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Review [Revisión]

Parthenium hysterophorus L: DISTRIBUTION, IMPACT, AND POSSIBLE MITIGATION MEASURES IN ETHIOPIA

[Parthenium hysterophorus L: DISTRIBUCION, IMPACTO Y POSIBLES MEDIDAS DE MITIGACIÓN EN ETIOPÍA]

Jemal Abdulkerim-Ute[1]* and Behailu Legesse[2]

[1] Madda Walabu University, Department of Plant Science, Bale Robe, Ethiopia. email: jemiye2003@gmail.com; jemal.abdulkerim@mwu.edu.et
[2]Madda Walabu University, Department of Rural Development and Agricultural Extension, Bale Robe, Ethiopia
**Corresponding author*

SUMMARY

The issue of *Parthenium hysterophorus* weed is very important in Ethiopian agriculture. It is spreading rapidly in the highland and lowland areas since its introduction. Currently, most of the regions are invaded by the weed, even the capital city Addis Ababa. There are several factors favoring its rapid distribution in the environment. Its ability to adapt wide range of climatic condition, its allelopathic effect, short life cycle, prolific nature and having large seed bank in the soil environment are among the principal factors. Parthenium has the capacity to decrease the composition and diversity of plant species and it has adverse effects on crop yield, as well as animal and human health. Despite its negative effects, the weed has potential uses such as preparing compost, botanical control of insect pests and bio-herbicide. On the other hand, mechanical control, chemical herbicides, phytochemicals, composting and biological control has been pointed out as an effective management ways and eradication of this weed. There is a need for ecologically balanced management of *Parthenium* weed aiming to enhance the quality of life for farmers and rural communities, especially in pastoral and agro-pastoral areas of Ethiopia. Hence, the objective of this review was to explore the distribution, harmful and beneficial effects as well as the possible controlling practices against *P. hysterophorus.*

Key words: *Parthenium hysterophorus*; distribution; impact; beneficial effects; allelopathy.

RESUMEN

El problema de la maleza *Parthenium hysterophorus* es relevante para la agricultura de Etiopia. Desde su introducción se está diseminando rápidamente tanto en las zonas elevadas como bajas. Actualmente, la mayoría de las regiones se encuentra invadida por la maleza, incluso la capital Addis Ababa. Existen muchos factores que favorecen su rápida distibución en el ambiente. Su habilidad para adaptarse a un amplio rango de condiciones climáticas, su efecto alelopático, ciclo de vida corto y su alta prolificidad que resulta en grandes bancos de semilla son los principales factores entre otros. Parthenium tiene la capacidad de reducir la composición y diversidad de las especies y afecta negativamente la producción agrícola así como la salud animal y humana. A pesar de sus efectos negativos, la maleza tiene usos potenciales tales como su empleo en la preparación de composta, control de plagas y como bio-herbicida. Por otro lado, el control mecánico, el empleo de herbicidas, fitoquímicos, compostaje y el control biológico han sido propuestos como métodos de manejo efectivo o para su erradicación. Se requiere de un manejo ecológico equilibrado de esta maleza con el objetivo de mejorar la calidad de vida de los productores y comunidades rurales, especialmente en las regiones agro-silvopastorales de Etiopia. Por lo tanto, el objetivo de la revisión fue explorar la distribución, efectos positivos y negativos, así como las posibles prácticas para el control de *P. hysterophorus.*

Palabras clave: *Parthenium hysterophorus;* distribución; impacto; efectos benéficos; alelopatía.

INTRODUCTION

Parthenium weed is an annual herb in the family Asteraceae which is characterized by deep tap root, pale green leaves and an erect stem that becomes woody gradually. At maturity, the plant develops several branches in its top half and may finally reach a height of 1.5-2 meters (EPPO, 2014). It is originated in northern Mexico and southern USA, and spreading in more than 20 countries of Africa, Asia and Oceania (Dhileepan and Strathie, 2009; EPPO, 2014).

Parthenium was probably introduced to Ethiopia through army vehicle during 1976 Ethio-Somalian war or along with contaminated grain in the course of food aid (Tamado and Milberg, 2000; Sushil kumar and Varshney JG, 2010). However, Wise *et al.* (2007) reported Parthenium was first recorded in Ethiopia at the Haramaya University campus in 1968. Since its introduction the weed has rapidly spread throughout agricultural lands, forests, orchards, poorly managed arable crop lands and rangelands in Ethiopia (Tamado and Milberg, 2000; Tefera, 2002).

In the presence of Parthenium the growth and development of crops can be suppressed, and if not controlled on time, it will occupy the land alone. Due to its Aggressive coverage, Bale zone farmers call it 'Anamalee,' in Afaan Oromo- meaning 'Only me' (Personal Communications). Ayele *et al.* (2014) reported species richness and evenness indices of both the above ground vegetation and the soil seed bank significantly decreased at the high level of Parthenium weed infestation and that the decline in species heterogeneity could be due to the strong allelopathic effect of parthenium and/or competition for common resources and thus, suppress the performance of the neighboring plant species. Similarly, Kumari *et al.* (2014) reported that Parthenium weed has the capacity to overwhelm the surrounding weed species and it could absolutely dominate the area inhabits and finally leads to loss of bio diversity. According to O'Donneli and Adkins (2005) parthenium affects agricultural and natural ecosystem production and biodiversity, and on human and animal health. Mirza *et al.* (2013) also said the damage of this weed does not end up with direct competition but also the reduction of the quantity and quality of a crop produced through allelopathic effect (Figures 1 and 2).

The report of case study conducted in South Africa revealed that if parthenium weed left uncontrolled and allowed to spread, returns to small-scale farmers would decline between 26 and 41%, while commercial farmer's yearly total economic returns would reduce between US$38, 818 and US$60, 957 (Wise *et al.*, 2007).

Even though, *P. hysterophurus* is among the top five highly targeted weed in the weed management program of the Research Institutes and Ministry of Rural Development and Agriculture of Ethiopia (G/selase and Getu, 2009) some areas are still left untreated. Ayele *et al*., (2014) reported that there have been no specific studies on the impact of parthenium weed on the diversity and composition of the standing vegetation and the soil seed bank of rangelands in southeast Ethiopia. Similarly, despite rapid spread and the presence of dense colonies of *Parthenium hysterophorus*, very limited initiative has been taken to investigate the impacts of this dangerous weed and still no visible large scale mapping and quantification of its distribution accomplished in south eastern Ethiopia, especially in Bale Zone. There are also farmers and agricultural experts even who do not know its impact on the eco-system, its way of distribution, and controlling methods. Therefore, the objective of this review was to explore the distribution, harmful and beneficial effects as well as the possible controlling practices against *P. hysterophorus.*

Ecology and causes of rapid distribution of Parthenium weed

Parthenium weed is counted as one of the most serious invasive alien plant on the planet earth, because of its potential for rapid distribution, its impact on ecosystem and socio- economy of the people (Asad and Steve, 2011). So far it was not considered a weed of orchards and forests but now it has spread rapidly into these areas (Kumar, 2012); which propagates itself largely in forest due to the absence of weeding practices in such environments.

The invasion of *parthenium* weed was reported in forest and grazing lands with little or no growth of any other species which results threatening of local biodiversity (Kumar, 2012). Parthenium weed has much more potential to invade bare lands like disturbed road sides and overgrazed pastures than dense pasture (Ayana *et al*., 2011); it also grows under grass land, and crop field (Netsere and Mendesil, 2011).

It has already become invasive in South Africa and Ethiopia, and appears to be extensively spreading in Uganda and Kenya. Parthenium weed has invaded more than 2 million ha of grazing and crop land, thus becoming a risk for the biodiversity, agriculture and human health in Ethiopia (Asad and Steve, 2011). Based on the estimation of CLIMEX model, south-east and south-west part of Dire Dawa (where *P. hysterophorus* was first recorded in Ethiopia) is to be most Eco climatically suitable area for *Parthenium hysterophorus*. This probably enhanced the

distribution of *Parthenium hysterophorus* widely after its introduction in Ethiopia. Rate and extent of spread of this weed since its introduction has been more noticeable in Ethiopia and Swaziland than Kenya, South Africa and Zimbabwe although environmental conditions are also suitable in the latter countries. Higher distribution in Ethiopia and Swaziland could be due to higher levels of disturbance (e.g. overgrazing) and particular land use practices (Mc Connachie *et al.*, 2011).

Figure 1. Range land infestation by Parthenium weed at Ginnir district, Bale Zone (Photo by Jemal A.)

