategies, nonchemical methods are preferred because of their inexpensiveness and eco-friendliness. However, for the last century integrated methods are gaining attention due to limitations associated with individual methods. Currently new means are also being discovered for controlling various weeds, among which utilization has been seen as an irresistible alternative because of multitude of benefits associated with it. For employing this method massively, complete exploration of usefulness of the weed in question is essential beforehand. Reports have shown many useful biological activities and applications of *Parthenium*. The objective of this review article is to discuss them briefly, along with problem of *Parthenium* weed, to suggest new and diverse ways of management of this weed.

2. Phytochemical Analysis of *P. hysterophorus*

The beneficial and harmful effects shown by *Parthenium hysterophorus* are due to its chemical constituents. All parts of its plant including hair, trichomes, and pollens contain several secondary metabolites such as alkaloids, flavonoids, pseudoguaianolides, oils, and phenolics [25]. The concentration of these metabolites is highest in leaves followed by inflorescence, fruit, root, and stem [26]. These secondary metabolites are produced by the plant for defence against herbivory, pathogens, and competing with other plants. Due to the allelopathic effects shown by some of these chemicals, they are commonly referred to as allelochemicals. The chemical constitution of *Parthenium* plant and various activities associated with different constituents has been summarized in Table 1. The beneficial effects signify the usefulness of *Parthenium* weed.

3. Detrimental Effects

Parthenium weed has many ill effects on animals, human beings, other plants, and ecological biodiversity [9, 13]. Contact with *Parthenium* plant parts, in all stages of its life cycle, causes dermatitis in man. Pollens cause air borne contact dermatitis and when inhaled cause allergic rhinitis [27] which can lead to serious respiratory problems such as asthma and bronchitis. The harmful effects are induced by secondary metabolites, particularly parthenin toxin, present in different parts of the plant [28]. Constant exposure with weed causes immunity loss [29], excessive water loss, fatigue [9], and allergic responses [30] such as hay fever, peeling skin, puffy eyes, swelling and itching of mouth and nose, persistent cough, rhinorrhea, and eczema. Incidences of health hazards caused by *Parthenium* are more common among children and persons with weak immune system.

Parthenium is unpalatable to the animals due to its odour, taste, and presence of trichomes [9]. This results in grazing shortage. Contact of cattle with weed causes rashes and inflammation of skin especially in the areas of mouth and udder. Ingestion in large amounts can cause ulceration in mouth and digestive tracts [17]. Fever and diarrhoea are also observed. Severe effect has been reported on kidneys and liver of buffalo and sheep [13]. If mixed with fodder in a concentration of 10–50%, cattle consuming it can die within 30 days [31, 32]. Weed causes bitterness in milk and reduction in milk yield [9] and also deteriorates quality of milk by tainting it with parthenin toxin [14]. Tainting with toxin is also observed in meat, degrading its quality. In 1994, *Parthenium* was reported to cause heavy losses to the cattle industry in Queensland [17] due to invasion and dominance in grazing land.

In agricultural ecosystems, *Parthenium* weed competes directly with crop plants for space, nutrients, water, and sunlight. One of its prominent indirect effects is exhibited through allelochemicals, phenolics, and sesquiterpene lactones (mainly parthenin). These chemicals, present in roots, stems, leaves, fruits, and pollens of *Parthenium* weed [29], are released in surrounding soil through exudates or in decaying process. They show inhibitory effect on growth and germination of a wide variety of agriculturally important plants including both food and fodder crops [4, 7]. Contamination of pasture seeds and grains with *Parthenium* seeds reduces their market value. Deterioration of soil quality has been observed, which affects forage productivity [17]. Marked change is noticed in properties of soil such as soil texture, pH, and content of organic matter, phosphorus, nitrogen, and potassium [9]. In India, a decline of up to 90% in pasture carrying capacity [3] and 40% in agricultural productivity [33] has been reported in areas infested with *Parthenium*. In Australia, pasture replacement with *Parthenium* weed monoculture resulted in an annual loss of AU$ 16.5 million [17]. A reduction in grain yield and weight has been observed in irrigated *sorghum* in India [19] and Ethiopia [9] due to uncontrolled invasion by *Parthenium*. Burnt residues of weed also affect soil quality as evidenced by reduction in seed germination and biomass growth in *Phaseolus mungo* plant [24]. Extracts form *Parthenium* plant have shown negative effects on growth of various plants such as *Zea mays* [20, 22], *Sorghum vulgare*, *Glycine max* [22], *Gossypium hirsutum* [22, 34], *Vigna radiate* [21], *Oryza sativa, Triticum aestivum, Raphanus sativus, Brassica campestris, Brassica oleracea, Artemisia dubia* Wall. ex. Besser, and *Ageratina adenophora,* [20]. Residues of weed also show inhibitory effect as noticed in *Acacia catechu* wild, *Achyranthes aspera* L., and *Cassia tora* L. [23]. Reports have indicated marked reduction in growth and nodulation in leguminous plants due to antimicrobial effects of allelochemicals from *Parthenium* on nitrogen fixing and nitrifying bacteria [35]. *P. hysterophorus* functions as an alternate host for pests against other plants causing decline in population of their crops [9].

Being incursive, *Parthenium* threatens ecological biodiversity [12]. The impact of weed on biodiversity is due to the competition with native species for resources as well as its allelopathic nature. Invasions may alter hydrology, nutrient accumulation and cycling, and carbon sequestration in habitats. Biodiversity loss is observed due to displacement of natural vegetation and interruption in natural succession in natural ecosystems. Invasion by *P. hysterophorus* in North Western Indian Himalayas showed immense loss to indigenous species diversity [15]. In Nepal, reports have shown disturbance in grassland ecosystem due to change in nutritional properties of soil in the area infested with *Parthenium* [13]. Similar negative effects have been detected on herbaceous plant diversity of Awash National Park (ANP), Ethiopia [16]. *Parthenium* has strong competitiveness against coexisting species, which leads to gradual dominance of habitat by this weed [36].

Table 1: Phytochemical constituents of *Parthenium hysterophorus* plant.

Chemical class	Major constituents	Plant part	Associated biological activities	References
Phenolics	Caffeic acid, vanillic acid, ferulic acid, chlorogenic acid, neochlorogenic acid, anisic acid, p-coumaric acid, protocatechuic acid, and p-hydroxy benzoic acid	Leaves, stems, roots, flowers, pollens, and trichomes.	Allelopathic phytotoxicity useful as herbicide, growth regulation in micro- and macroflora, and autotoxic effect	[29, 122–124]
Flavonoids	Apigenin, luteolin, lignan, syringaresinol, quercetagetin dimethyl ether, 6-hydroxykaempferol 3,6-dimethyl ether, 6-hydroxykaempferol-3,6,4′-trimethyl ether (tanetin), kaempferol glucoside, quercetin glucoside, kaempferol glucoarabinoside, chrysoeriol, santin, saponins, jaceidin, centaureidin, and so forth	Leaves, stems, flowers and their calli, and pollens	Antioxidant, antimicrobial, anticancer, anti-inflammatory activities; antiulcerative, antispasmodic, diuretic, antihypertensive effects; platelet aggregation inhibition; inhibition of aldose reductase; cell cycle regulation; nodulation induction in pea*R. leguminosarum* association; plant defence against herbivores, pathogens, and harmful UV rays	[29, 122–125]
Pseudoguaianolides	Parthenin, anhydroparthenin, 11-H,13-hydroxyparthenin, dihydroxyparthenin, dihydroisoparthenin, 13-methoxydihydroparthenin, 2β,13α-dimethoxydihydroparthenin, ambrosin, 13-methoxydihydroambrosin, coronopilin, 2β and 8β-hydroxycoronopilin, damsin, hymanin, scopoletin, hysterin, hysterones A to E, 8β-acetoxyhysterone C, tetraneurin-A and tetraneurin-E, deacetyltetraneurin A, charminarone, conchasin A artecanin, balchanin, costunolide, 3-β-hydroxycostunolide, epoxyartemorin, 8-α-hydroxyestafiatin, 1-β-hydroxyarbusculin, 5-β-hydroxyreynosin, and acetylated pseudoguaianolides	Stems, leaves, capitula/flowers and their calli, and trichomes	Cytotoxic, anticancer, antimicrobial, bioherbicidal, anti-inflammatory, antiprotozoan, pesticidal, insectidical, antimalarial activities; antineoplastic, antifeedant, larvicidal effects; allergies, diseases and milk tainting in livestock; inhibition of mitochondrial oxidative phosphorylation; autotoxic effect to regulate plant's own germination and population	[29, 122, 123]
Oils	α-Pinene, α-thujene, α-phellandrene β-pinene, β-myrcene, β-terpene, β-ocimene, p-cymene, ρ-cymen-8-ol, camphor, camphene, caryophyllene, humulene, limonene, linalool, ocimene, sabinene, α-terpinene, γ-terpinene, α-terpineol, terpinene-4-ol, bornyl acetate, tricylene, chrysanthenone, pinocarvone, borneol, myrtenal, carvacrol, eugenol, trans-myrtenol acetate, isobornyl 2-methyl butanoate, caryophyllene oxide, germacrene, farnesene and their esters	Stems, leaves, roots, and flowers	Antimicrobial (against bacteria and fungi as well as viruses), pesticidal and insecticidal, antitussive, and helmethicidal activities, useful in medicinal and cosmetic industries and irritant, cardiotonic, antispasmodic and analgesic, stimulant, and sweat inducing effects	[29, 123–125]
Alkaloids	—	Roots and shoots	Antifungal, antioxidant, and anti-inflammatory activities and analgesic action	[123–126]
Others	Histamine	Roots and shoots	—	[5, 122]
	Free amino acids (abundant glycine, proline, alanine, and lysine) glucose, galactose, and KCl	Whole plant	Useful in compost and green manure; increases nutritive value of animal feed	[5, 29, 122]

4. Management of *Parthenium* by Conventional Methods

The management of *Parthenium hysterophorus* is a difficult task because of its high proliferation rate and ecological adaptability. Several physical, cultural, chemical, and biological methods [9, 25, 26, 37] are known for its control. Using combinations of these methods and following several preventive measures further aid in effective management of this troublesome weed.

Mechanical and cultural methods of control [38–41] of *Parthenium* include manual uprooting, hoeing, ploughing, burning, and replacement with competitive crops. Hoeing is especially followed by farmers in rural areas to remove this weed from crop fields. Removal is easier in wet soil. It is most effective if accomplished at a stage before plant starts bearing flowers and seeds. Uprooting the plant after seed setting will disperse the seeds increasing the area of infestation. Manual uprooting increases the incidences of contact dermatitis and other allergic reactions among workers. This method is labour intensive and uneconomical [39], requires repeated removals [38], and is feasible only in agroecosystems with sparse weed cover. Ploughing the field infested with *Parthenium* removes the weed and also enriches the soil with weed plant nutrients. This method is also effective before plants reach the flowering stage. Burning the uprooted and collected weed plants is not encouraged because it decreases soil quality [13] and increases pollution and also the ash of burnt *Parthenium* shows negative effect on plants as found in *Phaseolus mungo* [24]. Certain plant species can suppress the growth of *Parthenium* and replace it competitively reducing its population in the infested area. Examples include *Cassia sericea, Cassia occidentalis, Cassia auriculata, Cassia tora, Tagetus erecta, Abutilon indicum, Amaranthus spinosus, Sida acuta, Croton sparsiflorus, Croton bonplandianum, Hyptis suaveolens, Chenopodium album, Achyranthes aspera, Alternanthera sessilis, Stylosanthes scabra,* and *Tephrosia purpurea* [9, 25, 42]. In some parts of India, *Tagetus* is used for crop rotation and shows marked reduction in *Parthenium* infestation in cultivated land. However, the method of control of *Parthenium* by growing competitive crops is effective only in limited situations [25]. Prevention is very cost effective strategy of weed management [4]. Risk of spread of *Parthenium* is associated with movement of vehicles, machines, livestock, and crop seeds or grains. Spread by vehicles and machines can be limited by washing them before their movement to noninfested areas. Livestock should be rendered free from *Parthenium* seeds before they are taken to new places. Good quality pasture seeds and grains, free from *Parthenium* seeds, should be conserved and marketed commercially following strict seed acts. Pasture maintenance by avoiding over grazing, spelling, and fencing can also reduce invasion rate by the weed. Government of a country should make strict weed control laws and acts, which should be enforced stringently and followed rigorously [25].

Parthenium is controlled chemically using various herbicides, which can be used alone or in several combinations. Examples include 2,4-D; atrazine; anilofos; alachlor; bromoxynil; common salt; chlorimuron; chlomazone; diquat; dicamba; flumioxazin; *fluometuron*; glufosinate ammonium; glyphosate; gesaprim combi; glycel, halosulfuron; hexazinone; indaziflam; imazaquin; isoxaben; metsulfuron methyl; metribuzin; MON-8793; MON-8794; MSMA; Mera 71; oxyfluorfen; oxadiazone; norflurazon; paraquat; pendimethalin; picloram; quinclorac; sulfosulfuron; S-metolachlor; thiobencarb; trifloxysulfuron; and Tordon 75-D, [9, 43, 44]. Effectiveness of these chemicals depends on their dose and time of application. Several chemical formulations are effective at preemergence stages, while others are most effective when applied at postemergence stages [45]. Those applied after plant emergence are advised to be sprayed before flowering and seed setting stages [46]. Herbicides affecting photosynthesis are most effective in controlling *Parthenium*. Spray of selective herbicides, allowing growth of pasture grasses, helps in rapid control of weed due to recolonization of land by the grasses. Open, uncultivated land areas colonized by *Parthenium* can be relieved from this weed by spraying with a solution of 15–20% sodium chloride (common salt) [9]. Chemical methods are economically expensive and are hazardous to environment causing pollution [25]. Action spectrum of herbicides can also involve certain useful plant species and cause their undesired removal. Biological methods of *Parthenium* control offer best, long-term solution for the management of weed in an environment friendly manner. Several insects such as *Zygogramma bicolorata* (leaf beetle); *Epiblema sternuana* (stem galling moth); *Listronotus setosipennis* (seed feeding weevil); *Smicronyx lutulentus* (seed feeding weevil); *Bucculatrix parthenica* (leaf mining moth); *Conotrachelus albocinereus* (stem galling moth); *Carmenta ithacae* (stem boring moth); and *Platophalonidia mystica* (stem boring moth) have been reported to be used for biocontrolling *Parthenium* [9, 25, 37]. These arthropods attack different parts of the weed plant and damage caused by them varies with the stage of their life cycle, larval or adult. Several fungal species are also known for their bioherbicidal potential against *Parthenium* and can be used as potent biocontrol agents for controlling this weed. Reported fungi include *Alternaria alternata, A. dianthi, A. macrospora, Fusarium oxysporum, F. moniliforme, Rhizoctonia solani, Colletotrichum capsici, C. gloeosporioides; and Oidium partheni* [9]; species of *Puccinia abrupta* var. *partheniicola* [47] and *Puccinia melampodii* [48]; *and Macrophomina phaseolina, Cladosporium oxysporum, Ascochyta rabiei, Fusarium equiseti, Phoma glomerata, Cochliobolus hawaiiensis,* and *D. Tetramera* [49]. Also some allelopathic plants showing negative effect on growth of *Parthenium* weed can be used for managing this weed. These plants include *Imperata cylindrica* (L). Beauv, *Desmostachya bipinnata* Stapf, *Dichanthium annulatum* Stapf, *Cenchrus pennisetiformis* Hochest, *Sorghum halepense* Pers., *Azadirachta indica* (L.) A. Juss., *Ficus bengalensis* L., *Melia azedarach* L., *Mangifera indica* L., and *Syzygium cumini* [25].

Many new methods are also being developed to manage *P. hysterophorus*. However, no single method is promising enough to eradicate it effectively. In the past few years, research in different parts of the world has been dedicated to find economic importance of various weeds including *Parthenium*. Large scale utilization of weeds can be an attractive alternative to economically signify as well as manage hazardous weeds [25]. The scientists are trying to test the potential of *Parthenium* weed for various activities and utilities so that the strategy of its management could be restructured involving its utilization.

5. Management of *Parthenium* by Utilization

The *Parthenium hysterophorus* plant, though a weed, has many benefits associated with it. The plant has a number of pharmacological and medicinal effects as well as many industrial and other applications. The plant, therefore, can be used directly for different purposes and control of this weed can be done by utilizing it variously on large scale. The reported utilities of *Parthenium hysterophorus*, which can be used for its management by utilization, have been discussed here.

(1) Biochar Preparation. Biochar has been formulated successfully from *Parthenium hysterophorus* by its pyrolysis to sequester carbon for negative carbon dioxide emission [50]. Addition of this biochar to the soil improved soil quality as evidenced by increased growth of *Zea mays*, increased basal respiration and microbial biomass carbon, increased catalase and dehydrogenase activities, and decreased soil stress and hydrolytic enzymes activities. During charring, ambrosin chemical present in *Parthenium*, having phototoxic effect [13], was lost by degradation at high temperature. Adding large amounts of biochar did not show any negative effect on soil.

(2) Dye Degradation. Textile effluents are rich in recalcitrant and carcinogenic azo dyes, which when disposed untreated cause great damage to the environment. Dyes are toxic to micro- and macroflora of the soil and water bodies. Discoloration of water preventing light penetration decreases photosynthetic activity in water bodies resulting in ecological disturbances. Expensive physicochemical methods used for removal of dyes are being replaced by biological methods exploiting degradation potential of microbial and plant enzymes. Shinde et al. [51] have used leaves of fast growing *Parthenium hysterophorus* for extracting plant phenoloxidase enzyme having ability to degrade various aromatic rings in dyes. Concentrated enzyme showed rapid degradation of Yellow 5G and Brown R dyes present in golden color imparting indanthrene formulation using free oxygen. Toxic effects in treated water were also minimized as indicated by survival of test bacteria, *E. coli* and *S. aureus*.

(3) Biogas Production. Nallathambi Gunaseelan [52] used *Parthenium hysterophorus* as an additive (10%) in cattle manure and achieved 60–70% CH_4 production, suggesting potential of *Parthenium* weed as a substrate for biogas production. Subsequently Gunaseelan and Lakshmanperumalsamy [53] successfully produced 75% methane per kg biomass from *Parthenium hysterophorus* alone. Alkali pretreatment of *Parthenium* has been documented to increase biogas production than untreated biomass [54]. During the process of biogas production, degradation of phytotoxic allelochemicals has been seen [55]. Various inocula have been tested in differing ratios for maximizing yield of methane. Readily available sugarcane press mud cake mixed with cow dung augmented methane production from *Parthenium* [56]. Careful monitoring of anaerobic digestion of the weed showed maximum methane formation only after 45 days, with decreasing pH and C : N ratio becoming constant after 45 days [57]. These results were reproduced by Thakur and Singh [58], while also using other weeds and agricultural wastes for biogas production. Biogas has also been produced from mixture of cow dung and *Parthenium* [59]. Reduction in C : N ratio was suggested due to loss in organic carbon in CH_4 and CO_2 formation and accumulation of hydrolyzed nitrogen in the slurry. Addition of *Parthenium* leachate, obtained by soaking plant in water for one week, to cow dung boosted biogas production from cow dung [60], while slurry left could be used as manure.

(4) Composting. Composting of *Parthenium hysterophorus* biomass has been done expeditiously. Compost derived from *Parthenium* contains plenty of micronutrients such as Fe, Zn, Mn, and Cu and macronutrients including NPK making it two times richer than farmyard manure [61]. Organic acids released during composting help in liberation of insoluble K and increase the uptake of P and K [62]. Compost also contains abundant enzymes, vitamins, antibiotics, plant growth regulators, and large number of associated useful microorganisms including *Azotobacter* and phosphate solubilizers [63]. Moisture holding capacity of compost increases its utility value [64]. Amendment with other plant materials such as saw dust [65] and poultry manure also gives good quality compost, minimizing the required dose of chemical fertilizers [66]. Compost formed has shown growth promotion in chilli, *Sorghum* [61], *Vigna radiata* and *Triticum* [66], and *Arachis hypogaea* [67]. Chances of weed emergence are reduced greatly if composting is done before flowering in plants as all seeds are not destroyed completely during the process [68, 69]. Allelochemicals present in the final compost lessen the chances of infestation by other weeds. Though significant reduction in allelochemicals occurs during composting but better compost is obtained from plants in preinflorescence stage [66]. Effect of compost has been intensified by addition of useful bacterial species *Azotobacter chrococcum* evidenced by increased productivity in wheat [63]. One research study has reported production of improved compost (millicompost), with more nutrients and less allelochemicals, upon introduction of millipede *Harpaphe haydeniana* during composting [70].

(5) Vermicomposting. According to the research study conducted by Biradar and Patil [71] *Parthenium* weed upon composting with *Eudrilus eugeniae* supports growth of worms, indicating potential of weed as good substrate for vermicomposting. This concept was confirmed by another study, showing increase in cocoon yield of earthworm, when *Parthenium hysterophorus* was vermicomposted in definite combination with cow dung [72]. Vermicompost produced

contains moderate amounts of useful bacteria, actinomycetes, fungi, phosphate solubilizers, and large number *of Azotobacter* [73]. However, pathogenic *E. coli* has been found to be absent [74]. The manure obtained has low pH and C : N ratio and contains sufficiently high amounts of essential nutrients such as N, P, K, Ca [72, 75–77], Zn, Cu, and Mn [78]. Consequently, manure produced increased crop productivity in lady's finger [79], *Lampito mauritii* (Kinberg) [80] and sesame [81]. Amendment with cow dung and press mud showed significant improvement in quality of manure produced, upon vermicomposting using *E. Fetida* [80]. Blending with mill sludge and biogas plant slurry also increased nutritive value of manure [82]. Fertilizer value of sewage sludge has also been enhanced by its vermicomposting with added *Parthenium*, promoting growth and germination in tomato seeds [74]. *Parthenium* vermicomposted in its vegetative state produced manure with more N content whereas that produced from flowering stage had more P content [83]. Also manure obtained shows less toxicity [75, 77] as allelochemical constituents such as parthenin and phenols are degraded during vermicomposting [84].

(6) Role in Agriculture. Evaluation of leachates from *Parthenium* plant parts for their effect on growth of agriculturally important plants showed marked increase in growth of some plants. Flower leachate, with high amounts of auxin hormone extracted in it, showed positive effect on seed germination in *Phaseolus mungo* and metal tolerance of the seeds against Fe, Pb, Hg, and Ni [85]. The extract was also effective against brinjal fruit borer and pathogenic fungi in seeds. The effect of extract from fresh and dried parts is different for different species and on different stages of plant growth, [86, 87]. Application of extract before plant emergence was more effective in promoting growth [88]. But application in very high concentration could retard the growth due to allelopathic effect aggravated by high hormonal concentration in the extract [89]. Extracts are rich in allelochemicals, known for their bioherbicidal behavior against other plants [90, 91], which can be used in crucial agronomic manipulations such as weed control [92]. Several reports supporting this finding include decreased seed germination of *Lepidium pinnatifidum* [63], *Eragrostis* by *Parthenium* extract [93], and reduction in weed density in rice fields manured with *Parthenium* biomass [63]. The reason of allelopathic exclusion of other plant species is negative impact of allelochemicals on cell division and release of reserved nutrients [63].

(7) Green Manure. Another use of *Parthenium* in agriculture is exploiting its biomass for green manuring [63]. Addition of *Parthenium* leaf manure to rice crop resulted in increased height of plants, increased yield of grains and straw, with no emergence of weed in submerged conditions during rice cultivation [94, 95]. Maize growth was also enhanced by green manure from *Parthenium* [96, 97]. Addition of weed biomass reduced the amount of chemical fertilizers needed for crop cultivation to about 25% [98]. An enhancement has also been noticed in growth of wheat plant when treated with *Parthenium* green manure [99]. It is advised to utilize this weed for manuring at preflowering stage to avoid spread of weed through dissemination of seeds after seed setting in the plant. *Parthenium* green leaf manure has shown marked increase in number of filled grains in ratoon rice crop and residual effect on biomass of crop [63]. Reports have indicated that green manure obtained from *Parthenium hysterophorus* showed high assimilation rate of nitrogen and phosphorus by maize crop [97]. Thus this freely available weed can be utilized for enriching soil with manure, while replacing chemical fertilizers.

(8) Pulp and Paper Making. P. hysterophorus represents rich source of lignocellulosic biomass. Chemical composition of *Parthenium* lignocelluloses has been reckoned as around 13–17% lignin, 21% hemicelluloses, and 28% cellulose [100, 101]. It has been proved to be of a potential low cost and readily available raw material for manufacturing variety of papers with adequate strength and appropriate quality for various commercial applications [100].

(9) Cellulose Production. Water soluble α-cellulose can be produced using standardized methods from lignocellulosic substrates [90], which can be modified (esterified or etherified) variously to obtain derivatives such as carboxymethyl cellulose (CMC), cyanoethyl cellulose (CEC), hydroxymethyl cellulose (HMC), ethyl cellulose (EC), methyl cellulose (MC), hydroxyphenylmethyl cellulose (HPMC), and carboxymethylhydroxyethyl cellulose (CMHEC). These compounds have wide variety of applications as additives in chemicals used in textile, paint, pharmaceutical, cosmetic, food, adhesives, and packaging industries. *P. hysterophorus,* being an annual plant having more cellulose, has been suggested as a good candidate for producing α- cellulose.

(10) Corrosion Inhibition. Corrosion of metals used for making various appliances and devices has been a matter of concern since their use. Acidic conditions enhance the rate of corrosion. These days plants are being explored for their oils and extracts to be used as biodegradable and eco-friendly corrosion inhibitors of metals. Crude extract from leaves of *P. hysterophorus* suppressed corrosion of steel in acidic conditions [102]. Water was used for extract preparation to avoid toxins, which are more soluble in organic solvents.

(11) Effect on Other Weeds. Extracts from *Parthenium* plant parts have been recorded to show inhibitory effect towards *Eragrostis* [93] and common aquatic weeds, the water hyacinth [103], and *Salvinia* [104]. Among various parts, flowers and leaves are the richest in allelochemicals and can kill water hyacinth plant in one month. On the other hand, stem and root parts containing lower phenolics concentrations have been found to show nutritive properties supporting growth of the weed. Therefore, appropriate parts and dose of *Parthenium* plant can be used effectively to control certain weeds.

(12) Source of Dye. One report has shown natural dye extraction from *Parthenium* plant. Though amount of dye

Table 2: Bioadsorption of pollutants by *Parthenium hysterophorus* weed.

S. number	Adsorbed pollutant	Adsorbent	References
1	Leather dye-acid blue 92	*Parthenium* leaves ash	[127]
2	Chloride (30–34% reduction at low level of pollution)	*Parthenium* dried biomass	[128]
3	Safranin dye (rapid removal in 40 min)	*Parthenium* biomass	[129]
4	Cd (II) ions (99.7% achieved adsorption efficiency; 82% recovery by desorption)	*Parthenium* biomass	[130]
5	Cr (VI) (endothermic adsorption @ 63.97%)	*Parthenium* ash	[131]
6	p-Cresol	Activated carbon (prepared at high temp. using H_2SO_4)	[132]
7	Nickel (II) (exothermic adsorption)	*Parthenium* ash	[116]
8	Rhodamine-B	Formaldehyde treated *Parthenium* biomass (more efficient) and phosphoric acid treated *Parthenium* carbon	[133]
9 (a)	Malachite green	Activated carbon from *Parthenium*	[134]
(b)	Methylene blue		
(c)	Phenol		
(d)	Hg		[135]

obtained was low (13%), dying results observed for wool, cotton, and silk were satisfactory [105].

(13) Feed Additive for Silkworm. Larvae of phytophagous insect, *Bombyx mori* L., a silkworm, have been found to be tolerant to pure parthenin, toxic for most of the other insects. Feeding these larvae on a diet supplemented with *Parthenium* root extract showed increased cocoon yield and hence silk production [106]. Similar results were recorded in a previous study for silkworm larvae fed on mulberry leaves (common feed used for rearing silkworm) supplemented with 20% extract from *Parthenium*, though growth of mulberry plant itself is retarded on treating with *Parthenium* extract [107]. A correlation can be seen between nutritional requirements of *Bombyx mori* for its growth promotion [108] and micronutrient composition of *Parthenium* plant, a proposed hyperaccumulator.

(14) Synthesis of Nanoparticles. Another use of *Parthenium* weed exposed in recent years is use of its extract for synthesising silver nanoparticles [109–112] and zinc oxide nanoparticles [113] having reasonable stability. It is based on the capability of chemicals present in the plant extract to reduce silver ions present in $AgNO_3$ solution [112]. It was found that microwave irradiation could effectively reduce time of synthesis from days to even seconds [110]. Nanoparticles synthesized by this method inhibited the growth of potent bacterial pathogens such as *E. coli, Pseudomonas putida*, *Klebsiella pneumoniae*, *Staphylococcus aureus, Salmonella typhi, Pseudomonas aeruginosa, Proteus vulgaris,* and *Bacillus subtilis* [110, 111], some even more than known antibiotics such as gentamicin sulphate [114]. Zinc oxide nanoparticles were also found effective against pathogenic fungi.

(15) Bioethanol Production. Recent research activities for the development of biofuel technology are focused on tapping nonconventional feedstock for bioethanol production. *Parthenium* weed species growing exuberantly and difficult to manage can be an attractive substrate for producing second generation biofuels [6]. Acid pretreatment of *Parthenium* lignocelluloses at high temperature has shown its autohydrolysis to a mixture of sugars, with xylose (fermentable pentose) being predominant [6, 101]. Different conditions [6, 101] and particle size of biomass [115] have been standardized to maximize the yield of xylose from plant hemicelluloses, which can be fermented subsequently to ethanol. Several other studies have indicated release of large amounts of total reducing sugars upon saccharification of *Parthenium* biomass delignified with lignolytic fungi such as *M. palmivorus* [116] and *Trametes hirsuta* [117].

(16) Bioadsorption. Research efforts are in progress worldwide to find novel and efficient bioadsorbents for removal of industrially generated harmful pollutants. *Parthenium* has been proposed as low cost substrate for use as adsorbent [118]. Literature illustrating removal of pollutants by *Parthenium hysterophorus* has been summarized in Table 2.

(17) Phytoextraction. Parthenium hysterophorus has been found to play vital role in accumulation of heavy metals especially in contaminates sites [119]. Table 3 shows list of some metals extracted by *Parthenium*. Addition of certain chemicals in the soil augments phytoextraction of some metals as observed for Pb with addition of EDTA and GA3 [120] and for Zn with addition of EDTA [121].

(18) Other Uses. Very vast literature is available describing various useful activities of *Parthenium* plant. Activities, effects, and some uses (not mentioned above) of *Parthenium hysterophorus* have been summarized in Table 4, supported with few references.

Possible utilities of *Parthenium* plant have been depicted in Figure 2. The weed can be managed by utilization in any of these ways. The waste of one process can be used as substrate for another process. For example, the lignocellulosic rich waste, generated after extracting plant enzyme or separation

Table 3: Metal extraction by *Parthenium hysterophorus* plant.

S. number	Extracted metal	References
1	Pb	[120, 136–139]
2	Cd	[136, 138–140]
3	Cr	[136, 138, 139]
4	Zn	[127, 136, 137, 139]
5	Cu	[136, 137, 139]
6	Ni	[136, 139]
7	Mn	[136, 139]
8	Fe	[136, 139]

of useful plant extracts, can be employed for other usages associated with lignocelluloses. Also the waste left after production of biogas, biofuel, pulp and paper, and celluloses can be utilized for manure formation (not shown in figure). The multiple integrated utilizations of weed can prove an effective strategy for its control with an additional advantage of generating nearly zero waste at the end.

6. Conclusion

The ubiquitous nature of *Parthenium hysterophorus* is attributed to its greater adaptability to diverse ecological niches, high fecundity, high regenerative potential, production of allelochemicals and repulsion to herbivores, and so forth. Established chemical and nonchemical methods of management of *Parthenium* weed show limited success in controlling this unmanageable weed. This necessitates the development of new strategies for the management of *Parthenium*. Novelty is desired in new methods in terms of their eco-friendliness and economic significance. Abundance of *Parthenium* weed in abandoned land accounts for its easy procurement as low cost material for various purposes. The weed can be used on a large scale for various applications. Nutritionally rich compost can be obtained from the weed by composting it formally or by using techniques of vermicomposting, which can be employed for increasing productivity of wide variety of agriculturally important crops. Practice of green manuring utilizing *Parthenium* weed has also proved an effective tool for raising fertility of cultivated land soil. The proposed usefulness of *Parthenium* in agriculture has been demonstrated by several research activities. The lignocellulose rich biomass of weed plant can be exploited in recent energy conserving strategies of biofuel and biogas formation. It can also be used as low cost substrate for other cellulose based applications, that is, production of cellulose, oxalic acid, xylanase, and pulp or paper. Potential of *Parthenium* has also been traced in phytoextraction of heavy metals, bioadsorption of pollutants, dye degradation, biochar preparation, corrosion inhibition, and inhibition of other weeds, which suggests diverse ways of utilization of this weed. Role of *Parthenium* discovered in nanotechnology presents new ways of using this weed. Capability of weed to function as a source of dye, edible protein, spices, feed additive, and animal feed after ensilage opens more directions for utilization of this weed. Multitudes of chemotherapeutic and curative properties propose medicinal value of the *Parthenium*. These are reflected in antimicrobial, anticancer, antioxidant, anti-inflammatory, antimalarial, antitrypanosomal, antiamoebic, antifeedant, and muscle relaxant activities and the cidal effect

Table 4: Useful biological activities, effects, and some uses of *Parthenium hysterophorus* weed plant.

Activity/effect/use	References
Hypoglycemic effect	[141]
Effect against dengue parasite	[142, 143]
Antitrypanosomal activity	[144, 145]
Cytotoxic activity	[29, 146]
Anticancer activity	[122, 147]
Antioxidant activity	[145, 148, 149]
Muscle relaxant activity	[150]
Depolarization of neuromuscular junction in rats	[122]
Hypotensive response in dogs	[122]
Ovicidal for pathogenic insects	[151]
Cardiac depressant effect in rats	[122]
Antibacterial activity	[124, 125, 152]
Antifungal activity	[124, 125, 152]
Antiviral activity, for example, against *Potato virusY*	[122]
Antiamoebic activity	[5, 122]
Antifeedant activity	[153]
Repellent activity against flea and other insects	[154, 155]
Nematicidal activity	[153, 156, 157]
Spermicidal activity	[158]
Anti-inflammatory activity	[29, 148]
CNS depressant activity	[29, 159]
Thrombolytic activity (useful in migraine treatment)	[29, 146]
Antimalarial	[5, 29, 122]
Mutagenic effect on bacteria and eukaryotic (mouse) leucocytes	[29]
Menstrual stimulator in females (emmenagogue)	[124, 154]
Folk remedy against skin diseases, wounds, ulcerated sores, facial neuralgia, fever, malaria, urinary tract infections, dysentery, eczema, anaemia, heart trouble, and gynaecological ailments	[122, 124, 160, 161]
Analgesic in muscular rheumatism	[29, 154]
Vermifuge to eliminate helminthes	[154]
Used as spices in several parts of the world	[5]
Useful as low cost substrate for xylanase production	[162]
Oxalic acid production	[163]
Edible protein (biological value for rats)	[164]
Animal feed additive after ensilage	[165]

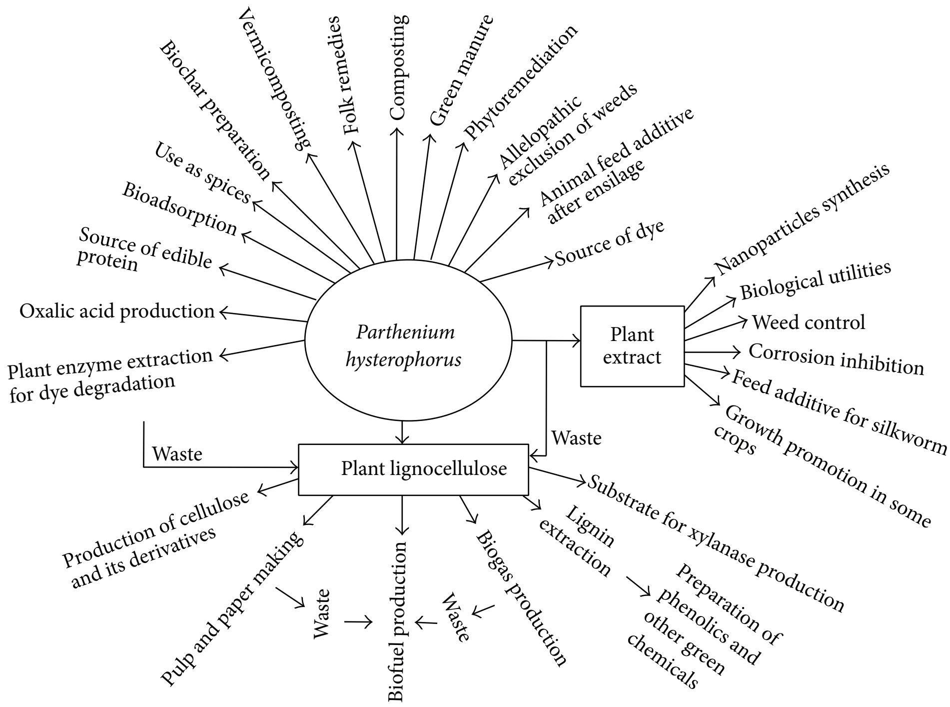

Figure 2: Utility potential of *Parthenium hysterophorus*.

against nematodes, ova and sperms of insects, and so forth. The use of weed has also been found in certain folk remedies, menstrual stimulation and treatment of migraine, and so forth. Thus versatility of applications of *Parthenium* unfolds numerous ways for sustainable management of this weed.

7. Future Prospects

In light of designing new control strategies for *Parthenium* management, limited work done so far for exploring beneficial uses of *Parthenium* should be expanded further to broaden the utilization scope of the weed. Also the research work dedicated to one particular application is very restricted and needs elaborative studies. The weed has many utilities, each of which can be used separately to control this weed. Such methods can also be designed in future, which integrate two or more applications, aiming at maximum utilization of weed for acquiring economic benefits. Zero waste technology, being followed these days, can also be taken into account while shaping these integrated approaches. Thus new and improved methods of managing *Parthenium hysterophorus* weed, encouraging well-being of human society, are anticipated in near future.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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