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Review Article

Parthenium hysterophorus: a review of its weed status and the possibilities for biological control

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ABSTRACT

The neotropical composite, *Parthenium hysterophorus*, has achieved major weed status in India and Australia within the past few decades. The reasons for its success as an alien invasive weed are discussed, particularly those relating to allelopathy, together with its effect on crop production, animal husbandry, human health and biodiversity. The actual and potential use of natural enemies as classical biological control agents is reviewed and the work undertaken over the last 20 years on screening and evaluating both insect and fungal agents is analysed. It is concluded that successful management of this weed can only be achieved by an integrated approach in which biological control, because of its cost effectiveness, environmental safety and sustainability, could play a significant role.

INTRODUCTION

Parthenium hysterophorus (Heliantheae: Asteraceae) is an annual herb of neotropical origin which now has a pantropical distribution. Since its first reported occurrence in India in the early 1950s, and a little later in Australia, much has been written about this weed. Indeed, the CAB ABSTRACTS Database contains almost 400 references on *P. hysterophorus* from 1985 to the present. There have been a number of recent reviews on this weed in both Australia and India, one of the most comprehensive being that by Navie *et al.* (1996), and this should be consulted for basic details of the biology and ecology of *P. hysterophorus*. The current review is an attempt to provide an update on the status of the weed and to analyse critically the results of the published, as well as unpublished, work on biological control in order to explore the options available for its management.

WEED STATUS

Parthenium weed, as it is commonly known in Australia, or congress grass, as it is uniquely called in India, where the flower shape has been fancifully compared to the Congress building in New Delhi, has achieved major weed status in both these countries within a relatively short period. For example, it is not included in the Weeds of Australia (Lamb & Collet, 1976) and, indeed, no mention is made of it in the classic treatise on the World's Worst Weeds (Holm *et al.*, 1977). However, in the sequel, Noxious Weeds of Australia (Parsons & Cuthbertson, 1992), *P. hysterophorus* merits five pages. It is thus that parthenium weed has come to the fore in the last 20 years, based mainly on its rapid spread in both Australia and India. In addition, recent reports from Israel (Joel & Liston, 1986), Taiwan (Peng *et al.*, 1988), Nepal (Mishra, 1991) and Ethiopia (Medhin, 1992), suggest that parthenium weed is still spreading and may become more prominent in other parts of the World in the near future. The weed can affect crop production, animal husbandry, human health and biodiversity. Few other weeds have such a wide ranging and potentially lethal impact on man's affairs. These issues are discussed in more detail in the various production systems delimited below, as well as in urban and natural ecosystems.

Crop production

The impact of this weed on agriculture in the Indian subcontinent has been summarized most ably by Parsons & Cuthbertson (1992): "Experience in India presents a salutary warning in Australia. Parthenium weed was first noted near Poona in Maharashtra State in 1951. By 1972 it had spread into the majority of the western states from Kashmir in the north to Kerala in the south. Continuing to spread it was found in Assam in 1979 and is now present almost throughout the subcontinent and is probably the dominant weed in Karnataka State where it infests about 5 million hectares."

Because parthenium weed is an extremely prolific seed producer, with up to 25,000 seeds (achenes) per plant (Navie *et al.*, 1996), and with an enormous seed bank, estimated at 200,000 seeds / m^2 in abandoned fields in India (Joshi, 1991a), it has the potential to be an extremely aggressive colonizer of crops. However, its overall impact on the production system may be multifacetted, and direct or indirect, thus making it difficult to quantify losses.

Direct competition

The allelopathic nature of *P. hysterophorus* has been well documented and water soluble phenolics and sesquiterpene lactones have been reported from the roots, stems, leaves, inflorescences, pollen and seeds. Rajan (1973) and Kanchan (1975) were the first to report the presence of plant growth inhibitors in parthenium weed, and the latter author identified parthenin, caffeic acid and *p*-coumaric acid as the primary inhibitors in stem tissues. Later, Kanchan & Jayachandra (1979) found that these inhibitors were present in root exudates and could be extracted from the leaves of *P. hysterophorus* (Kanchan & Jayachandra, 1980a). In addition, a range of phenolics, including caffeic acid, ferulic acid, vanicillic acid, anisic acid and fumaric acid were found in air-dried root and leaf material. These were shown subsequently to have an inhibitory effect on nitrogen fixing and nitrifying bacteria (Kanchan & Jayachandra, 1981). Srivastava *et al.* (1985) discovered that aqueous extracts of leaves and inflorescences inhibited the germination and seedling growth of barley, wheat and peas but that extracts from the roots and stems were less inhibitory. Kohli *et al.* (1985) suggested that two allelochemicals acting synergistically were responsible for the significant decrease in seed germination and subsequent growth of cabbage, when placed in leaf and inflorescence leachates from parthenium weed. The same authors showed that cell survival and chlorophyll content were markedly reduced when leachates were sprayed directly on the crop plants (Kumari *et al.*, 1985). Jarvis *et al.* (1985) reported on the presence of a number of sesquiterpene lactones, including parthenin and coronopilin, in ethanol extracts of *P. hysterophorus* whilst Dayama (1986) noted allelopathic effects of aqueous extracts of both roots and shoots of parthenium weed on the growth and nodulation of the important agroforestry tree *Leucaena leucocephala* (Leguminosae) in India. Patil & Hedge (1988) isolated and purified parthenin from leaves of *P. hysterophorus* and demonstrated that this compound significantly decreased the germination of wheat seeds and adversely affected seedling growth. Valliappan & Towers (1989) used a continuous trapping system to collect the root exudates from undisturbed parthenium plants, thus simulating a more natural system, and, once again, identified parthenin and coronopilin in the exudates. Significant reduction in both the radicle and plumule growth of *Pennisetum americanum* (Poaceae) was subsequently demonstrated. Similar allelopathic effects have been shown with foliar leachates of *Parthenium hysterophorus* on a diverse range of agricultural and tree crops: cowpea, sunflower, *Casuarina*, *Acacia*, *Eucalyptus* and *Leucaena* (Swaminathan *et al.*, 1990); rice, wheat, black gram and chickpeas (Singh & Sangeeta, 1991); green gram and wheat (Agarwal & Anand, 1992); barley and *Cassia tora* (Singh *et al.*, 1992); mung beans and guar (Kohli & Rani, 1992); various species of Indian forage crops, pulses and oil seeds (Aggarwal & Kohli, 1992); sorghum (Ayala *et al.*, 1994); maize, ragi (*Eleusine coracana*; Eragrostidae) and soyabeans (Bhatt *et al.*, 1994); sunflower, french beans and cotton (Madhu *et al.*, 1995); radish (Mehta *et al.*, 1995); okra, chilli peppers and clover (Dhawan & Dhawan, 1995a); "spinach" (*Amaranthus gangeticus*; Amaranthaceae) (Gupta, 1996); mulberry (Singhal *et al.*, 1996); as well as some common Australian pasture grasses (Adkins & Sowerby, 1996). Kohli & Batish (1994) have demonstrated that the germination and yields of traditional Indian pulse crops (guar, black and green gram) were reduced when these were grown in soils previously infested by parthenium weed, whilst Bhatt *et al.* (1994) investigated a more cryptic effect of parthenium extracts and found that almost 90% pollen sterility could be induced in radish when seeds were pre-treated in varying concentrations and then subsequently field sown.

As shown above, the types of crops which can be affected by allelochemicals from parthenium weed, either directly in the field or in laboratory / greenhouse trials, are many and varied but there is still an overall dearth of precise quantitative data to support this qualitative assessment. One of the few attempts to measure the competitive ability of parthenium weed was undertaken by Channappagoudar *et al.* (1990) in irrigated sorghum in India. They found that the presence of *P. hysterophorus* reduced grain yields from 6.47 to 4.25 tons / hectare and decreased grain weight by almost 30%.

Indirect effects

From field observations of the poor fruiting of the leguminous crops *Crotalaria* and *Desmodium* when growing in parthenium-infested fields in southern India, Kanchan & Jayachandra (1980b) associated this with the presence of a white dust, later found to be pollen of *P. hysterophorus*, covering the plants. In experiments using crop plants typical of the region, pollen was dusted onto the flowers of tomato, brinjal, chilli pepper and bean; pollen leachates were also tested *in vitro* against pollen from the crop plants. The results clearly demonstrated an inhibitory effect both on fruit set in the field and pollen germination in the laboratory. Parthenium pollen was also found to reduce the chlorophyll content of heavily contaminated crops, probably owing to interference with porphyrin biosynthesis (Rice, 1974). This constitutes the first report of pollen allelopathy and, such is the production of pollen, estimated at 3375×10^6 grains / m^2 (Kanchan & Jayachandra, 1980b) or 624×10^6 grains / plant (Towers & Subba Rao, 1992), that the negative effects on the crop within the infested fields, as well as in neighbouring weed-free crops, may be significant. This indirect (or cryptic) factor which can influence crop yields is thus even more difficult to quantify than direct competition and much of the evidence, such as reduction of grain filling in maize (Mew *et al.*, 1982; Towers & Subba Rao, 1992), is anecdotal.

Another indirect effect of the presence of parthenium weed is its potential role as an alternate host for crop pests, functioning as an inter-season reservoir or inoculum source; as, for example, in the case of the scarab beetle pest of sunflower (*Pseudoheteronyx* sp.) in central Queensland (Robertson & Kettle, 1994) and plant parasitic nematodes in the USA (Navie *et al.*, 1996). Also in the USA, it has been shown that the agromyzid, *Liriomyza trifolii* (Burgess), a pest of bell pepper (*Capsicum annuum*; Solanaceae), has a preference to feed and oviposit on *Parthenium hysterophorus* which occurs along roadsides in the pepper-growing regions of Texas. It was concluded that better management of the weed would help to reduce the pest populations (Chandler & Chandler, 1988). In a bizarre interpretation, Remadevi & Sivaramakrishnan (1996) report on the suitability of *P. hysterophorus* as a food source for the polyphagous lepidopteran *Diacrisia obliqua* Walker (Arctiidae), which is an important pest of both agriculture and forestry, including teak, and recommend that the insect could be exploited for biological control of parthenium weed. There is no mention that the build-up of pest populations on *P. hysterophorus* could lead to a massive invasion of neighbouring teak plantations and, therefore, that the *D. obliqua*–*P. hysterophorus* association is far from being a beneficial one. Ironically, 20 years earlier, Rajulu *et al.* (1976) had advocated the use of the polyphagous black bean aphid, *Aphis fabae* Scopoli (Aphididae), to control parthenium weed in southern India. Doubtless there are many more instances of *P. hysterophorus* harbouring crop pests. In addition, *P. hysterophorus* may act as a secondary host of plant diseases. Ovies & Larrinaga (1988) in Cuba found that the bacterial pathogen, *Xanthomonas campestris* pv. *phaseoli*, could be transmitted from the weed to *Phaseolus vulgaris* (Leguminosae) with reciprocal infection, at the pre-flowering and pod formation stages. Elimination of parthenium weed was recommended in order to contain disease spread. The notorious bacterial wilt pathogen, *Pseudomonas solanacearum*, has also been recorded on *Parthenium hysterophorus* in India (Kishun & Chand, 1988), whilst a number of crop viruses have similarly been detected, including four transmitted by *Bemisia tabaci* (Gennadius) (Aleyrodidae) in the southern Indian state of Tamil Nadu (Jeyarajan *et al.*, 1988) and one (tomato leaf curl virus) in the neighbouring state of Karnataka (Sastry, 1984). Earlier work in Cuba had reported that *P. hysterophorus* is also a natural host and reservoir of potato virus X and Y (Cordero, 1983).

Animal husbandry

The impact of parthenium weed on livestock production is similarly diverse, and both direct and indirect, affecting:

grazing land, animal health, milk and meat quality, marketing of pasture seeds and grain.

Jayachandra (1971) reported that the weed can be a serious problem in grasslands in India and can reduce the pasture-carrying capacity by up to 90%. However, it is from Australia that the most comprehensive analysis of its economic impact on livestock production, or indeed on any production system, has been made. Chippendale & Panetta (1994) undertook a mail survey of beef producers in heavily infested areas in Central Queensland, following reports that parthenium could completely dominate grazing land, resulting in weed monocultures and reduced stocking rates of up to 80% (McFadyen, 1992). From this survey, it was estimated that over 17,000 km^2 was infested by *P. hysterophorus*, with the problem becoming progressively worse over the previous 10 years, and that an extra 45,000 cattle could have been marketed during the survey year in the absence of parthenium weed, with a net annual loss of revenue calculated as AU$ 5-17 million. Cattle grazing in parthenium-invaded pastures were also found to be marketed with a lower weight, compared to those from weed-free areas, accounting for more losses to the producer. This was coupled with additional expenses for herbicide application, labour and machinery hire to control weed infestations. A further negative effect on cattle ranching in Queensland can occur if the infested farms also supply pasture seed and forage, since there is legislation to prevent the sale or movement of these goods because of their contamination by parthenium seed. Harvesting machinery may also be subject to state legislation. A similar situation is now present in New South Wales (NSW), with sunflower hull stock fodder being implicated as a major source of spread of parthenium (Gray, 1995).

Earlier investigations in India had revealed serious health hazards to livestock in parthenium-invaded areas. Narasimhan *et al.* (1977) found that, while cattle and buffalo feed sparingly on parthenium weed, goats readily graze it. However, in artificial feeding tests buffalo bull calves accepted the weed, alone or in mixtures with green fodder, with severe consequences. The majority (11 out of 16) developed severe dermatitis and toxic symptoms, and died within 8-30 days. Lesions were found subsequently in the gastrointestinal tract, liver and kidneys. Similar results have been reported since (Ahmed *et al.*, 1988a, b; Kadhane *et al.*, 1992), with external symptoms of pruritis, alopecia, loss of skin pigmentation, facial and body dermatitis, erythematous eruptions and anorexia. Gastrointestinal irritation resulted in diarrhoea. Changes in blood chemistry and inhibition of liver dehydrogenases, as well as degenerative changes in both the liver and kidneys, have been reported in buffalo (Ahmed *et al.*, 1988c) and sheep (Rajkumar *et al.*, 1988). The milk of cattle, buffalo and sheep may also be tainted by parthenin (Towers & Subba Rao, 1992), which can also affect sheep meat (Tudor *et al.*, 1982).

Human health

More than two decades ago, serious human health risks from *P. hysterophorus* were reported from India (Lonkar *et al.*, 1974), and 12 deaths were attributed to allergenic responses, particularly flu and asthma, from Poona alone (Anonymous, 1976). The initial symptoms were described as itching, redness, swelling and blisters on the eyelids, face and neck, which then spread to the elbows and knees. In the later stages, the skin thickens and darkens. “At present there is no cure for the disease other than moving away from the parthenium infested area” (Anonymous, 1976); an impossible solution now given the ubiquitous presence of the weed in India. Since then there has been a series of publications on the impact of parthenium weed on the welfare of human populations, which has steadily accumulated evidence indicating that this is a much more serious problem than originally supposed. Recently, these have been comprehensively reviewed with the emphasis on India and Australia (Towers & Subba Rao, 1992; McFadyen, 1995). The latter review was aimed specifically at alerting the Australians, particularly in Queensland and NSW, to the dangers of parthenium weed as it continues to spread southwards into the urban areas: “After 1 to 10 years exposure to the weed, 10% to 20% of the population will develop severe allergenic reactions. These may be hayfever, asthma, or dermatitis and can be caused by dust and debris from the plant as well as pollen” (McFadyen, 1995).

Prolonged skin contact with parthenium can result in allergenic eczematous contact dermatitis (AECD), whilst inhalation of pollen can cause allergenic rhinitis which can develop into bronchitis or asthma if the pollen enters the respiratory tract during mouth breathing. The mechanisms involved have been documented by Towers & Subba Rao (1992). The principal culprit, parthenin, has enhanced biological activity (toxicity) due to the presence of a cyclopentene group, which can cause chromosomal damage in animal cells, uncouple phosphorylation and inhibit key cellular enzymes. Indeed, extremely small doses injected intravenously into mice can cause rapid death. This compound is concentrated particularly in the leaf hairs (trichomes), as well as in the general foliage and pollen. Over a six-year period, aeropollen sampling in Bangalore (southern India) revealed that 40-60% of the total pollen count was from *P. hysterophorus*. It is not surprising, therefore, that parthenium pollen is now a major cause of allergenic rhinitis in that city with 7% of the population affected and over 40% sensitive to the pollen (Sriramarao *et al.*, 1991). “To our knowledge, nowhere in the world has such a high incidence of allergenic rhinitis to a specific pollen type ever been reported” (Towers & Subba Rao, 1992). Subsequent studies in northern India (Punjab), showed that a significant proportion of bronchial asthma patients is sensitized to *P. hysterophorus* (Suresh *et al.*, 1994), whilst out of a total of 63 patients in New Delhi, clinically diagnosed with airborne contact dermatitis, 62 showed a positive reaction to parthenium weed (Nandakishore & Pasricha, 1994). Perhaps even more disturbing are the results of a study on the allergenic cross-reactivity between ragweed (*Ambrosia*) pollen allergies which revealed that there is a high degree of cross-infectivity, leading to the suggestion that individuals sensitized to parthenium may develop type-1 hypersensitivity reactions to ragweed, and *vice versa*, when they travel to regions infested with the weed to which they have not previously been exposed (Sriramarao & Rao, 1993). Fisher (1996) also noted that *P. hysterophorus* in India was the first reported case of an imported sensitizer causing widespread AECD. In fact, the instances of AECD in India are probably much higher because, as Kumar & Greval (1993) observed, they generally escape clinical detection and consequently are wrongly diagnosed.

Perhaps an even more sinister effect of parthenium weed on human health has been highlighted by Tanner & Mattocks (1987), who hypothesized that parthenium-contaminated animal feed leads to tainted milk and that the hepatotoxic parthenin reacts synergistically with copper in causing Indian childhood cirrhosis (ICC). Hepatic copper accumulation is characteristic of the disease but this alone does not induce significant liver damage.

Biodiversity

Parthenium weed, because of its invasive capacity and allelopathic properties, has the potential to disrupt natural ecosystems. It has been reported as causing a total habitat change in native Australian grasslands, open woodlands, river banks and floodplains (McFadyen, 1992; Chippendale & Panetta, 1994). Similar invasions of national wildlife parks have been observed recently in southern India (author, personal observation), encroaching from settlements, but whether or not the weed can compete with already well-established and equally aggressive aliens, such as *Chromolaena odorata* (Eupatorieae) and *Lantana camara* (Verbenaceae), remains to be seen.

BIOLOGICAL CONTROL

Arthropods

Parthenium hysterophorus was declared a noxious weed in Queensland in 1975 and surveys for natural enemies were soon underway in its neotropical centre of origin, coordinated by the Queensland Department of Lands (QDL) (Haseler, 1976). This was based on the fact that *P. hysterophorus* is essentially a ruderal plant in the New World and only occasionally achieves weed status in crop or pasture situations. It was argued that biotic factors suppress the plant within its native range compared to its increased fitness or vigour in their absence, as in Australia and India, and, therefore, that biological control appeared to offer the best, long-term solution for management of the weed (Haseler, 1976). Subsequently, entomological surveys and the screening of selected arthropods were undertaken in both Brazil / Argentina (1977-1981) and Mexico (1978-1983) by both QDL and IIBC (then CIBC, the Commonwealth Institute of Biological Control) scientists. The results of this research are reviewed by McClay (1985) and McFadyen (1985), and later updated to include additional surveys which were eventually phased out in 1991 (McFadyen, 1992).

Navie *et al.* (1996) list the insects (eight species) introduced so far into Australia with details of their origin, release date and establishment. The complete results of the North American surveys have been summarized recently by McClay *et al.* (1995). Over 260 phytophagous arthropod species were collected from *P. hysterophorus,* although only 144 species actually fed on the plant. Thirteen of these were assessed as being restricted to the subtribe Ambrosiinae, a level of specificity which was considered to be adequate given the fact that no indigenous members of the Ambrosiinae occur in Australia, and those present are exotic weeds. After preliminary screening in Mexico and final evaluation in quarantine in Australia, five oligophagous or monophagous species, covering a range of feeding niches, were released in Queensland in the 1980s: a defoliating beetle, *Zygogramma bicolorata* Pallister (Chrysomelidae); a seed-feeding weevil, *Smicronyx lutulentus* Dietz (Curculionidae); a stem-galling moth, *Epiblema strenuana* (Walker) (Tortricidae); a leaf-mining moth, *Bucculatrix parthenica* Bradley (Lyonetiidae); and a sap-feeding planthopper, *Stobaera concinna* (Stål) (Delphacidae). In addition, a stem-boring curculionid weevil, *Listronotus setosipennis* Hustache from Argentina, which is probably the most damaging of the arthropods (Wild *et al.*, 1992), has been released and successfully established. The fate of the remaining two South American species, *Conotrachellus* sp., a stem-galling curculionid weevil (Anonymous, 1993), and *Platphalonidia mystica* Rakowski & Becker, a leaf-feeding cochylid moth (Griffiths & McFadyen, 1993), is unknown (Navie *et al.*, 1996).

McClay *et al.* (1995) noted that severe damage to *Parthenium hysterophorus* by arthropods was observed only rarely during the North American surveys, except occasionally by *Zygogramma* and *Epiblema*. Significantly, these are proving to be having the most impact in Australia (McFadyen, 1992). McClay *et al.* (1995) also commented on the importance of faunal relationships for the practical selection and screening of potential biocontrol agents. Surprisingly, there was a high degree of similarity between the faunas of *P. hysterophorus* and *Helianthus* (>8%), but significantly lower between it and the congeneric species, *Parthenium argentatum* (<5%). The testing of *Helianthus annuus*, an important cash crop in Queensland, has proven to be critical, both in Australia and India, as will be shown later. In the case of the most recently released insect agent, *Platphalonidia mystica*, larval feeding damage occurred on sunflower in laboratory tests, but the risk of field damage to this crop was considered to be negligible weighed against the threat from the weed, not only to Queensland, but to the neighbouring states (Griffiths & McFadyen, 1993). A similar situation had previously been encountered during screening of the *Listronotus* weevil, which showed some feeding development on sunflower, although this was later released between 1982 and 1986 (Wild *et al.*, 1992). In view of the continued scepticism, not to say antagonism, surrounding the introduction of exotic biocontrol agents, it is relevant here to discuss the risks and benefits involved in relation to the insect natural enemies already released, particularly in the light of the controversial events in India.

In Australia, the moth *Epiblema* has been reported as exerting significant control of parthenium weed; several larvae being sufficient to stunt plants and reduce seed production (McFadyen, 1992). The problem has been that erratic rainfall patterns have disrupted the moth populations, reducing them to very low levels and these have failed to build up sufficiently during the rains to catch up with host populations. This agent was later re-screened in India but was rejected because it attacked a native composite species not found in Australia. This was not unexpected since it had been established that the moth is oligophagous (McClay, 1987), but was considered safe for release in Australia because of the absence of native or economic species of Ambrosiinae. In fact, McClay *et al.* (1995) had commented that releases should be "tailored" to the proposed area of introduction, which may entail undertaking additional host specificity tests. The *Zygogramma* beetle showed considerable promise during the early years following the release in Australia, causing severe defoliation during population explosions and significantly reducing seed set. However, this initial optimism was short-lived as the beetle probably failed to adjust to the variable rainfall patterns. Nevertheless, there are recent indications that *Z. bicolorata* is now having a greater impact on parthenium weed in Australia (Navie *et al.*, 1996). The history of its introduction in India, however, merits more detailed analysis.

The beetle was imported into quarantine in Bangalore (Karnataka State) from the CIBC substation in Mexico in April 1983 and, after further host specificity testing (Jayanth & Nagarkatti, 1987), it was considered to be monophagous and released in August 1984. Based on the initial poor recoveries, it was concluded that *Z. bicolorata* would perform better in those areas of India with a better-distributed rainfall pattern (Jayanth, 1987). Nevertheless, later reports showed that this was proving to be an effective control agent in the Bangalore environs with five to six generations per year (Jayanth & Bali, 1992), but that inundative releases may be necessary early in the season to maximize its impact (Jayanth & Bali, 1993). This was tempered, however, by observations of beetle attacks on sunflowers in a few localities in Karnataka (Jayanth, 1993); although it was demonstrated that feeding could be induced by the presence of parthenin leading to the theory that, because abundant parthenium pollen was found on sunflower leaves in the affected areas, the beetle was reacting to the parthenin stimulus and not to the crop plant *per se* (Jayanth *et al.*, 1993). Recriminations came thick and fast, fuelled by journalistic fervour, including the suggestion that the wrong beetle species (i.e. *Zygogramma conjuncta* (Rogers)) had been introduced into India (Chakravarthy & Bhat, 1993), which was immediately refuted (Kumar, 1993), and led to the establishment of the Parthenium Fact Finding Committee. The latter concluded that the beetle in question is *Z. bicolorata* and that, despite the widespread occurrence of sunflower as a crop in Karnataka, Maharashtra, Tamil Nadu, Andhra Pradesh and Kerala, there had been no further reports of beetle-feeding on sunflower in field situations. In no-choice, cage tests, however, there is no doubt that *Z. bicolorata* will attempt to feed on sunflower and *Xanthium strumarium* (author, personal observation). Similarly in Australia, despite the release of *Z. bicolorata* over 17 years ago in areas of massive sunflower cultivation, there have been no reported instances of beetle attack on the crop. In the meantime, increasingly optimistic reports on the biocontrol potential of *Z. bicolorata* have appeared (Jayanth & Bali, 1994a, b; Jayanth & Visalakshy, 1994), with the most recent claim that beetle defoliation can cause up to 99.5% decline in weed populations, and their replacement by up to 40 different plant species in fallow land (Jayanth & Visalakshy, 1996). On the negative side, however, there are indications that indigenous parasitoids (*Palexorista* sp.; Tachinidae) may be beginning to adapt to this host (Kayanth *et al.*, 1996).

Pathogens

Research has focused mainly on fungal pathogens, although the potential of bacteria and viruses has been considered, and involves the exploitation of both exotic, coevolved, biotrophic agents as classical releases, as well as adapted or opportunistic, local, plurivorous pathogens as mycoherbicides.

Classical biological control agents

Based on information supplied by the CIBC Mexican substation, specifically on observations of rust damage on parthenium weed in North America (McClay *et al.*, 1995), surveys were initiated in Mexico in 1983 by CIBC scientists within a QDL-funded programme. From field observations, the rust species *Puccinia abrupta* Diet. & Holw. var. *partheniicola* (Jackson) Parmelee was selected for further study, because of its occurrence in climatically similar habitats to those in the target area in Queensland and also based on significant damage to the host (Evans, 1987a), despite the fact that the taxonomy and life cycle were still unresolved. The life cycle was eventually elucidated, following prolonged experimentation in the laboratory and greenhouse (Evans, 1987b), and the rust was proven to be autoecious as indicated by Parmelee (1967). Rust strains were collected in Mexico and assessed in the UK for pathogenicity to the Australian weed biotype, based on sporulation capacity and host damage. Rust infection hastened leaf senescence, significantly decreased the life span and dry weight of parthenium plants and reduced flower production by 90% (Parker, 1989; Parker *et al.*, 1994). Host specificity testing involved using the centrifugal, phylogenetic method developed by Wapshere (1974), which constituted the basis of the guidelines of the Plant Quarantine Branch of the Australian Department of Primary Industries and Energy for the importation of exotic weed pathogens. As an in-built safeguard, a range of well-defined criteria was used to select additional test plants, including 17 commercial varieties of sunflower. The test requirements for exotic fungal pathogens are significantly more stringent than those for the import of arthropod biocontrol agents. This was highlighted recently using *Parthenium hysterophorus* as an example (Evans, 1995). A total of 69 test plant species was included for screening the insect agents (McFadyen, 1985), whilst 120 species and varieties were employed for the rust (Parker *et al.*, 1994). An additional assessment involved the use of a whole leaf clearing and staining technique (Bruzzese & Hasan, 1983), which permitted a microscopic, as well as a macroscopic examination of the screened plants, making it possible to identify different levels and mechanisms of resistance (Parker *et al.*, 1994). Minor external and internal symptoms were identified in several sunflower cultivars, necessitating additional screening involving both climatic and biotic variables in order to stress or predispose the plants to infection. The investigations demonstrated that the rust was sufficiently host specific to be considered for introduction, and permission to import and release was given by the Australian Quarantine and Inspection Service (AQIS) in April 1991. Since then it has been released at *circa* 150 sites in central Queensland (Tomley & Evans, 1995). Although severe infection was readily achieved in the field, drought and consistently high night-time temperatures have, so far, limited the dispersal of the rust from the release areas. However, recent movement of the rust has been observed following more compatible climatic conditions (A. J. Tomley, pers. comm.). Of relevance to this and future biological control programmes was the enthusiasm shown by local farmers, generated by regular progress bulletins issued by QDL (Anonymous, 1988, 1991), as evidenced both by the press release emanating from the Queensland Minister for Land Management: "Many landholders have contacted Lands Department staff for supplies of the rust. But they should be aware that it will not be supplied on request. However, release sites will be strategically planned by my Land Protection Branch Officers" (Eaton, 1991), and by the subsequent theft of rusted plants from the "strategic" release sites (A. J. Tomley, pers. comm.). This community involvement in biological control programmes in Australia was recently the subject of a review article (Briese & McLaren, 1997).

In 1995, after meetings of all the interested parties in Australia concerned about the moving parthenium front, more funding

Table 1. Fungal pathogens associated with parthenium weed.

Pathogen[1]	Neotropics	Palaeotropics
Mastigomycotina, Peronosporales		
Plasmopara halstedii (Farl.) Berl. & de Toni (= *Bremia lactucae*)	Dominican Republic, Mexico	-
Basidiomycotina, Uredinales		
Puccinia abrupta Diet. & Holw. var. *partheniicola* (Jackson) Parmelee[2]	Argentina, Bolivia, Brazil, Central America, Mexico	Kenya, Mauritius
Puccinia melampodii Diet. & Holw.	Central America, Mexico	-
Basidiomycotina, Ustilaginales		
Entyloma parthenii Sydow (= *E. compositarum*)	Argentina, Dominican Republic, Mexico	-
Ascomycotina, Erysiphales		
Erysiphe cichoracearum DC var. *cichoracearum* Braun	Mexico	-
Sphaerotheca fuliginea (Schlecht.) Poll.	-	India
Mitosporic fungi (= Fungi Imperfecti)		
Alternaria spp.	-	India
A. protenta E. G. Simmons	Mexico	-
A. zinniae M. B. Ellis	Mexico	-
Cercospora partheniphila Chupp & Greene	Cuba, Mexico	India
Colletotrichum capsici (Syd.) Butler & Bisby	-	India
C. gloeosporioides (Penz.) Sacc.	-	India
Curvularia lunata (Walker) Boedjin	-	India
Fusarium spp.	-	India
Myrothecium roridum Tode ex Fr.	-	India
Oidium parthenii Satyaprasad & Usharani	-	India
Rhizoctonia solani Kuhn	-	India
Sclerotium rolfsii Sacc.	-	India

[1] Data from Evans (1987a), updated from Indian records and recent IIBC surveys.
[2] Lindquist (1982) proposed the name *Puccinia schileana* Speg. var. *partheniicola* (Jackson & Holw.) Lindquist, but this has not been taken up.

became available to resuscitate the surveys for other fungal pathogens, or better adapted strains of *Puccinia abrupta* var. *partheniicola,* with the emphasis being on tolerance to higher temperatures. The rust strains evaluated thus far were all more effective when night-time temperatures fell below 20°C and were preferably around 17°C (Parker *et al.*, 1994). Together with collaborators in Mexico (Instituto de Ecologia, Xalapa, Veracruz), surveys have been undertaken throughout the country and extended to Central and South America. Preliminary indications are that the microcyclic rust, *Puccinia melampodii* Diet. & Holw. (Evans, 1987a; Parker, 1989) may be a suitable candidate for release and better suited to the climate in southern Queensland, where parthenium weed is causing considerable concern because of its potential urban impact. The white smut, *Entyloma parthenii* Sydow, collected in Mexico and Argentina, also shows promise in the field but successful establishment in the greenhouse is proving to be problematic. The complete list of neotropical pathogens is presented in Table 1.

Mycoherbicides

All the work on this approach has been concentrated in India. Deshpande (1982) appears to have been the first to explore the possibility of exploiting local pathogens as bioherbicides for control of parthenium weed, although no specific potential agents were identified. Rajak *et al.* (1990) undertook a survey around Jabalpur (Madhya Pradesh), collecting diseased specimens of *Parthenium hysterophorus* and isolating suspected pathogens. A total of 25 fungal species was identified, the majority being opportunistic necrotrophs. *Myrothecium roridum* Tode ex Fr. appeared from the field survey and subsequent pathogenicity tests, to show most potential for mycoherbicide development (Pandey *et al.*, 1990, 1992a). From further pathogenicity screening of the other fungi, it was concluded that most of them had the ability to suppress seed germination of *P. hysterophorus* and cause high seedling mortality, whilst a few could effectively kill mature plants, including: *Colletotrichum gloeosporioides* (Penz.) Sacc.; *Fusarium oxysporum* Schlect.; *Fusarium monoliforme* Sheld.; in addition to *Myrothecium roridum* (Pandey *et al.*, 1991). The two soilborne *Fusarium* spp. were the subject of a later study and it was considered that, although their biological potential was high, their safety and specificity remained to be evaluated (Pandey *et al.* 1992b). This group also reported a ‘new’ collar rot disease of *P. hysterophorus* due to *Sclerotium rolfsii* Sacc. (Pandey *et al.*, 1992c), although in fact this had been recorded on the same host much earlier in Karnataka (Siddaramaiah *et al.*, 1984), and intimated that it had considerable potential as a mycoherbicide for control of parthenium weed. Subsequent host range screening showed that their isolates of *S. rolfsii* were pathogenic to a number of crop plants (cabbage (*Brassica*), beans (*Phaseolus*), castor (*Ricinus*) and *Amaranthus*), as well as to other weeds (Mishra *et al.*, 1994). However, the possibility of using *S. rolfsii* as a mycoherbicide to control weeds in non-agricultural situations was considered a feasible proposition and studies on mass production of the fungus are in progress (Mishra *et al.*, 1995).

Aneja *et al.* (1994) recorded a new leaf spot disease on *Parthenium hysterophorus* in Haryana State, caused by *Curvularia lunata* (Walker) Boedjin, whilst Dhawan & Dhawan (1995b) isolated a range of fungi (13 species) from the phylloplane of *P. hysterophorus* plants also from this region. The latter authors concluded, however, that their low virulence and wide host ranges made them unsuitable as candidates for exploitation as mycoherbicides. Other workers in India are pursuing similar lines of research (Aneja, 1991; Anonymous, 1996), but, as far as can be ascertained, no formulated product has reached the stage of field testing.

Antagonistic plants

The first observation that antagonistic competitor plants could replace *P. hysterophorus,* and, therefore, had potential for biological control, appears to have been made by Singh (1983) who noted that *Cassia uniflora* (Leguminosae) moved into areas previously (“traditionally”) occupied by parthenium weed in the Maharashtra State of India. Subsequently, Naithani (1987) also observed that *Cassia sericea* had the ability to smother or overgrow *P. hysterophorus* in northeast India, whilst in southern India it was reported to reduce the vigour of parthenium weed (Mahadevappa & Ramaiah, 1988). The presence of inhibitory or allelopathic substances in aqueous extracts of *C. sericea,* which affected both the germination and growth of *P. hysterophorus,* was discovered soon after (Jayakumar *et al.*, 1989). There followed a spate of publications on the allelopathic effects and the potential of *C. uniflora* for biological control of parthenium weed, in which phenolic leachates were identified (Joshi 1991a, b, c). From the reports, it would appear that the wholesale propagation of *C. uniflora* was recommended for use in the biological control of parthenium weed. However, it would appear that this was aborted when it was discovered that *C. uniflora* is a major host of *Bemisia* whiteflies and a reservoir of tomato leaf curl virus, which was readily transmitted from the legume to neighbouring crops, including tomato (Reddy & Ravi, 1991). Leachates from a number of other plants have also been tested for their allelopathic effects to *P. hysterophorus,* including: *Eucalyptus* spp. (Kohli *et al.*, 1988; Theagarajan *et al.*, 1995); neem, mulberry (Dhawan & Dhawan, 1995b); and a wide range of woody plants of the Leguminosae (*Acacia* spp., *Albizia lebbek, Cassia* spp., *Prosopis* spp.) (Dhawan, 1994, 1995; Dhawan & Dhawan, 1995c, d, e; Dhawan *et al.*, 1996). Most tested positive with significant inhibition of parthenium weed at different growth stages, and have been considered as possible biological control agents. More recent work with marigold (*Tagetes erecta*; Heliantheae) at the National Research Centre for Weed Science (Jabalpur, Madhya Pradesh) has shown that in field trials, this plant can readily outcompete *Parthenium hysterophorus* in mixed stands, probably through allelopathy (L. P. Kauraw, pers. comm.; author, personal observation).

FUTURE STRATEGY

From the data presented here, there is no doubt that *Parthenium hysterophorus* poses a serious health risk, particularly to the urban populations of Australia and India as it moves into new areas and consolidates established ones. The problem is now being more widely acknowledged and it has probably achieved the status of a major weed, and would thus qualify as one of the world’s worst weeds, as evidenced by the fact that the First International Conference on Parthenium Management will be held shortly in India (Dharwad, Karnataka State).

In addition to the health hazards, this review also highlights its impact on agricultural as well as on natural ecosystems. As a consequence of its increasing weed status, diverse groups of specialists have been stimulated to investigate control strategies. Many appear to be working in isolation and perhaps the time is ripe to coordinate these research efforts in order to develop a feasible and sustainable management strategy. Hopefully, the conference will provide the necessary stimulus and forum to achieve this end.

This review has not touched upon the alternative control methods (cultural, chemical) through which an integrated pest management (IPM) strategy can be formulated, nor indeed upon the many, often obscure uses of the weed, information on which are essential in order to assess the benefits, losses and risks. The CAB ABSTRACTS Database provided many examples of these and they will form the basis of a separate review. Australian farmers are employing a range of control measures in order to manage parthenium weed more successfully, and the emphasis has always been, and will continue to be, on using an integrated management strategy. Queensland Department of Lands recognized at an early stage the potential of biological control as an economically viable, sustainable and environmentally safe approach for the long-term management of the weed. The vast areas infested in Australia and the low value of the land made it uneconomical for the large-scale application of herbicides in these situations. Similarly in India, the areas now covered by the weed are even more astronomical, with populations stretching from the Punjab in the north to Tamil Nadu in the south. Once again, wholesale use of chemicals is not a feasible option. The cheap and plentiful labour market in India, however, does suggest that organized manual control would be feasible, particularly in intensively cultivated land, although this presents a health risk in itself. However, it is in the fallows, wasteland and roadsides in urban situations where control is urgently needed in order to reduce the health hazards, but is rarely carried out. It is here, perhaps, that village communities, city councils and other organized groups should be encouraged to manage the weed, and chemical herbicides currently offer the best solution.

Of the many allelopathic plants considered for control, relatively few have serious potential, particularly in the problematic urban situations, although marigold is a highly traditional, readily marketed plant in India and could be used in such areas to provide not only control of parthenium weed but also a marketable product, in addition to its aesthetic value.

As discussed over 25 years ago (Chandras & Vartak, 1970), and still relevant today, an economic assessment of the weed status, particularly in India, is essential in order to determine with some precision, the nature and extent of the problem and to quantify losses due to parthenium weed. The study by Chippendale & Panetta (1994) is an excellent example of what can be achieved and how the information generated from such a socio-economic study can be used to stimulate policy makers and to help them reach meaningful decisions. In this case study, it was argued that the biological control programme was a relatively cheap option given the amount spent on alternative control measures and the losses incurred. Undoubtedly, these data were used to lobby for an extension of the programme. Unlike most other weeds, however, there is an added dimension to the parthenium weed problem, because of the potential impact on human populations in the infested areas and, thus, of trying to put a price on health.

The biological control programme is still active in Australia, 20 years on, so it may be opportune to assess the progress. Nine natural enemies (eight insect species and one fungal species) have been released in Queensland but, so far, no dramatic (short-term) returns have been forthcoming: an economist/accountant would conclude, therefore, that it has been a costly failure. Unlike some other weed biological control programmes there has been no magic bullet (e.g. *Opuntia* (Cactaceae), *Salvinia molesta* (Salvinaceae), *Chondrilla juncea* (Lactuceae) and *Ageratina riparia* (Eupatorieae)); no single agent which has solved the problem. Perhaps with such a prolific and aggressive weed this should come as no surprise. It is still considered, however, that the long-term solution will lie in releasing a guild of specific agents in order to hit as many of the plant organs as possible and thus gradually reduce weed vigour over time: but how long are donors, farmers, politicians and the affected public prepared to wait for tangible results? With the right combination of natural enemies and favourable or stable climatic patterns, the pieces in the biocontrol jigsaw may eventually fall into place. There can be no doubt that adverse climatic factors have prevented the released agents from achieving their full potential and that a longer period of adaptation than originally envisaged may be necessary. Certainly, there are indications that some of the agents may be performing better. The *Zygogramma* beetle in India, for example, is now causing significant defoliation of parthenium weed in the Bangalore region (author, personal observation), despite initial misgivings about the suitability of the local climate (Jayanth, 1987). Further introductions of natural enemies, perhaps even of fungi, if the quarantine hurdles can be overcome, may consolidate this situation. Whilst the mycoherbicide approach, using local pathogens, should still be explored in India, it is more than likely that parthenium weed is merely acting as a secondary host, and, therefore, as an inoculum source, for crop diseases. In addition, the problems of using such a product, if it ever reached the production stage, would be the same as for chemical herbicides. The plan of action adopted in Australia, as described recently by Briese & McLaren (1997), may serve as a suitable model for India, with the creation of a Parthenium Action Group comprising representatives of the farmers, local government and State Government Departments. The aims of which are to eradicate or contain the weed, where possible, to improve communications between researcher and farmer, to educate farmers in best management practices and to promote community awareness of the weed problem. Whilst biological control forms a major part of the strategy of the group, reduction of weed populations through additional control practices will be needed for successful management of the weed, to suppose otherwise would be naive and even heretical in the present IPM climate.

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REFERENCES

Adkins, S.W.; Sowerby, M.S. (1996) Allelopathic potential of the weed *Parthenium hysterophorus* L. in Australia. *Plant Protection Quarterly* **11**, 20–23.

Agarwal, C.; Anand, A. (1992) Ecological studies on allelopathic potential of *Parthenium hysterophorus* L. in relation to *Phaseolus aureus* L. and *Triticum aestivum* L. *In*: Tauro, P.; Narwal, S.S. (*eds*) Proceedings of the 1st National Symposium on Allelopathy in Agroecosystems, Hisar, India, February 1992. Hisar; Haryana Agricultural University, pp. 64–65.

Aggarwal, A.; Kohli, R.K. (1992) Screening of crops for seed germination against *Parthenium hysterophorus* L. leachates. *In*: Tauro, P.; Narwal, S.S. (*eds*) Proceedings of the 1st National Symposium on Allelopathy in Agroecosystems, Hisar, India, February 1992. Hisar; Haryana Agricultural University, pp. 66–68.

Ahmed, M.N.; Rao, P.R.; Mahender, M. (1988a) Experimental introduction of acute toxicity in buffalo calves by feeding *Parthenium hysterophorus* Linn. *Indian Journal of Animal Sciences* **58**, 731–734.

Ahmed, M.N.; Rao, P.R.; Mahender, M. (1988b) Hematological observations in experimental partheniosis in buffalo calves. *Indian Veterinary Journal* **65**, 972–974.

Ahmed, M.N.; Rao, P.R.; Mahender, M.; Moorthy, A.S. (1988c) A study on changes in blood chemistry in *Parthenium* toxicity in buffalo calves. *Cheirion* **17**, 57–60.

Aneja, A.K. (1991) Deadly weed *Parthenium hysterophorus* L. and its control - a review. *In*: Aery, N.C.; Chaudary, B.L. (*eds*) Botanical researches in India. Udaipur, India; Himanshu Publications, pp. 258-269.

Aneja, K.R.; Kaur, M; Sharma, A. (1994) Leaf-spot disease of *Parthenium hysterophorus* - a new disease record. *National Academy of Science Letters India* **17**, 179–180.

Anonymous (1976) Parthenium, a “new” weed in India. *PANS* **22**, 280–282.

Anonymous (1988) Parthenium weed and its control. Bulletin of the Queensland Rural Lands Protection Board, Brisbane, 4 pp.

Anonymous (1991) Parthenium weed rust. Queensland Department of Lands. *Information Bulletin* No. 1, May 1991, 2 pp.

Anonymous (1993) Report of the Fact Finding Committee Meeting on *Parthenium*. *Current Science* **65**, 902–903.

Anonymous (1995) New control agent against parthenium weed. *AQIS Bulletin* **6**, 11–12.

Anonymous (1996) Biological control of *Parthenium hysterophorus* L. Tamil Nadu Agricultural University, Coimbatore, India, unpublished report, 20 pp.

Ayala, J.R.; Cruz, A.M.; Miranda, Z. (1994) Effects of the aqueous extract of *Canavalia ensiformis, Bursera graveolens, Petiveria* *allicea* and *Parthenium hysterophorus* on sorghum germination. *Cuban Journal of Agricultural Sciences* **28**, 371–373.

Bhatt, B.P.; Chauhan, D.S.; Todaria, N.P. (1994) Effect of weed leachates on germination and radicle extension of some food crops. *Indian Journal of Plant Physiology* **37**, 177–179.

Briese, D.T.; McLaren, D.A. (1997) Community involvement in the distribution and evaluation of biological control agents: Landcare and similar groups in Australia. *Biocontrol News and Information* **18**, 39–49.

Bruzzese, E.; Hasan, S. (1983) A whole leaf clearing and staining technique for host specificity studies of rust fungi. *Plant Pathology* **32**, 335–338.

Chakravarthy, A.K.; Bhat, N.S. (1993). An 'elusive' leaf beetle from Mexico. *Current Science* **65**, 905–906.

Chandler, L.D.; Chandler, J.M. (1988) Comparative host suitability of bell pepper and selected weed species for *Liriomyza trifolii* (Burgess). *Southwestern Entomologist* **13**, 137–146.

Chandras, G.S.; Vartak, V.D. (1970) Symposium on problems caused by *Parthenium hysterophorus* in Maharashtra region, India. *PANS* **16**, 212–213.

Channappagoudar, B.B.; Panchal, Y.C.; Manjunath, S.; Koti, R.V. (1990) Studies on influence of parthenium on sorghum growth under irrigated conditions. *Farming Systems* **6**, 102–104.

Chippendale, J.F.; Panetta, F.D. (1994) The cost of parthenium weed to the Queensland cattle industry. *Plant Protection Quarterly* **9**, 73–76.

Cordero, M. (1983) *Parthenium hysterophorus* (escoba amarga), planta indeseable, reservorio natural de los virus X y Y de la papa. *Ciencia Tecnica en la Agricultura* **2**, 23–32. [in Spanish]

Dayama, D.P. (1986) Allelopathic potential of *Parthenium hysterophorus* Linn. on growth, nodulation and nitrogen content of *Leucaena leucocephala. Leucaena Research Reports* **7,** 36–37.

Deshpande, K. (1982) Biocontrol of *Parthenium hysterophorus* L. and *Xanthium strumarium* L. through phytopathogens. Annual Conference of Indian Society of Weed Science, 1982, Maharashtra, India, p. 48 (abstract).

Dhawan, S.R. (1994) Biocontrol of *Parthenium hysterophorus* L. - studies on seed germination. *Advances in Plant Sciences* **7**, 367–369.

Dhawan, S.R. (1995) Allelopathic potential of *Prosopis* for containing the spread of *Parthenium hysterophorus* Linn. *Advances in Plant Sciences* **8**, 289–292.

Dhawan, P.; Dhawan, S.R. (1995a) Allelochemic effect of *Parthenium hysterophorus* Linn. on the germination behaviour of some agricultural crops. *Flora and Fauna* **1**, 59–60.

Dhawan, S.R.; Dhawan, P. (1995b) Phyllosphere mycoflora of *Parthenium hysterophorus* L. *World Weeds* **2**, 203–210.

Dhawan, S.R.; Dhawan, P. (1995c) Biocontrol of congress grass: studies on seed germination. *World Weeds* **2**, 3–9.

Dhawan, S.R.; Dhawan, P. (1995d) Potential of leguminous plants in containing congress grass II: Effect of aqueous foliar extracts. *World Weeds* **2**, 77–81.

Dhawan, S.R.; Dhawan, P. (1995e) Effect of aqueous foliar extracts of some trees on germination and early seedling growth of *Parthenium hysterophorus* Linn. *World Weeds* **2**, 217–221.

Dhawan, S.R.; Gupta, S.K.; Dhawan, P. (1996) Potential of leguminous plants in containing congress grass I: Effect of aqueous foliar leachates. *Advances in Plant Sciences* **9**, 151–154.

Eaton, A.G. (1991) Parthenium rust testing. Press release, April 1991.

Evans, H.C. (1987a) Fungal pathogens of some subtropical and tropical weeds and the possibilities for biological control. *Biocontrol News and Information* **8**, 7–30.

Evans, H.C. (1987b) Life-cycle of *Puccinia abrupta* var *partheniicola*, a potential biological control agent of *Parthenium hysterophorus. Transactions of the British Mycological Society* **88**, 105–111.

Evans, H.C. (1995) Pathogen-weed relationships: the practice and problems of host range screening. *In*: Delfosse, E.S.; Scott, R.R. (*eds*) Proceedings of the 8th International Symposium on Biological Control of Weeds, Canterbury, New Zealand, February 1992. Melbourne, Australia; DSIR/CSIRO, pp. 539–551.

Fisher, A.A. (1996) Esoteric contact dermatitis. Part IV: devastating contact dermatitis in India produced by American parthenium weed (the scourge of India). *Cutis* **57**, 297–298.

Gray, P. (1995) Parthenium weed alert. *In*: Tanner, L.; Nolan, P. (*eds*) Proceedings of the 8th Biennial Noxious Weeds Conference, Goulborn, NSW, Australia. Orange, NSW; NSW Agriculture, pp. 90–92.

Griffiths, M.W.; McFadyen, R.E. (1993) Biology and host specificity of *Platphalonidia mystica* (Lep.: Cochylidae) introduced into Queensland to biologically control *Parthenium hysterophorus* (Asteraceae). *Entomophaga* **38**, 131–137.

Gupta, A. (1996) Allelopathic influence of *Parthenium hysterophorus* L. over *Amaranthus gangeticus. Flora and Fauna* **2**, 57–58.

Haseler, W.H. (1976) *Parthenium hysterophorus* L. in Australia. *PANS* **22**, 515–517.

Holm, L.G.; Plucknett, D.L.; Pancho, J.V.; Herberger, J.P. (1977) The world's worst weeds. Honolulu, Hawaii; University Press of Hawaii, 609 pp.

Jarvis, B.B.; Pena, N.B.; Rao, M.M.; Coumlaut, N.S.; Coumbut, T.F.; Mandava, N.B. (1985) Allelopathic agents from *Parthenium hysterophorus* and *Baccharis megapotamica. In*: The chemistry of allelopathy. Washington DC, USA; American Chemical Society, pp. 149–159.

Jayachandra (1971) *Parthenium* weed in Mysore State and its control. *Current Science* **40**, 568–569.

Jayakumar, R.; Kempuchetty, N.; Subramanian, S. (1989) Allelopathic effect of *Cassia sericea* on *Parthenium hysterophorus. Madras Agricultural Journal* **76**, 645–647.

Jayanth, K.P. (1987) Introduction and establishment of *Zygogramma bicolorata* on *Parthenium hysterophorus* at Banagalore, India. *Current Science* **56**, 310–311.

Jayanth, K.P. (1993) Ecological impact of insects introduced for biological control of weeds - conflicting interests. *Current Science* **65**, 903–905.

Jayanth, K.P.; Bali, G. (1992) Estimation of number of generations of the Mexican beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) by measurement of thermal units. *Journal of Entomological Research* **16**, 273–276.

Jayanth, K.P.; Bali, G. (1993) Diapause behaviour of *Zygogramma bicolorata* (Coleoptera: Chrysomelidae), a biological control agent for *Parthenium hysterophorus* (Asteraceae), in Bangalore, India. *Bulletin of Entomological Research* **83**, 383–388.

Jayanth, K.P; Bali, G. (1994a) Life table of the parthenium beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) in Bangalore, India. *Insect Science and its Application* **15**, 19–23.

Jayanth, K.P; Bali, G. (1994b) Biological control of *Parthenium hysterophorus* by the beetle *Zygogramma bicolorata* in India. *FAO Plant Protection Bulletin*, **42**, 207–213.

Jayanth, K.P.; Nagarkatti, S. (1987) Investigations on the host specificity and damage potential of *Zygogramma bicolorata* Pallister [Coleoptera: Chrysomelidae] introduced into India for the biological control of *Parthenium hysterophorus. Entomophaga* **12**, 141–145.

Jayanth, K.P; Visalakshy, P.N.G.; (1994) Dispersal of the parthenium beetle *Zygogramma bicolorata* (Chrysomelidae) in India. *Biocontrol Science and Technology* **4**, 363–365.

Jayanth, K.P; Visalakshy, P.N.G. (1996) Succession of vegetation after suppression of parthenium weed by *Zygogramma bicolorata* in Bangalore, India. *Biological Agriculture and Horticulture* **12**, 303–309.

Jayanth, K.P.; Mohandas S.; Asokan, R.; Visalakshy, P.N.G. (1993) Parthenium pollen induced feeding by *Zygogramma bicolorata* (Coleoptera: Chrysomelidae) on sunflower (*Helianthus annuus*) (Compositae). *Bulletin of Entomological Research* **83**, 595–598.

Jeyarajan, R.; Doraiswamy, S.; Sivaprakasam, K.; Venkata Rao, A.; Ramakrishnan, L. (1988) Influence of whitefly transmitted viruses in Tamil Nadu. *Madras Agricultural Journal* **75**, 212–213.

Joel, D.M.; Liston, A. (1986) New adventive weeds in Israel. *Israel Journal of Botany* **35**, 215–223.

Joshi, S. (1991a) Interference effects of *Cassia uniflora* Mill. on *Parthenium hysterophorus* L. *Plant and Soil* **132**, 213–218.

Joshi, S. (1991b) Biological control of *Parthenium hysterophorus* L. (Asteraceae) by *Cassia uniflora* Mill (Leguminosae), in Bangalore, India. *Tropical Pest Management* **37**, 182–184.

Joshi, S. (1991c) Biocontrol of *Parthenium hysterophorus* L. *Crop Protection* **10**, 429–431.

Kadhane, D.L.; Jangde, C.R.; Sudekar, R.D.; Joshirao, M.K. (1992) Parthenium toxicity in buffalo calves. *Journal of Soils and Crops* **2**, 69–71.

*Kanchan, S.D. (1975) Growth inhibitors from *Parthenium hysterophorus* Linn. *Current Science* **44**, 358–359.

Kanchan, S.D.; Jayachandra (1979) Allelopathic effects of *Parthenium hysterophorus* L. Exudation of inhibitors through roots. *Plant and Soil* **53**, 27–35.

Kanchan, S.D.; Jayachandra (1980a) Allelopathic effects of *Parthenium hysterophorus* L. II. Leaching of inhibitors from aerial vegetative parts. *Plant and Soil* **55**, 61–66.

Kanchan, S.; Jayachandra (1980b) Pollen allelopathy - a new phenomenon. *New Phytologist* **84**, 739–746.

Kanchan, S; Jayachandra (1981) Effects of *Parthenium hysterophorus* on nitrogen-fixing and nitrifying bacteria. *Canadian Journal of Botany* **59**, 199–202.

* There is considerable confusion over the correct citation of this author; on occasions only one initial is used, on others two, and may also be quoted as Sukhada, D.K.

Kayanth, K.P; Visalakshy, P.N.G.; Ghosh, S.K.; Chaudhary, M. (1996) An indigenous parasitoid on the parthenium beetle *Zygogramma bicolorata*. *Insect Environment* **2**, 67–68.

Kishun, R.; Chand, R. (1988) New collateral hosts for *Pseudomonas solanacearum*. *Indian Journal of Mycology and Plant Pathology* **17**, 237.

Kohli, R.K.; Batish, D.R. (1994) Exhibition of allelopathy by *Parthenium hysterophorus* L. in agroecosystems. *Tropical Ecology* **35**, 295–307.

Kohli, R.K.; Rani, D. (1992) Identification and bioefficacy of soil chemics of *Parthenium*. *In*: Tauro, P.; Narwal, S.S. (*eds*) Proceedings of the 1st National Symposium on Allelopathy in Agroecosystems, Hisar, India, February 1992. Hisar; Haryana Agricultural University, pp. 196–198.

Kohli, R.K.; Kumari, A.; Saxena, D.B. (1985) Auto- and teletoxicity of *Parthenium hysterophorus* L. *Acta Universitatis Agriculturae Brno* [Czechoslovakia] **33**, 253–263.

Kohli, R.K.; Chaudhry, P; Kumari, A. (1988) Impact of *Eucalyptus* on *Parthenium* - a weed. *Indian Journal of Range Management* **9**, 63–67.

Kumar, A.R.V. (1993) What is in a name: the case for the Mexican beetle. *Current Science* **65**, 906–907.

Kumar, S.; Greval, R.S. (1993) Parthenium dermatitis: an unsuspected allergy. *Indian Journal of Medical Science* **47**, 280–282.

Kumari, A.; Kohli, R.K.; Saxena, D.B. (1985) Allelopathic effects of *Parthenium hysterophorus* leachates and extracts on *Brassica campestris* L. *Annals of Biology* **1**, 189–196.

Lamb, C.; Collet, F. (1976) Weeds in Australia. Melbourne, Australia; Inkata Press, 332 pp.

Lindquist, J.C. (1982) Royas de la Republica Argentina. Buenos Aires, Argentina; Instituto Nacional de Tecnologia Agropecuaria, p. 452. [in Spanish]

Lonkar, A.; Mitchell, J.C.; Calnan, C.B. (1974) Contact dermatitis from *Parthenium hysterophorus. Transactions of the St John's Dermatological Society* **60**, 43–53.

Madhu, M.; Nanjappa, H.V.; Ramachandrappa, B.K. (1995) Allelopathic effect of weeds on crops. *Mysore Journal of Agricultural Sciences* **29**, 106–112.

Mahadevappa, M.; Ramaiah, H. (1988) Pattern of replacement of *Parthenium hysterophorus* plants by *Cassia sericea* in waste lands. *Indian Journal of Weed Science* **20**, 83–85.

McClay, A.S. (1985) Biocontrol agents for *Parthenium hysterophorus* from Mexico. *In*: Delfosse, E.S. (*ed*) Proceedings of the 6th International Symposium on Biological Control of Weeds, Vancouver, Canada, August 1984. Ottawa, Canada; Agriculture Canada, pp. 771–778.

McClay, A.S. (1987) Observations on the biology and host specificity of *Epiblema strenuana* [Lepidoptera, Tortricidae] a potential control agent for *Parthenium hysterophorus* [Compositae]. *Entomophaga* **32**, 23–34.

McClay, A.S.; Palmer, W.A.; Bennett, F.D.; Pullen, K.R. (1995) Phytophagous arthropods associated with *Parthenium hysterophorus* (Asteraceae) in North America. *Environmental Entomology* **24**, 796–809.

McFadyen, R.E (1985) The biological control programme against *Parthenium hysterophorus* in Queensland. *In*: Delfosse, E.S. (*ed*) Proceedings of the 6th International Symposium on Biological Control of Weeds, Vancouver, Canada, August 1984. Ottawa, Canada; Agriculture Canada, pp. 789–796.

McFadyen, R.E. (1992) Biological control against parthenium weed in Australia. *Crop Protection* **11**, 400–407.

McFadyen, R.E. (1995) Parthenium weed and human health in Queensland. *Australian Family Physician* **24**, 1455–1459.

Medhin, B.G. (1992) *Parthenium hysterophorus*, a new weed problem in Ethiopia. *FAO Plant Protection Bulletin* **40**, 49.

Mehta, U.C.; Mahato, K.C.; Singh, J.N. (1995) Effects of *Parthenium* extracts on pollen tetrad and pollen sterility in radish (*Raphanus sativus* L.). *Cruciferae Newsletter* **17**, 48–49.

Mew, D.; Balza, F.; Towers, G.H.N.; Levy, J.G. (1982) Anti-tumour effects of the sesquiterpene lactone parthenin. *Planta Medica* **45**, 23–27.

Mishra, K.K. (1991) *Parthenium hysterophorus* Linn. - a new record for Nepal. *Journal of Bombay Natural History Society* **88**, 466–467.

Mishra, J.; Pandey, A.K.; Rajak, R.C.; Hasija, S.K. (1994) Microbial management of *Parthenium* - I. Host specificity of *Sclerotium rolfsii* Sacc. *National Academy Science Letters, India* **17**, 169–173.

Mishra, J.; Pandey, A.K.; Hasija, S.K. (1995) Evaluation of *Sclerotium rolfsii* Sacc. as mycoherbicide for *Parthenium*: factors affecting viability and virulence. *Indian Phytopathology* **48**, 476–479.

Naithani, H.B. (1987) *Parthenium hysterophorus* - a pernicious weed in Arunachal Pradesh and Nagaland. *Indian Forester* **113**, 709–710.

Nandakishore, T.; Pasricha, J.S. (1994) Patterns of cross-infectivity of 4 Compositae plants, *Parthenium hysterophorus*, *Xanthium strumarium*, *Helianthus annuus* and *Chrysanthemum coronarium* in Indian patients. *Contact Dermatitis* **30**, 162–167.

Narasimhan, T.R.; Ananth, M.; Narayana Swamy, M.; Rajendra Babu, M.; Mangala, A.; Subba Rao, P.V. (1977) Toxicity of *Parthenium hysterophorus* L. *Current Science* **46**, 15–16.

Navie, S.C.; McFadyen, R.E.; Panetta, F.D.; Adkins, S.W. (1996) The biology of Australian weeds 27. *Parthenium hysterophorus* L. *Plant Protection Quarterly* **11**, 76–88.

Ovies, J.; Larrinaga, L. (1988) Transmisión de *Xanthomonas campestris* pv. *phaseoli* mediante un hospedante silvestre. *Ciencias y Técnica en la Agricultura* **11**, 23–30. [in Spanish]

Pandey, A.K.; Hasija, S.K.; Rajak, R.C. (1990) *Myrothecium roridum* Tode ex Fr. a new pathogen of *Parthenium hysterophorus* L. with biocontrol potential. *National Academy Science Letters, India* **13**, 369–370.

Pandey, A.K.; Luka, R.S.; Hasija, S.K.; Rajak, R.C. (1991) Pathogenicity of some fungi to *Parthenium*, an obnoxious weed in Madhya Pradesh. *Journal of Biological Control* **5**, 113–115.

Pandey, A.K.; Luka, B.M.; Hasija, S.K.; Rajak, R.C. (1992a) Evaluation of *Myrothecium roridum* for the management of *Parthenium hysterophorus*: inoculum rate studies. *Proceedings of the National Academy of Science, India* **62**, 449–453.

Pandey, A.K.; Farkya, S.; Rajak, R.C. (1992b) A preliminary evaluation of *Fusarium* spp. for the biological control of *Parthenium*. *Journal of the Indian Botanical Society* **71**, 103–105.

Pandey, A.K.; Mishra, J.; Rajak, R.C.; Hasija, S.K. (1992c) Possibility of managing *Parthenium hysterophorus* L. through *Sclerotium rolfsii* Sacc. *National Academy Science Letters, India* **15**, 111–112.

Parker, A. (1989) Biological control of Parthenium weed using two rust fungi. *In*: Delfosse, E.S. (*ed*) Proceedings of the 7th International Symposium on Biological Control of Weeds, Rome, Italy, March 1988. Rome / Melbourne; Ministero d' Agricoltura e delle Foreste / CSIRO, pp. 27–36.

Parker, A.; Holden, A.N.G.; Tomley, A.J. (1994) Host specificity testing and assessment of the pathogenicity of the rust, *Puccinia abrupta* var. *partheniicola*, as a biological control agent of parthenium weed (*Parthenium hysterophorus*). *Plant Pathology* **43**, 1–16.

Parmelee, J.A. (1967) The autoecious species of *Puccinia* on Heliantheae in North America. *Canadian Journal of Botany* **45**, 2267–2328.

Parsons, W.T.; Cuthbertson, E.G. (1992) Noxious weeds in Australia. Melbourne, Australia; Inkata Press, 692 pp.

Patil, T.M.; Hedge, B.A. (1988) Isolation and purification of a sesquiterpene lactone from the leaves of *Parthenium hysterophorus* L. - its allelopathic and cytotoxic effects. *Current Science* **57**, 1178–1181.

Peng, C.I.; Hu, L.A.; Kao, M.T. (1988) Unwelcome naturalisation of *Parthenium hysterophorus* (Asteraceae) in Taiwan. *Journal of Taiwan Museum* **41**, 95–101.

Rajak, R.C.; Farakya, S.; Hasija, S.K.; Pandey, A.K. (1990) Fungi associated with congress weed (*Parthenium hysterophorus* L.). *Proceedings of the National Academy of Science, India* **60**, 165–168.

Rajan, L. (1973) Growth inhibitor(s) from *Parthenium hysterophorus*. *Current Science* **42**, 729–730.

Rajkumar, E.D.M.; Kumar, N.V.N.; Haran, N.V.H.; Morthy, N.V.A.; Ram, N.V.S. (1988) Antagonistic effect of *Parthenium hysterophorus* on succinate dehydrogenase of sheep liver. *Journal of Environmental Biology* **9**, 231–237.

Rajulu, G.S.; Gowri, N.; Perumal, S.S. (1976) Biological control for the pernicious weed *Parthenium hysterophorus* Linn. *Current Science* **45**, 624–625.

Reddy, H.R.; Ravi, K.S. (1991) A leaf curl disease of *Cassia uniflora*. *Current Research University of Agricultural Sciences, Bangalore* **20**, 16–17.

Remadevi, O.K.; Sivaramakrishnan, V.R. (1996) Biomass utilisation by *Diacrisia obliqua* Walker feeding on *Tectona grandis* Linn. F. and *Parthenium hysterophorus* L. *In*: Nair, K.S.S., Sharma, J.K.; Sharma, R.V. (*eds*) Impact of diseases and insect pests in tropical forests. Proceedings of the IUFRO Symposium, Peechi, Kerala, India, November 1993. Peechi; Kerala Forest Research Institute, pp. 441–447.

Rice, E.L. (1974) Allelopathy. New York; Academic Press.

Robertson, L.N.; Kettle, B.A. (1994) Biology of *Pseudoheteronyx* sp. (Coleoptera: Scarabaeidae) on the central highlands in Queensland. *Journal of the Australian Entomological Society* **33**, 181–184.

Sastry, K.S. (1984) Strains of tomato leaf curl virus and its perpetuation under field conditions. *Journal of Turkish Phytopathology* **13**, 87–90.

Siddaramaiah, A.L.; Narendrappa, T.; Shivalingaradhya, M.V. (1984) A new collar rot disease of *Parthenium* from India. *Plant Pathology Newsletter* **2,** 11.

Singh, N.P (1983) Potential biological control of *Parthenium hysterophorus* L. *Current Science* **52**, 644.

Singh, S.P.; Sangeeta (1991) Allelopathic potential of *Parthenium hysterophorus* L. *Journal of Agronomy and Crop Science* **167**, 201–206.

Singh, K.; Shaki, A.K.; Pal, S.; Bahyan, S.S. (1992) Phyto-allelopathic influence of *Parthenium hysterophorus* L. *In*: Tauro, P.; Narwal, S.S. (*eds*) Proceedings of the 1st National Symposium on Allelopathy in Agroecosystems, Hisar, India, February 1992. Hisar; Haryana Agricultural University, pp. 61–63.

Singhal, B.K.; Chakraborti, S.; Thippeswamy, T.; Girdhar, K.; Datta, R.K. (1996) *Parthenium hysterophorus* allelopathy in mulberry [*Morus*]. *Alleopathy Journal* **3**, 251–254.

Sriramarao, P.; Rao, P.V. (1993) Allergenic cross-infectivity between parthenium and ragweed pollen allergens. *International Archives for Allergy Immunology* **100**, 74–85.

Sriramarao, P.; Nagpal, S.; Rao, B.S.; Prakash, O.; Rao, P.V. (1991) Immediate hypersensitivity to *Parthenium hysterophorus.* II. Clinical studies on the prevalence of Parthenium rhinitis. *Clinical Experimental Allergy* **21**, 55–62.

Srivastava, J.N.; Shukla, J.P.; Srivastava, R.C. (1985) Effect of *Parthenium hysterophorus* Linn. extract on the seed germination and seedling growth of barley, pea and wheat. *Acta Botanica Indica* **13**, 194–197.

Suresh, P.V.; Gupta, D.; Behera, D.; Jindal, S.K. (1994) Bronchial provocation with *Parthenium* pollen extract in bronchial asthma. *Indian Journal of Chest Diseases and Allied Sciences* **36**, 104.

Swaminathan, C.; Rai, R.S.; Suresh, K.K. (1990) Allelopathic effects of *Parthenium hysterophorus* on germination and growth of a few multi-purpose trees and arable crops. *International Tree Crops Journal* **6**, 143–150.

Tanner, M.S.; Mattocks, A.R. (1987) Hypothesis: plant and fungal biocides, copper and Indian childhood liver disease. *Annals of Tropical Paediatrics* **7**, 264–269.

Theagarajan, K.S.; Prabhu, V.V.; Sivaramakrishnan, V.R. (1995) A note on control of Parthenium weed. *Indian Forester* **121**, 855–856.

Tomley, A.J.; Evans, H.C. (1995) Some problem weeds in tropical and sub-tropical Australia and prospects for biological control using fungal pathogens. *In*: Delfosse, E.S.; Scott, R.R. (*eds*) Proceedings of the 8th International Symposium on Biological Control of Weeds, Canterbury, New Zealand, February 1992. Melbourne, Australia; DSIR/CSIRO, pp. 477–482.

Towers, G.H.N.; Subba Rao, P.V. (1992) Impact of the pan-tropical weed, *Parthenium hysterophorus* L. on human affairs. *In*: Richardson, R.G. (*ed*) Proceedings of the 1st International Weed Control Congress, Melbourne, Australia. Melbourne; Weed Science Society of Victoria, pp. 134–138.

Tudor, G.D.; Ford, A.L.; Armstrong, T.R.; Bromage, E.K. (1982) Taints in meat from sheep grazing *Parthenium hysterophorus. Australian Journal of Experimental Agriculture and Animal Husbandry* **22**, 43–46.

Valliappan, K.; Towers, G.H.N. (1989) Allelopathic effect of root exudates from the obnoxious weed *Parthenium hysterophorus. Indian Journal of Weed Science* **20**, 18–22.

Wapshere, A.J. (1974) A strategy for evaluating the safety of organisms for biological weed control. *Annals of Applied Biology* **77**, 201–211.

Wild, C.H.; McFayden R.E.; Tomley A.J.; Willson, B.W. (1992) The biology and host specificity of the stem-boring weevil *Listronotus setosipennis* (Col.: Curculionidae) a potential biocontrol agent for *Parthenium hysterophorus* (Asteraceae). *Entomophaga* **37**, 591–598.