Figure 2: Parthenium infestation near forest land at Madda walabu district, Bale Zone. (Photo by Jemal A.)

According to Rezene *et al*. (unpublished) *Parthenium hysterophorus* is spreading rapidly in various rangeland areas and farm lands of Gambella, Oromia, Afar, Amhara and Somali, national regional states which affecting crop production severely. Hadas and Taye (2015) reported its distribution in to Tigray region particularly,Waja, Alamta town, Bala, kukufto, Zata, Weyrawiha, Bedenoleka, Mohoni town, Maichew town, Kisad Gudo, Adishu, Adigura and Adigudom). It is found in all the Districts but more prominent in Alamata and Raya Azebo. According to the study conducted by Taye (2007) extensive infestation in the central farmlands of east Shewa, Dukem, Bishoftu, Modjo and Koka areas has been prevailed. Gebrehiwot and Berhanu (2015) reported that there has been an urgent need towards the management of parthenium weed in Arba Minch, before it further spread to Nech Sar National Park, which is a home of plants' diversity. Zuberi *et al*. (2014) informed that P. *hysterophorus* is spreading rapidly in the highlands of Ethiopia.

The distribution and spread of parthenium showed that it was not only restricted to the infested Districts but also spread to non-infested Districts like Arero, Bore, Dama and Uraga Districts of Borana and Guji Zones. It is found in Abaya occasionally, present in Bule Hora, abundant in Dugda Dawa, very abundant in Yabello, present in Teltele, frequent in Dire on roadsides, present in Miyo and Moyale, very abundant in Liben, present in Wadera, Adola and Shakiso Districts (Berhanu *et al*., 2015). Parthenium is widely spread in the range lands and in the cultivable fields of East Showa Zone of Boset district (Belachew and Tessema, 2015).

Causes of rapid distribution

The domination and rapid spread of *P. hysterophorus* in grazing lands with gradual reduction of native plant species could be due to its high invasive capacity, allelopathic properties, short life cycle and prolific character (Dalip *et al*., 2013**).** The species prefers neutral to alkaline pH soils, but tolerates a wide variety of soil types. *P. hysterophorus* is best suited to areas with an annual summer rainfall greater than 500 mm (Chamberlain and Gittens, 2004). Seeds of parthenium can germinate during any season of the year if the moisture is available. It can keep its viability for a long period of time and can grow under very harsh environmental condition (Williams and Groves, 1980) and at any climatic condition and environment (Netsere and Mendesil, 2011). Tamado *et al.,* (2002) has pointed out that there are no observable climatic conditions that may limit the germination of *Parthenium hysterophorus* in Ethiopia, with exception of high moisture requirement during germination. Such that the only major factor that can limit its germination could be moisture stress during the dry season. However, Ayana *et al*. (2011) concluded that Parthenium weed has the ability to utilize the opportunity of drought prone period in the area to use the chance where the indigenous plants deteriorate and leave much bare ground cover.

Parthenium produced numerous seeds, with reproductive capacity (Lorraine and Lin, 2015), rapid

maturity, large quantities of seed production (up to 25,000), easily transported by vehicles, machinery, animals, fodder, pasture seed, stock feed and water. As parthenium weed does not reproduce vegetatively from plant parts, the only method of reproduction and spread is by seed. Large colonies along waterways and drainage floodplains indicate its movement in sheet water. In addition, most long-distance dispersal of seed is by vehicles and farm machinery, as evidenced by the major spread of parthenium along roads. A period of drought followed by rain provides suitable environmental conditions for spread. Drought reduces pasture cover (competition) and increased movement of stock and stock fodder also aids the spread of seed. In particular, flooding after drought is advantageous to the weed, as flood is a dispersal mechanism for parthenium seed. However, seed spread by wind is limited (Agriculture and Resource Management Council of Australia and New Zealand, Australian and New Zealand Environment and Conservation Council and Forestry Ministers, 2001). *Parthenium hysterophorus* is not edible for animals (Hailu, 2010) and this could also be another opportunity for its distribution. Hina and Tahira (2009) suggested that in addition to its capability to withstand wide climatic ranges the weed is germinates and grow in all seasons. The seeds of *Parthenium* germinate in the hottest month of June (mean maximum 38.7ºC) and flourish by producing flowers, fruits and shedding seeds in the coldest months of December and January, when the mean minimum temperature is 3.4 and 2.6 °C respectively.

Impact of Parthenium on biodiversity

Globally, several studies revealed the aggressiveness of parthenium in the ecosystem. The report of Dalip *et al*. (2013**)** from Mehari Sub-Watershed of Rajouri Forest Range, India, indicated that Parthenium weed occupy new surroundings and often substitute the native plant species, resulting in a serious damage to biodiversity. A study by Ayana *et al*. (2011) in Awash National Park (Ethiopia) showed that Parthenium weed, within a few years from its introduction into Awash National Park, caused a decline (average 69%) in stand density of herbaceous species. Similarly, Asresie (2008) pointed out that an increase in the level of parthenium infestation causing rapid decline in the population and diversity of species in the ecosystem.

Impact of Parthenium on crop production

The impact of parthenium on the yield losses of various crops and orchards has been addressed in the report of earlier works. Crop losses are caused mainly due to allelopathic effects and its ability to compete for common resources like nutrients and moisture and its competitive nature is relatively very much higher than expected from a similar crop weed. Another mechanism by which parthenium affect crop productivity is through its ability to cover crops in pollen, which prevents seed set with resulting losses in yields of up to 40% (Wise *et al.,* 2007). *Parthenium* weed can infest the land where cereals, vegetables and horticultural crops found and reduce agricultural productivity due to its allelopathic effect (Mulatu *et al.,* 2009). The decline in yield due to its highly competitive ability was also reported by Netsere and Mendesil (2011). Tamado *et al.* (2002) reported that if *P. hysterophorus* is not weeded throughout the season the yield of sorghum bicolor can be reduced in the range of 40% and 90% in Ethiopia, this percentage was closer to the report of Wise *et al.* (2007), which was range from 45-80%. According to Nganthoi *et al*. (2014) there was a visible impact on the growth parameters, yield and yield components of *Zea mays* by Parthenium. Accordingly, at high ratio (20:1) population of parthenium the plant height, dry biomass, corn weight, corn length and grain weight per corn were reduced to 21.1%, 42.3%, 50.9%, 51.2%, and 52.7% respectively as compared to control. Furthermore, the finding indicate Parthenium in the form of extract or residue or growing weed can affect the germination and growth by reducing radicle and plumule length of *Zea mays.* Tefera (2002) also reported that 10% leaf aqueous extract of *Parthenium hysterophorus* resulted in total failure of seed germination in *Eragostis tef*. Similarly, Demissie *et al.* (2013) found the presence of allelopathic effect in *Parthenium* extracts which could affect the seed germination and elongation of Onion and Bean. Dangwal *et al.* (2010) investigated that while primary major essential nutrients (NPK fertilizer) supplied, but in the absence of herbicide application and mechanical weeding, parthenium weed along with other weeds were reduced the yield of wheat by 25.35%. Besides reducing the yield they also reduce the quality of germplasm of wheat crop. Raj and Jha (2016) disclosed that higher concentrations of leaf extract have irregularly affected the growth of *Phaseolus mungo* than lower concentrations.

Impact of Parthenium on animal production and human health

Toxic substances found in parthenium are lethal to human beings and animals (Singh *et al.,* 2002). It is considered to be a cause of allergic respiratory problems, contact dermatitis, mutagenicity in human and livestock. In addition, by reducing the species bio diversity it affect the productivity of grazing land and hence reduce feed supply for animals. It releases chemicals that inhibit the germination and growth of pasture grasses and other plants (Dalip *et al*., 2013**)**. If Parthenium is eaten by animals, the meat gets polluted due to its toxicity problem and these result in

direct economic losses. Thus, domestic animals should avoid eating it (Wise *et al.*, 2007).

When human beings come in contact with this weed, it may cause allergy, dermatitis, eczema, black spots and blisters around eyes, burning rings and blisters over skin, redness of skin and asthma (Handa *et al.*, 2001). Parthenium is spreading at alarming rate, threatening agricultural ecosystem, biodiversity, human and animal health in Ethiopia. The response of the 64 interviewed farmers in Ethiopia showed that all of them have health problems in different nuances. Most frequently they responded to parthenium contact with light allergic symptoms like hay fever or skin prickle on arms and hands. Some farmers had worse health problems: cracks on hand balms, fever, prickle on the whole body, skin irritations, and asthma. In addition to parthenin high concentrations of phenolic acids which might also contribute to health problems (Ulrichs *et al.*, 2007). Studies in Jijiga (Ethiopia) indicated that *Parthenium* causes asthma, bronchitis, dermatitis, and high fever in human (Shashie, 2007).

Potential beneficial uses of *Parthenium hysterophorus*

Parthenium compost helps in moisture conservation which is utilized for better root penetration and crop growth. This enhancement attributed to the higher water holding capacity of the soil due to the influence of organic waste application. The moisture in soil due to application of *Parthenium* compost can be 14.5 and 16.5% at 0-15 and 15-30 cm. depths as compared to 10.7 and 11.6% at 0-15 and 15-30 cm. depths of soil due to application of NPK alone. It was also found that if *Parthenium* compost was prepared following technical recommendation, then it avoid germination of non-dormant seed. It has higher percentage of micronutrient and macronutrient in respect to the other manure. It minimizes the utilization of chemical fertilizers which has bad impact on soil texture and pollutes our whole biosphere. It also reduces the weed growth up to 40% in the maize due to allelopathic effect which minimizes excessive use of herbicides. Examination of *Parthenium* compost was done and found that it has bacteria PSB, *Azotobactor*, Actinomycetes that also improves soil- texture and fertility without affecting soil health (Ambasta and Kumari, 2013). Hailu (2010) conducted research in Tigrai region (Ethiopia) on composting of different weeds including Parthenium and investigated that *Parthenium hysterophorus* contains 38.5, 2.8 and 51 $g.kg^{-1}$ of NPK, respectively, which is relatively high amount. Also, Rajiv *et al.* (2013) prepared various concentration of cow dung and Parthenium mixed compost as well as parthenium alone compost and determined physical properties and analysis of its allelopathic effect on germination and growth of *Arachis hypogeae* L. They investigated that compost formed from a combination of parthenium and cow dung, and compost had enhanced nutrient value and increased germination percentage of *Arachis hypogeae* as compared to their individual controls because high levels of cow dung, induce growth of microbes and reduce the allelopathic potential of parthenium. It can be used as a wealthy source of nutrients because the toxicity due to allelochemicals could be minimized.

Similarly, composted *Parthenium* and poultry manure can be used for preparing organic manures and be used in successfully increasing crop productivity as an alternative source to inorganic fertilizers. Sesame root length was more in composted poultry droppings and *Parthenium* treatments compared to the vermicomposted and fresh forms and NPK. Application of organic manures might have supplied N, P and K nutrients throughout the crop growth period as slow released nutrients. The length of shoots was increased in composted and vermicomposted poultry droppings and vermicomposted *Parthenium* treatments than in fresh *Parthenium*, poultry droppings and NPK (Vijayakumari and Hiranmai, 2012).Addition of different farm and animal wastes helped to degrade the Parthenium and improve the nutrient value (Yadav, 2015). Jelin and Dhanarajan (2013) reported that the combination of parthenium and sawdust in composting takes relatively short time for degradation and for preparing a complete compost of good quality. Similarly, Anbalagan and Manivannan (2012) concluded that *P. hysterophorus* mixed with other organic supplements (Cow dung and Press mud in equal quantities) provides adequate physico-chemical conditions for maximum worm production and large scale vermicompost production.

Apurva *et al.* (2010) revised the use of Parthenium for compost and concluded that ordinary *P. hysterophorus* compost contains allelopathic effects which can affect early growth, development and dry matter yield of both monocot and dicot plants. However, since it is rich in primary major essential nutrients (NPK) and other macro nutrients like Ca, Mg, if properly managed it could be best opportunity to use it for fertilizer. Kishor *et al.* (2010) tested the compost of P. hysterophorus and revealed that its compost increases the soil moisture level more than NPK alone. According to Javaid and Shah (2010) comparing the effect of *P. hysterophorus* green manure and EM (effective microorganisms), a bio fertilizer, on wheat (*Triticum aestivum* L.) cultivation, the highest root biomass was recorded in 3% green manure-amended treatment. Spike length, number of grains per spike and grain yield gradually increased by increasing the quantity of green manure. There was 43–253% increase in grain yield over control due to various green manure treatments as compared with

96% increase due to NPK fertilizers over control. Yadav (2015) concluded that the adoption of vermicomposting to eradicate the weeds and reduce the problems arising due to the weeds in agricultural fields is gaining momentum among farmers. However, Ajayan and Babu (2014) pointed out that traditional use of parthenium as vermicomposting ingredient and fencing material in agricultural field unknowingly affect soil fertility and have potential anthelmintic activity.

Lalitha *et al.* (2012) have utilized the leachate of different plant parts of *Parthenium* plant and observed the effect on several aspects such as seed germination of *Phaseolus mungo*, metal tolerating capacity of the seeds against iron, lead, mercury and nickel of seeds during germination, antimicrobial activity against fungal pathogens and effect on brinjal fruit borer. They investigated that there was a 48.8 % increase in the seeds germination of the seeds treated with flower leachate. The metal tolerating capacity was highest in leaf extract against iron, in stem extract against lead, in flower extract against mercury and leaf extract against nickel. The flower extract exhibited 100% mortality on brinjal fruit borer. Jiten *et al*. (2013) investigated that methanolic extract of *P. hysterophorus* has good acaricidal activity and may find scope in integrated pest management system of *Oligonychus coffeae*. Thus, methanol extract of *P. hysterophorus* is known to be a promising source for the controlling of *Oligonychus coffeae*. Nadir Baloach *et al.* (2014) tested parthenium water extract for its herbicidal effect (for weed control) on wheat crop. The parthenium water extract @ 24 L ha^{-1} combined with reduced doses of Buctril Super 60 EC @ 300, 225, 150 and 75 ml ha^{-1}, respectively, were tested. Individual herbicide (Buctril Super 60 EC) treatments @ 750 ml ha^{-1} full dose and a weedy check were included for comparison. Finally, concluded that water extract @ 24 L ha^{-1} combined with Buctril Super 60 EC@ 150 ml ha^{-1} inhibited total weed density by 38 and 84%, total weeds, fresh weight by 67 and 87% and total weeds dry biomass by 69 and 86% respectively and it increased grain yield by 91% as compared to control. The findings revealed that, allelopathy can be the best option in order to reduce herbicide dose and enhance the wheat yield. Similarly, Khan *et al.* (2008) Comparing the values in control, with the treated plots, there are convincing evidences of the presence of allelochemicals in *Parthenium* extracts that can selectively affect weeds and suggested that *P. hysterophorus* can be used as a bio herbicide.

Control measures of *Parthenium*

The development of effective prevention and control programs are very essential to overcome the problems of parthenium weed. However, no single method of control has been proved satisfactory (Mechanical, chemical and biological control strategies) to tackle the effect of *Parthenium hysterophorus.* Thus, integrated approaches are warranted to restrict the invasion of this weed by combining more than one option (Belachew and Tesema, 2015). To address this problem, public awareness has to be developed and participatory approach to control the invasive weeds should be adopted (Patel, 2011).

Chemical control methods

Effective herbicides are registered for use against parthenium but chemical control requires repeated, regular follow-up treatments (Lorraine and Lin, 2015). Generally, parthenium plants can effectively be controlled with glyphosate tank mixed with low concentrations of urea and common salt **(**Zelalem, 2013). Thus, treating 3000 ml of glyphosate with 150 ml of urea and 150 ml of common salt solutions and spraying at 6 to 8 leave stage resulted in complete mortality of parthenium weed in short period of time by increasing the phytotoxicity of this herbicide. While spraying this solution at 50 and 75% flowering stages showed poor mortality rates on this weed. The growth of Parthenium can be suppressed using amino acid synthesis and photosynthesis inhibitors as compared to herbicides with other modes of action. In wasteland, non-cropped areas, along railway tracks, water channels and roadsides, the use of glyphosate and metribuzin has been shown promising results. On the other hand, the treatment should be accomplished at rosette stage to be effective. Parthenium weed control at rosette stage is highest with glyphosate (96%) followed by metribuzin 87% at 4 weeks after treatment (WAT) and control is lowest with pendimethalin (42.5%) at 4 WAT. Thus, glyphosate and metribuzin are recommended for the control of parthenium weed in non-cropped areas (Haroon *et al.*, 2012). Bactril Super @ 0.67 ml/L water can control parthenium. However, huge amount of parthenium plants cannot be controlled economically by chemicals (Rezaul Karim, 2012). Reddy *et al.* (2007) suggested that Norflurazon, Clomazone, Fluometuron, Flumioxazin, Halosulfuron, