10 Parthenium Weed: Uses and Abuses

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10.1 Introduction

Parthenium weed (*Parthenium hysterophorus* L.), a plant of the Asteraceae family, has long been recognized as a weed of global significance (Aneja *et al*., 1991; Towers and Subba Rao, 1992; Evans, 1997; Pandey *et al*., 2003). It is an annual herb, native to the area around the Gulf of Mexico, including the Caribbean islands and central South America. After introductions and spread in other regions, parthenium weed now has a pantropical distribution. It normally grows fast, producing an adult plant, about 1.5 m in height, which produces flowers early, and sets a large number of seeds in its lifetime (Adkins and Shabbir, 2014). The weed can also grow under wide ecological conditions – from sea level up to 3000 m (K. Dhileepan, Australia, 2017, personal communication). Parthenium weed is now present in 91 countries around the globe, of which only 44 appear to be possibly in its native range. It is regarded as one of the worst weeds in several parts of Africa, Asia and Australia where it has been introduced (Evans, 1997). In the case of India, parthenium weed was first recorded in 1956 (Rao, 1956) and may have entered the country as a contaminant of wheat imported from the USA. Since then, it has become a major weed within a short period, spreading to over 35 million ha in 60 years (Sushilkumar and Varsheny, 2010). The weed occupies wastelands and disturbed habitat, including roadsides and railway tracks, and grows well in native grasslands, open scrub vegetation, floodplains, cultivated fields and grazed pastures, often forming pure stands (Dale, 1981; Evans, 1997; EPPO, 2014).

The negative impacts of parthenium weed are well documented, with the most profound effects being on livestock farming, productivity of grain crops and human health. Knox *et al*. (2011) estimated that parthenium weed in India caused yield declines of 50–55% in agricultural crops (>5–10 million rupees per annum) and a 90–92% reduction in forage production (1–2 million rupees per annum). Unlike with most other weeds, parthenium weed poses a serious added social dimension, the adverse health problems it causes for humans and animals. These are in addition to significant economic losses, biodiversity losses and habitat destruction it can cause. Parthenium weed causes severe dermatitis, allergy and toxicity in humans (Towers and Subba Rao, 1992). Most domesticated animals also dislike the weed. If eaten, however, the meat is tainted, causing economic losses. Other chapters in this book cover this subject (e.g. see Allan *et al*., Chapter 6, this volume).

Despite the well-documented negative impacts of parthenium weed, there is a large volume of published research, over three

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decades, that indicates both actual and potential uses of the weed and opportunities for further exploitation. There are a number of reviews of beneficial uses, which have largely originated from India (Pandey, 2009; Patel, 2011; Kushwaha and Maurya, 2012; Saini *et al*., 2014). The current review adds to the above, providing an update and a critical appraisal, focusing on the actual uses of the plant in different countries, and its demonstrable potential uses, based on published results. We also explore the question: should utilization be considered an effective management tool in countries like India, to manage existing infestations and prevent its further spread?

10.2 Chemical Constituents

In assessing the potentially useful or harmful aspects of a weed, such as parthenium weed, it is important to understand its dominant, bioactive chemicals. Over several decades, various researchers have described the chemical constituents of parthenium weed, establishing an impressive array of compounds (Table 10.1). Early research by Herz and Watanabe (1959), Dominguez and Sierra (1970), Picman *et al*. (1979, 1980, 1982) and Kanchan and Jayachandra (1979, 1980a, 1980b) indicated that various parts of parthenium weed contain parthenin a sesquiterpene lactone of pseudoguanolide

Table 10.1. The major secondary plant products of parthenium weed.

Chemical group	Chemical	Plant part	References
Sesquiterpene lactones (Terpenoids)	Parthenin	Stems, leaves, pollen	Herz and Watanabe (1959), Dominguez and Sierra (1970), Kanchan and Jayachandra (1980a, 1980b, 1980c), Belz (2008), Belz *et al.* (2007), Reinhardt *et al.* (2004, 2006), Ramesh *et al.* (2003), Chen *et al.* (2011)
	Coronopilin	Stem, fl wers, trichomes	Picman *et al.* (1980), Ramesh *et al.* (2003), Das *et al.* (1999)
	Pseudoguananolides	Stem, leaves	de la Fuente *et al.* (2000)
	Hysterin	Stem	Wickham *et al.* (1980)
	Acetylated pseudoguananolides	Flower	Das *et al.* (2007)
	Charminarone	Whole plant	Venkataiah *et al.* (2003)
	Hysterones A–D	Flower	Ramesh *et al.* (2003), Das *et al.* (1999)
Minor sesquiterpenes	Ambrosonalides; 2β-hydroxycoronopilin 1,3 hydroyparthenin; tetraneurin A	Flowers	Sethi *et al.* (1987), Das *et al.* (1999), Ramesh *et al.* (2003)
Phenolics	Caffeic acid; p-coumaric acid; ferulic acid; vanillic acid; anicic acid; fumaric acid	Roots, leaves	Kumar *et al.* (2013a, 2013b), Kumar and Pruthi (2015)
Flavonoids	Quercelagetin; 3,7-dimethylether; 6-hydroxyl kaempferol; p-hydroxy benzoin sitosterol	Aerial parts	Shen *et al.* (1976), Yadava and Khan (2013)
Volatile oils	Germacrene-D; trans-β-myrcene; camphor; camphene; p-cymene; borneol; bornyl acetate; β-pinene; euginol etc.	Aerial parts	Kumamoto *et al.* (1985), de Miranda *et al.* (2014)

nature. More than 45 sesquiterpene lactones have subsequently been recorded from the plant (Wickham *et al*., 1980; Patil and Hegde, 1988; Towers and Subba Rao, 1992). It is now established that all parts of the plant contain biologically active sesquiterpene lactones (Picman and Towers, 1982; Picman and Picman, 1984; Chhabra *et al*., 1999; de la Fuente *et al*., 2000; Ramos *et al*., 2002; Belz, 2008). Reinhardt *et al*. (2006) showed that parthenin is synthesized during the entire life of parthenium weed, reaching maximum levels during flowering and seed formation stages. It is sequestered in capitate-sessile trichomes on leaves, stems and the achene complex (Reinhardt *et al*., 2004). Saxena *et al*. (1991) had earlier demonstrated that parthenin is readily transformed by chemical or photochemical reactions into other derivatives, some of which have stronger bioactivity than parthenin itself.

Parthenium weed also releases a range of water-soluble phenolic acids (Table 10.1), from living roots, leaves and seeds, as well as from dead or decaying residues (Kanchan and Jayachandra, 1979, 1980a, 1980b, 1981; Batish *et al*., 2002a, 2002b). Analysing leaf extracts, Kumamoto *et al*. (1985) recorded the occurrence of many well-known essential oils in the leaves, yielding 0.033% oil. Subsequently, de Miranda *et al*. (2014) identified 27 essential oils in parthenium weed. Other phytotoxic compounds found in parthenium weed include various flavonoids (Shen *et al*., 1976; Yadava and Khan, 2013).

Rodriguez *et al*. (1975, 1976) had earlier reported that sesquiterpene lactones in plants, such as parthenium weed, exhibit a wide spectrum of biological activities, which include cytotoxic, antitumour, allergic, antimicrobial, phytotoxic, antifeedant and insecticidal properties. The production of such an array of bioactive chemicals as secondary metabolites (Table 10.1) is not unique to parthenium weed. However, combinations of these chemicals and their concentrations in various parts of the plant indicate that they may be of ecological significance, possibly as part of the defences against herbivory. The same chemicals may also be involved in the invasion success of parthenium weed through allelopathic interactions with neighbours. The fact that parthenium weed's phytochemicals elicit strong effects upon other organisms is the reason why numerous studies have attempted to determine if they are of any beneficial use in human health, crop protection, insect control or in other areas.

10.3 Uses of Parthenium Weed

From the large volume of published literature available, the discussions below focus on some of the most significant findings of actual uses and potential uses demonstrated in *in vitro* and *in vivo* experiments, as well as in various field studies. It is important to highlight that some of the experimental results we have reviewed only indicate potential uses and applications and are seriously constrained by the lack of comparisons against benchmarks. The suitability of the species being used in any given area is a critical aspect of utilizing any species with 'colonizing' attributes for beneficial purposes. Instead of any uniqueness of the species, our assessment reveals that the primary motivation for promoting utilization, particularly in India, is the integration of uses into a broader, national weed management effort. However, despite the extensive research, most authors acknowledge that the actual practical uses of the weed's demonstrated beneficial uses would require considerably more research to establish the cost effectiveness of developing useful products and/or applications. In dealing with a species like parthenium weed, it would also be important to consider not just economics, but also associated ecological and environmental considerations, which are quite significant (EPPO, 2014).

10.3.1 Medicinal uses and medical applications

Reports indicate that the word parthenium is derived from the Latin word parthenice, which suggests medicinal uses (Bailey, 1960). According to Lindley (1838) in *Flora Medica*: 'The whole plant is bitter and strong-scented, reckoned tonic, stimulating and anti-hysteric. It was once a popular remedy in ague. Its odour is said to be peculiarly disagree to bees and that insects may be easily kept at a distance by carrying a handful of the flower heads'.

There is ethnobotanical evidence that parthenium weed is used as a folk remedy in the Caribbean and Central American countries (Cuba, Guyana, Trinidad, Jamaica and Mexico), the USA and sub-Saharan Africa, where it is applied externally to cure skin disorders or taken internally, often as a decoction in the treatment of a variety of ailments (Dominguez and Sierra, 1970). The *Dictionary of Economic Plants in India* (Singh *et al*., 1996) records the use of parthenium weed as a tonic, febrifuge, an emmenagogue, and for the treatment of inflammation, eczema, skin rashes, herpes, colds, heart problems, amoebiasis, gynaecological ailments, muscular rheumatism, neuralgia and dysentery. An ethnobotanical study in Mauritius and Rodrigues (Gurib-Fakim *et al*., 1993) reported that tea made from parthenium weed is used as a tonic, febrifuge, analgesic and emmenagogue. A similar survey in Venezuela recorded the use of a decoction from dried roots as an antimalarial drug (Caraballo *et al*., 2004).

Table 10.2 provides a summary of recent laboratory-based evidence of potential medical uses, major effects reported and the sources. The studies indicate that apart from the traditional medicinal uses, parthenium weed extracts may also have other potential applications. Although the 'causes and effects' are not quite proven, the bioactivity recorded by these studies may justify the uses of parthenium weed in traditional medicine. These studies have non-specifically attributed the properties to the occurrence of flavonoids, terpenoids, alkaloids and phenolic compounds in the weed's extracts (Kumar *et al*., 2014; Kumar and Pruthi, 2015). However, despite the evidence from largely *in vitro* and *in vivo* studies indicating the anticancer, antioxidant and antibacterial potential in parthenium weed extracts, developing these properties towards modern medicines is still a long way off.

10.3.2 Non-medicinal uses: potential uses as a pesticide

Secondary metabolites of plants are part of their chemical defences against natural enemies, such as fungi, bacteria and insects; these compounds are often antimicrobial. Given the array of phytochemicals found as secondary metabolites in parthenium weed, it has featured strongly in the search for alternative and 'eco-friendly' pesticides. Datta and Saxena (2001) demonstrated that pesticidal bioactivity was evident at relatively low concentrations of parthenin and its derivatives, as pure compounds – in the range above 25 mg/l up to 1000 mg/l. Table 10.3 provides a summary of recent studies and their findings, which demonstrate the pesticidal potential of parthenin and its derivatives. However, it should be noted that despite the large amount of research and empirical demonstrations, over nearly two decades, commercial production of a 'botanical pesticide' based on parthenin or its derivatives, as an alternative to synthetic chemicals, is yet to occur.

10.3.3 Herbicidal potential of parthenium weed allelochemicals

Parthenin is released from the plant by being washed from ruptured trichomes or from decomposing tissues and may contribute to parthenium weed's interference with surrounding neighbours. However, after its release into the soil environment, the persistence and phytotoxicity to neighbours of parthenin or any other phytochemical would be significantly modified by physical, chemical and biological soil properties. Therefore, whether allelochemicals in parthenium weed can be utilized in various applications depends on their fate and persistence in soil, and soil concentrations (Belz *et al*., 2007). Despite the promising allelopathic potential demonstrable in laboratory experiments

Table 10.2. Potential medicinal uses of parthenium weed extracts.

Medicinal use	Plant part/extract	Major outcome reported	References
Diabetes mellitus treatment	Aqueous extracts of dried leaves and fl wers, hypoglycaemic activity tested in diabetic rats (blood glucose 280–310 mg/dl)	A dose of 100 mg/kg body weight reduced blood glucose in test animals to below 240 mg/dl at 2 h; this compared favourably with the reduction achieved by a standard diabetic drug in control animals, at 2 h	Patel *et al.* (2008)
Antimalarial activity	Ethanolic leaf extract tested against the malarial parasite	Antimalarial activity demonstrated (*in vitro*), but not linked to any specific phyto-constituent	Valdés *et al.* (2010)
Antimalarial activity	Parthenin, extracted from whole plant tested against malarial parasite	Significant antimala ial activity (*in vitro*) against a multidrug resistant strain of *Plasmodium falciparum*	Hooper *et al.* (1990)
Amoebicidal activity	Parthenin, extracted from the whole plant tested *in vitro* against *Entamoeba histolytica*	Parthenin was amoebicidal and as effective as the standard drug used in treating amoebiasis	Sharma and Bhutani (1988)
Anticancer activity	Parthenin tested on mice (*Mus musculus* L.) injected with cancer cells	Sublethal parthenin doses either cured mice or increased their survival time	Mew *et al.* (1982)
Cytotoxicity and antitumour potential	Extracts of dried aerial parts; tested *in vivo* and *in vitro* using bacterial cell lines, lymphocytes and mice	Weed extracts and parthenin showed no mutagenicity in the Ames Salmonella/ microsomal assay, but demonstrated potent cytotoxicity	Ramos *et al.* (2002)
Cytotoxic and anticancer properties	Methanol extracts of dried fl wers tested on human cell lines	Extracts showed significant cytot xicity against T lymphocytes and T-cell leukaemia, HL-60 (leukaemia) and Hela (human cervical carcinoma) cell lines	Das *et al.* (2007)
Anticancer properties	Ethanolic extracts of dried leaves tested *in vivo* (rat kidney cells) and in *in vitro* models	Potent cytotoxicity against MCF-7 and THP-1 human cancer cell lines at 100 µg/ml; concentration-dependent inhibition of HL-60 cancer cell lines; moderately anti-HIV activity	Kumar *et al.* (2013a, 2013b)
Anti-inflammato y activity	Extracts of parthenium weed	Ferulic acid (FA) extracted from the weed inhibited the enzyme cyclooxygenase-2 (COX-2) by molecular docking; this may lead to developing anti-inflammato y drugs	Kumar and Pruthi (2015)
Antibacterial activity	Ethanolic extracts of parthenium weed, compared with extracts from 20 other species	Parthenium weed extracts had the highest antibacterial activity; antibacterial activity was strongest against gram-positive, pathogenic bacteria	Nair and Chanda (2006)
Antibacterial activity	Ethanolic extracts of parthenium weed	Extracts showed greater antibacterial properties against some bacteria compared with standard antibiotics (Azithromycin and Cepaxim)	Fazal *et al.* (2011)
Antibacterial activity	Solvent extracts of leaves and other parts	Leaf extracts were significantly higher in antibacterial activity against several common pathogenic bacteria compared with stem, fl wers or root extracts	Kumar *et al.* (2014)
Antibacterial, antifungal activity	Petroleum-ether extracts of dried aerial parts	Strong antibacterial and antifungal activity against several common, pathogenic bacteria and fungi	Madan *et al.* (2011)

Table 10.3. Potential non-medicinal uses of parthenium weed extracts.

Potential use	Plant part/extract	Major outcome reported	References
Antifungal activity	Aqueous leaf extracts against rice blast fungus *Pyricularia grisea* Sacc. using *in vitro* studies	Strong inhibition of mycelial growth of *P. grisea* on rice (*Oryza sativa* L.) seedlings by a 10% aqueous extract; no adverse effects on rice	Pedroso *et al.* (2012)
Dengue fever vector control	Leaf extracts with several solvents tested against *Aedes aegypti* (L.)	High concentration extracts (1000 ppm) were selectively effective against female mosquitoes; potential of developing as an oviposition deterrent and ovicidal agent	Kumar *et al.* (2011, 2012)
Malarial vector control	Leaf extracts tested against *Anopheles stephensi* Liston	Strong larvicidal potential against the fourth instar larvae of *A. stephensi*	Ahmad *et al.* (2011)
Nematicidal activity	Parthenin and derivatives tested against root-knot nematode (*Meloidogyne incognita* Fab.)	Lethal concentration (LC50) at 72 h was 512 mg/l; an acid-converted derivative was fi e times more nematicidal (LC50 104 mg/l at 72 h)	Datta and Saxena (2001)
Insecticidal activity	Parthenin and derivatives tested against the cowpea beetle (*Callosobruchus maculatus* Fab.)	The pyrazoline derivative was 17 times more insecticidal than parthenin, and was as toxic as azadirachtin from neem (*Azadirachta indica* A. Juss.)	Datta and Saxena (2001)
Insecticidal activity	Whole plant extracts tested on mustard aphid (*Lipaphis erysimi* Kaltenbach)	More effective than other plant extracts in reducing the mustard aphid populations on mustard (*Brassica juncea* L.)	Bhattacharyya *et al.* (2007)

and some field situations, short half-lives and low field levels of major phytotoxins would mean that allelochemicals may not always be involved in interference mechanisms between parthenium weed and its neighbours.

The early research of Kanchan and Jayachandra (1979, 1980a, 1980b, 1980c), Kohli *et al*. (1996), Pandey *et al*. (1996a, 1996b) and others recorded strong allelopathic effects of parthenium weed on a range of crops and weeds, although species varied considerably in their sensitivity to weed extracts or exudates. The effects were largely attributed to the bioactivity to parthenin in leaf washings and root exudates, while acknowledging the possible inhibitory role of other terpenoids, phenolic acids, such as *p*-hydrobenzoic acid, in the extracts. Several laboratory studies in India (Batish *et al*., 2002a, 2002b, 2007) have documented parthenin phytotoxicity towards a range of weeds and crops. Based on such results, several research groups in India have promoted parthenium weed as a 'botanical herbicide', for both pre-emergent and post-emergent activity, without much selectivity. However, the selectivity of parthenin, or just parthenium weed extracts, against crops remains largely unknown. Consequently, despite an early suggestion by Datta and Saxena (2001) that parthenin and its derivatives may be developed as commercial herbicides, this is yet to occur.

A summary of major studies that have recorded phytotoxic effects on other weeds is given in Table 10.4. It is clear from these studies that parthenium weed extracts are toxic to some species. However, most studies indicate relatively low persistence of parthenin in aquatic environments. For instance, Pandey (1994a, 1994b, 2009) showed that the phytotoxicity of the extracts was gradually lost in water within about 30 days under outdoor conditions. The possibility of incorporating parthenium weed biomass for weed management in the field has not been widely tested. At least in one study, Marwat *et al.* (2008) tested the herbicidal potential of parthenium weed in

Table 10.4. Selected studies showing the herbicidal potential of parthenium weed extracts.

Potential use	Plant part/extract	Major outcome reported	References
Botanical herbicide	Parthenin and derivatives tested against sickle pod (*Senna tora* L.)	Parthenin reduced seed germination by 50% at 364 mg/l, a propenyl derivative and a cyclopropyl derivative were much more effective (50% inhibition at 136 mg/l and 284 mg/l, respectively)	Datta and Saxena (2001)
Water hyacinth (*Eichhornia crassipes* (Mart.) Solms.) control	Dried leaf powder; aqueous extract	Low concentrations (0.25% w/v) reduced growth; higher concentrations (0.5% w/v) killed water hyacinth in 2–4 weeks; death was due to leakage of solutes from roots, loss of dehydrogenase activity in roots and chlorophyll in the leaves	Pandey *et al.* (1993a, 1993b)
Salvinia (*Salvinia molesta* Mitchell)	Dried leaf powder; aqueous extract	Higher concentrations (0.75% w/v) killed Salvinia within 5–15 days	Pandey (1994a, 1994b)
Submerged aquatic weeds	Dried leaf powder; aqueous extract	Submerged aquatics were sensitive to parthenin at 25 ppm; however, effects were short-lived, as parthenin degraded	Pandey (1996b)
Laboratory studies and field applications	Dried leaf powder, soaked in water for 24 h, at various concentrations (10 to 250 g/l)	Differential response of weed species to parthenium weed extracts; pre-emergent applications were more effective in reducing the abundance of some weeds in field plots than post-emergence sprays	Marwat *et al.* (2008)

field applications, and despite its low persistence in soil, still suggested that the extracts could be developed as a bio-herbicide in Pakistan.

Parthenin is rapidly degraded in the environment to various metabolites that have little or no phytotoxicity (Belz *et al.*, 2009). Parthenin concentrations declined to less than 50% of the initial levels within 60 h in soil, and the degradation was accelerated by soil pre-conditioning with parthenin, higher clay content and higher temperatures. While parthenin is likely to contribute to allelopathic effects, high parthenium weed densities are required to have high levels of parthenin in soil and favourable soil conditions for parthenin or its derivatives to persist in bioactive forms (Belz *et al.*, 2009). Overall, the short-lived nature of parthenin in soil and loss of its phytotoxicity in the aquatic environment is a major limitation. This raises considerable doubts whether the bioactivity demonstrable in parthenium weed extracts can lead to a commercially viable 'eco-friendly' bio-herbicide.

10.3.4 Use in phyto-remediation of heavy-metal-contaminated soils

The interest in using parthenium weed for phyto-extraction of heavy metals and other pollutants has been growing in the past few years, stimulated by the observations that parthenium weed has the capacity to grow well even in contaminated sites. Bapat and Jaspal (2016) have recently summarized much of the available research. The important findings of some studies are summarized in Table 10.5, as examples. Collectively, these studies confirm parthenium weed's ability to tolerate high levels of soil contamination and conditions, which are relatively unfavourable to the growth of most plants. They also demonstrate the capacity of parthenium weed to take up, accumulate and sequester heavy metals in its tissues. However, we find that most of the published studies have not benchmarked parthenium weed against other known hyper-accumulators. This makes it difficult to draw firm conclusions as to the comparative

Table 10.5. Examples of removal of heavy metals from contaminated soil by parthenium weed.

Pollutant	Experimental set-up	Major outcome reported	References
Lead (Pb)	Parthenium weed grown in soil spiked with lead nitrate	Parthenium weed extracted Pb from soil in significant amounts. Foliar applications of gibberellic acid GA3 aided the uptake and accumulation of Pb in stems	Hadi and Bano (2009)
Zinc (Zn)	Parthenium weed grown in soil spiked with zinc sulphate	Parthenium weed 'hyper-accumulated' Zn with a bio-concentration factor (BCF) >1.0 and a translocation factor >1.0. Addition of Ethylenediaminetetraacetic acid (EDTA) at 0.1 g/kg of soil increased the Zn uptake	Sanghamitra *et al.* (2012)
Cadmium (Cd)	Parthenium weed grown in soil spiked with Cd	Parthenium weed 'hyper-accumulated' Cd with a high BCF (1.85); addition of EDTA to the soil (40 mg/kg of soil) and foliar sprays of GA3 increased the uptake and translocation of Cd	Ali and Hadi (2015)
Heavy metals: Fe, Zn, Cu, Pb, Ni and Cd	Parthenium weed grown in fly ash mixed soil	Parthenium weed accumulated considerable amounts of the heavy metals in different parts of the plant. Heavy-metal accumulation by 90 days was in the order Fe > Zn > Cu > Pb > Cd > Ni. Translocation of Pb, Ni and Cd was much higher than Fe, Zn and Cu	Ahmad and Al-Othman (2014)

advantages of using parthenium weed for remediating contaminated soil. Therefore, whether the phyto-extractive capacity of parthenium weed can be put into actual practice in ecological restoration – to reduce heavy-metal pollution in contaminated soils, on any scale, is still largely untested in field situations.

10.3.5 Use of parthenium weed carbon as bio-adsorbent in pollution removal

Many agricultural and wood wastes, such as sugar cane pith, sawdust, coconut husks, wheat shells, corncobs and similar materials are considered useful as bio-adsorbents of organic pollutants from waste effluents of industrial processes. These materials are of considerable value in developing countries, because activated carbon (AC) – the most widely used adsorbent – is quite expensive and needs to be regenerated. On the other hand, in countries like India, parthenium weed biomass is freely available in large quantities, throughout the year (Shrivastava, 2010), and is potentially useful after conversion into a bio-adsorbent form. In addition, the adsorbent can be safely discarded after use and does not need costly regeneration. There is a large volume of literature available, mostly from India (summarized in Table 10.6), that demonstrates adsorbent properties of parthenium weed in laboratory-based experiments. These studies characterize the nature of the adsorbent material that it can generate, and provide details of varied adsorption processes. Despite the demonstration of adsorbent properties in laboratories, we find this research largely academic and there is no evidence of practical uses up to the time of this review.

Collectively, the studies show that parthenium weed biomass is a low-cost biomaterial that can be used as an alternative to costly adsorbent for dye removal in wastewater, or for extracting heavy-metal pollutants from effluents. Adsorption efficiency is highly dependent on initial dye or heavy-metal concentration; the lower the initial pollutant concentration, the higher the adsorption. Particle size of parthenium activated carbon (typically in the range of 0.3–1.0 mm) is also a significant factor; the smaller the particle size, the higher the surface area and sorption. Other influential

Table 10.6. Summary of potential uses of parthenium weed in removing industrial dyes and heavy-metal pollutants from aqueous solution.

Industrial pollutant	Adsorbent	Major outcome reported	References
Methylene Blue	Sulfuric acid-treated carbon (SWC); phosphoric acid-treated carbon (PWC)	Compared with standard activated carbon (AC); both SWC and PWC effectively removed the dye; order of adsorption capacity: AC > PWC > SWC	Lata *et al.* (2007)
Rhodamine-B	SWC, PWC and formaldehyde-treated carbon	All three were quite effective in removing the dye	Lata *et al.* (2008a, 2008c)
Safranine	Dried and crushed biomass (particle size 60–250 μm)	Maximum adsorption 89.3 mg/g from a dye concentration 400 mg/l in wastewater	Shrivastava (2010)
p-Cresol	Sulfuric acid-treated parthenium activated carbon (PAC) particle size < 0.5 mm	Adsorption of p-cresol from wastewater by PAC was as good as commercial-grade AC	Singh *et al.* (2008a)
Cadmium (II)	Dried powder made from the whole plant	Removal of 99% of Cd (II) from wastewater; an endothermic process; maximal at pH 4.0	Ajmal *et al.* (2006)
Nickel (II)	Sulfuric acid-activated weed ash	Effectively removed Ni; maximal removal 17.2 mg/g of ash at pH 5.0	Lata *et al.* (2008b)
Nickel (II)	Weed ash from whole plant	Effectively adsorbed and removed Ni; maximal removal at pH 11.0	Singh *et al.* (2009)
Chromium (VI)	Weed ash from whole plant	Effectively adsorbed Cr; maximal removal 64% at pH 2.0	Singh *et al.* (2008b)

factors are adsorbent dose, pH and contact time. Ajmal *et al*. (2006) also suggested that the inexpensive material could be used to sequester Cd ions in contaminated soil and potentially reduce Cd uptake by agricultural crops grown in polluted areas. The claim from the research groups that have conducted highly detailed studies (summarized above) is that parthenium weed biomass could become a useful adsorbent carbon. Sivaraj *et al*. (2010) have described the preparation of activated carbon from parthenium weed biomass using various physical (thermal) and chemical methods, along with characteristics of the material. Their work demonstrated $ZnCl_2$-impregnated parthenium weed carbon as the most efficient adsorbent, due to its porous nature and higher adsorption area. However, we find that comparative research against less controversial species demonstrating a unique capacity of the parthenium weed biomass to be of exceptional value as bio-adsorbent is yet to be presented.

10.3.6 Use of parthenium weed biochar as soil amendment

Kumar *et al*. (2013c) showed that parthenium weed biomass could be converted to biochar by burning at different temperatures (200–500°C) for varying periods. With increased temperature, biochar yield decreased, but its stability was highest at 300–350°C and charring for 30–45 min. Incorporation of this biochar up to 20 g/kg of soil increased the soil microbial biomass and several important soil enzymes. The charring also removed allelochemicals of parthenium weed, which was demonstrated using a maize (*Zea mays* L.) seedling assay. It is reasonable to expect that parthenium weed residues could be converted to usable carbon residues via pyrolysis. However, any future adoption of this as a wide-scale practical use would depends on a number of factors, not least the energy cost of pyrolysis.

10.3.7 Parthenium weed uses in biofuel production

Utilization of biomass of various common weeds, including parthenium weed, for biofuel production are promoted as methods that would help rural communities in obtaining energy from cheap feedstock. A large volume of research, mainly from India, confirms that this is a valid premise with practical application. Opinion is also strong that large-scale utilization of parthenium weed for biofuel generation will also pave the way for its eradication. Proponents point out that after generating biogas, the digested parthenium weed could also be used as organic manure, as the nutrients (N-P-K) are largely conserved.

In some early research, Gunaseelan (1987) used dried parthenium weed biomass (10%) and cattle manure slurry as feedstock and produced methane by anaerobic digestion. When parthenium weed biomass alone was anaerobically digested, it produced a maximum of 35 l methane/kg of biomass at a total solids (TS) loading of 5% (Gunaseelan and Lakshmanaperumalsamy, 1990). The low methane yield was due to the high lignin content of parthenium weed (Gunaseelan, 1994). Sodium hydroxide treatment of the dried biomass for 24 h significantly enhanced the digestibility, cellulose reduction and methane production. Pre-treatment doubled the methane yield (214 ml of gas/g of solids, at 10-day retention time and 40°C) compared with untreated biomass (Gunaseelan, 1994), proving the feasibility of biogas production by anaerobic fermentation of parthenium weed at minimal cost.

Recent research has focused on using parthenium weed biomass for bioethanol production. Ghosh *et al.* (2013) converted the lignocellulosic biomass of parthenium weed (cellulose 28%; hemicellulose 21% and lignin 14%) into a fermentable sugar mixture by a pre-treatment with dilute sulfuric acid at 150–210°C, which was then efficiently fermented by yeasts to produce bioethanol. Pandiyan *et al.* (2014) subsequently showed that pre-treatment with 1% NaOH enhanced lignin recovery, increasing the yields of reducing sugars. Rana *et al.* (2013) demonstrated that basidiomycetes fungi could be used to de-lignify parthenium weed biomass, generating large amounts of reducing sugars.

Singh *et al.* (2014) reported that the large amount of cellulose in the parthenium weed biomass makes it a suitable substrate for bioethanol production. A hot acid hydrolysis was the most effective pre-treatment, yielding 398 mg/g of total fermentable sugars from the raw biomass. While acknowledging the high cost of commercial cellulose enzymes and slow kinetics, Singh *et al.* (2014, 2015) obtained a final bioethanol yield of *c.*203 mg/g through an optimized enzymatic process, aided by an ultrasound sonication process. When the hot acid hydrolysis and ultra-sonication-aided digestion with two enzymes was combined with yeast fermentation of the sugars, an even higher bioethanol yield of 260 mg/g raw biomass was obtained (Bharadwaja *et al.*, 2015). Further optimization of the combined process and fermentation by different strains of yeasts achieved a maximum fermentable sugar yield of 615 mg/g of biomass, producing 240–270 mg of bioethanol/g biomass (Tavva *et al.*, 2016).

Comparisons with published literature on other lignocellulosic biomass, including some weeds, reveal that parthenium weed biomass compares favourably as biofuel feedstock with other conventional biomass from agricultural and non-agricultural residues. The consensus of these studies is that parthenium weed biomass is highly suitable for bioethanol generation, as a cheap feedstock, where it is plentifully available. As the processes are cost effective, utilization of parthenium weed biomass for biogas (methane) or bioethanol production are valid applications for the large amounts of weed biomass removed during control efforts in countries such as India.

10.3.8 Utilizing parthenium weed as compost, vermi-compost or green manure

Parthenium weed biomass has long been considered as a useful source of compost or green manure to improve soil health and crop yields (Raju and Gangwar, 2004; Biradar and Patil, 2001). Although the compost contains abundant macro- and micronutrients, and is much richer than farmyard manure, there has been concern that high levels of parthenin, phenolics and other allelochemicals in parthenium weed may adversely affect seed germination and seedling development of sensitive crop species. Therefore, effective composting is essential to break down the constituent phytochemicals (DWSR, 2010). At the same time, effective composting is needed to kill parthenium weed seeds, preventing further spread of the weed through compost.

Over the past two decades, several research groups in India have examined the process of composting parthenium weed, often with cow dung slurry or mixture (Fig. 10.1). The research has also attempted to quantify the benefits of incorporating the parthenium weed compost either alone or in combination with inorganic fertilizer or other organic manures. The results of numerous studies indicate variable nutrient compositions in the compost, but generally positive effects in improving the growth of crop species, provided the compost is well prepared and has undergone mineralization for more than about 60 days. In one study (Channappagoudar *et al*., 2007) the nutrient contents from pre-flowering parthenium weed biomass were much higher than those made from older, post-flowering plants.

In some early research, Biradar and Patil (2001) showed that parthenium weed biomass, mixed with cow dung, provided a good substrate for the growth of the earthworm *Eudrilus eugeniae* Kinberg and for vermicomposting. The nutrient composition of

Fig. 10.1. Compost prepared from parthenium weed in India. (S. Adkins.)

vermi-compost, produced by *E. eugeniae*, in a 1:1 mixture of weed biomass to cow dung, was higher than that of its individual substrates (Sharma *et al*., 2008). Although this vermi-compost, incorporated at 10 t/ha, increased the yield of wheat (*Triticum aestivum* L.), a comparison showed that its performance was inferior to vermi-compost from lantana (*Lantana camara* L.), farmyard manure and a reduced inorganic fertilizer (Sharma *et al*., 2008).

Sivakumar *et al*. (2009) evaluated the efficiency of vermi-composting of parthenium weed by the earthworm *Eisenia fetida* (Savigny), in mixture with neem and cow dung. While varying levels of neem leaves had no effect on the earthworms, parthenium weed significantly reduced their growth and number of castings above a rate of 75 g in 500 g of cow dung. Recently, Yadav and Garg (2011) confirmed this adverse effect and found a 25% parthenium weed biomass mixed with 75% cow dung was the optimal feed material for *E. fetida*. In another study, Rajiv *et al*. (2013b) found that the biomass gain, cocoon production and antioxidant enzyme production of *E. eugeniae* were adversely affected by a high concentration of parthenium weed without cow dung.

The utilization of parthenium weed as green manure has also received attention. Research in India by Saravanane *et al.* (2012) using a mixture of both pre-flowering and flowering parthenium weed biomass, incorporated at 5.0 t/ha into soil, significantly increased the productivity of rice compared with the control (no added fertilizer). Incorporation of weed biomass, combined with 75% of the recommended NPK fertilizer dose for rice, produced grain and straw yields similar to that of application of 100% of the recommended fertilizer dose. In another study, addition of parthenium weed green leaf manure to the first crop of a sequential cropping system, potato (*Solanum tuberosum* L.), markedly improved the grain yield of the succeeding finger millet (*Eleusine coracana* (L.) Gaertn.) in Karnataka, India (Saravanane *et al*., 2011).

In promoting parthenium weed biomass as compost, vermi-compost or green manure, the consensus in India is that this ecologically friendly use will also help better manage the spread of the weed. Utilization of parthenium weed biomass in these ways, without letting it go to waste, are valid practical applications where the weed is abundantly available. Anecdotal evidence is that the practices are widely used in different states and regions in India. However, there is little evidence of such uses from other regions of the world.

10.4 Other Potential Uses

10.4.1 Parthenium weed biomass as a source of cellulose

Renewable and non-conventional raw materials, such as fibres from weeds, grasses, bamboos, and agricultural and forest wastes, are gaining interest as alternative sources of cellulose. Naithani *et al.* (2008) showed that parthenium weed biomass is a rich source of lignocellulose that can be extracted cost effectively. The cellulose could be readily converted into derivatives, such as ethers (carboxy-methyl cellulose, CMC), hydroxymethyl cellulose (HMC), or cross-linked with formaldehyde and other chemicals to produce much stronger cellulose for textile and paper products (Varshney and Naithani, 2011). However, parthenium weed is not a species unique as a source of cellulose and comparative assessments with other less controversial sources are needed to justify such a use.

10.4.2 Nanoparticles from parthenium weed and their uses

Nanotechnology is the field of science that includes synthesis and utilization of various nanoparticles, which are objects ranging in size from 1 to 100 nm. Nanoparticles have the potential to revolutionize various fields of endeavour, due to their exceptional stability, high resistance to oxidation, high thermal conductivity, and other properties. Various plant extracts can be used to biologically reduce metallic ions, such as silver, gold and zinc, into their corresponding nanoparticles, with potential applications in medicine and other fields (Sanvicens and Marco, 2008). Exploring this potential as a 'green synthesis', Ranjani and Sakthivel (2013) used parthenium weed leaf extracts to reduce silver ions and form silver nanoparticles. Mondal *et al.* (2014) also synthesized silver nanoparticles using parthenium weed root extracts, and suggested that soluble carbohydrates in the aqueous extracts were involved in the reduction of silver ions to highly stable, spherical nanoparticles, which showed considerable larvicidal activity against the filarial vector mosquito (*Culex quinquefasciatus* Say). In other work, Rajiv *et al*. (2013a) synthesized highly stable zinc oxide nanoparticles using parthenium weed leaf extracts, and showed these to possess significantly higher antifungal activity against plant pathogens *Aspergillus flavus* Link and *Aspergillus niger* van Tieghem than a standard antifungal drug (amphotericin B). Nanotechnology is an emerging field of endeavour. However, the risks of applying nanotechnology to cosmetics and human and veterinary medicines are still under review. The research to date has not indicated evidence of any special attributes of parthenium weed extracts that will justify their use as reducing agents over other non-controversial species. Therefore, the use of parthenium weed extracts for the production of nanoparticles remains to be further explored and justified.

10.5 Potential Abuses

Despite the various actual and potential uses of parthenium weed, promoted by several research groups, our view is that its utilization presents significant challenges outside its native range, particularly in regions where the weed's expansion has been spectacularly rapid. Our review finds that most medicinal uses of parthenium weed in different countries fall within the realm of traditional medicine, which is currently undergoing a global revival. However, as with other modern medicines, large-scale use of a potentially toxic species like parthenium weed requires more rigorous clinical testing of toxicity and safety of dosages, validation of cause and effect, and regulation, so that its improper use can be prevented. Despite records of potential medicinal applications, there is very little information on actual uses and clinical results. The well-known allergic sensitivity of humans to parthenium weed indicates that its medicinal use would be a contraindication to at least part of the population, introducing a serious public health risk for some individuals.

Other potential abuses or harm could occur if the biomass of parthenium weed growing in metal contaminated sites is harvested and used as fodder for animals. Heavy metals are poorly secreted and not well metabolized within animal systems, so there is a potential risk of unacceptable levels of heavy metals entering the food chain via livestock (Ahmad *et al*., 2013). Similarly, parthenium weed obtained from heavy-metal-contaminated sites could also pose risks to its traditional medicinal uses (Rehman *et al*., 2013).

When used as a soil amendment, partially burnt parthenium biomass may not be good enough to improve soil conditions and could be detrimental to sensitive crop species. If the compost-making process is substandard, parthenium weed seeds will not be fully killed (DWSR, 2010) and the use of poorly prepared compost in agricultural fields would greatly increase the risk of spread of the weed across all landscapes. In promoting the use of parthenium biomass to produce biofuel, Ghosh *et al*. (2013) cautioned that parthenin and other allelochemicals hinder the growth of microorganisms, resulting in reduced fermentation and bioethanol yield. They also warned that the collection of parthenium weed causes negative health effects on workers if they are sensitive to the allergens.

Recent research from Africa has demonstrated an additional potential problem that can arise from sustaining populations of parthenium weed. In the malaria-endemic regions of East Africa, the malaria-transmitting mosquito vector *Anopheles* *gambiae* Giles feeds on nectar from various plants and honeydew to obtain sugars (Nyasembe *et al*., 2012, 2015). Controlled feeding assays showed that the fitness, energy reserves and survival of female *A. gambiae* mosquitoes increased substantially when fed on parthenium weed nectar compared with sugar from two other weeds, castor oil (*Ricinus communis* L.) and cobbler's pegs (*Bidens pilosa* L.). The females tolerated the toxins parthenin produced by parthenium weed and 1-phenylhepta-1,3,5-triyne produced by cobblers pegs, but not ricinine produced by castor oil. The authors suggest that if parthenium weed suppresses other weed species that are less suitable host plants for the malaria disease vector, this could lead to a higher transmission of the disease in endemic areas (Nyasembe *et al*., 2015). Other potential abuses of parthenium weed is in the creation of floral bouquets (Fig. 10.2) and in packaging of goods (Fig. 10.3).

10.6 Conclusions

Parthenium weed is a unique colonizing species, possessing an array of strongly bioactive chemical compounds that can pose considerable problems to sensitive plant and animal species. The phytochemicals are part of the robust and adaptive defence system of the plant, which allow it to compete with other organisms, survive and reproduce in new environments and spread further. Despite the evidence of relatively low persistence in the environment, under certain circumstances the biologically active secondary metabolites extruded from the plant may be implicated in discouraging or actively displacing other species occupying similar ecological niches. The same compounds are implicated in causing undesirable health impacts on sensitive humans and in the medicinal values of the plant. However, whether or not the same array of phytochemicals in parthenium weed can be extracted and exploited more broadly for a variety of practical uses remains a question.

The intensive attention given to parthenium weed in India is because it has greatly increased its invaded territory in the subcontinent, and continues to spread widely. The second major reason is the management of parthenium weed over the past three decades has been broadly ineffective, despite major efforts (DWSR, 2010). However, it is noteworthy that the existing reviews on parthenium weed (Patel, 2011; Kushwaha and Maurya, 2012; Saini *et al*., 2014; Bapat and Jaspal, 2016) have refrained from commenting specifically on the issue of deliberate cultivation, or sustaining its populations for utilization. The majority of published studies, collated in the above reviews, only demonstrate bioactivity in parthenium weed extracts in laboratory or greenhouse studies, which is not unique to this species.

Fig. 10.2. Parthenium weed collected for its use in flo al bouquets in Pakistan. (A. Shabbir.)

Fig. 10.3. A pile of parthenium ready for use as packaging material in Ethiopia. (A. Witt.)

Many of the studies stop short of extending potential applications to actual proving of practical uses. A large number also suffer from inadequate benchmarking of parthenium weed against less controversial species that can also be harnessed for the specific uses being promoted.

However, potential uses may expand in the near future based on the emerging evidence in various treatments, such as diabetes and malaria. Understanding the scientific basis behind the traditional usage may also improve with more ethno-pharmacological studies. Further exploration of the antioxidant, cytotoxic and anticancer potential is also likely. Nevertheless, the role of different bioactive compounds must be separated, and the 'causes and effects' better understood to make the traditional practices of using parthenium weed a modern reality. Thus far, there is no evidence of explorations of parthenium weed by the pharmaceutical industry for the development of any medicines, despite the recent spike in pharmacological research.

Given the short persistence of parthenin (Belz *et al*., 2007), the commercial production of an 'eco-friendly', 'botanical' bioherbicide from parthenium weed with wide application in agriculture appears unlikely. Nevertheless, with additional research there is a possibility of developing the fungicidal, insecticidal and nematicidal bioactivity of some parthenium weed phytochemicals as 'eco-friendly' natural products with targeted, commercial applications.

Among other uses, parthenium weed biomass can yield nutritionally rich compost or green manure, which can be used as a partial substitute for inorganic fertilizers, provided care is taken to properly compost the material or use plants prior to flowering. The lignocellulose-rich biomass of the weed can also be exploited for biofuel and biogas production, or for a low-cost substrate for the production of cellulose and for the pulp and paper industry. The potential of parthenium weed for phyto-extraction of heavy metals and pollutants, biochar preparation and soil amendment also suggests other ways of using the plant. However, in nanotechnology, the evidence of a comparative advantage of parthenium weed extracts over the reducing power of extracts of less controversial species is yet to be presented.

The utilization potential and abuse potential of parthenium weed pose dilemmas that should be resolved. Reporting from the Botanical Survey of India, Singh and Garg (2014) suggested that parthenium weed has been 'a victim of ignorance and misconceptions' (p. 1260) and that the emerging vista of applications 'may endorse the species as a fast growing medicinal herb with immense multifarious relevance, out numbering the harmful properties' (2014, p. 1261). In our view, the above suggestion is yet to be proven. The premise that utilization should be considered as a new strategy for controlling this unmanageable weed (Saini *et al.*, 2014) has to be balanced with the established evidence of negative effects of the species on the welfare of societies, environment and agriculture.

Given the strongly negative, known social impacts and the potential to cause even larger-scale economic damage in cropping and non-agricultural situations, we agree with Marwat *et al.* (2008, p. 1940), who pointed out from Pakistan 'all efforts should be made to restrict its further spread and eliminate it in a planned way by declaring it as a noxious weed under the Seed Act'. In our view, the focus on parthenium weed should be on containment and reduction of its abundance, possibly leading to its eradication, instead of commercial exploitation. This would be particularly true for all non-native areas and countries to which the weed has spread. Outside the field of traditional medicine, the economic potential of parthenium weed and practical uses remain largely exploratory, descriptive and speculative. While some of the laboratory findings, such as the antidiabetic and anticancer activity of the extracts, are compelling, we find most other research unconvincing with regard to future practical value for uses, until further, systematic evaluations are carried out. Any parthenium weed uses promoted can only be acceptable on the grounds that they will not contribute to further spread of the weed, and perhaps might be of short-term value to its overall management in a given region or area. Finally, our assessment is that the risks of spread and the overall negative economic, social and environmental impacts of parthenium weed may far outweigh its potential benefits, particularly in regions susceptible to new invasions. Therefore, a precautionary approach is suggested in promoting utilization of parthenium weed, not least because failure to do so would undermine the current efforts to contain its spread across many countries in Asia, South-east Asia, Africa and Australia.

Acknowledgements

The authors wish to thank the editors – Drs Steve Adkins, Asad Shabbir and K. Dhileepan for the invitation to write this chapter and for their editorial assistance. They also provided several articles on parthenium weed, which we were able to review and include in the chapter. Additional information was kindly provided by Sushilkumar (ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh, India), R.K. Ghosh (Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India) and several other colleagues who helped improve our review. Their assistance is also gratefully acknowledged.

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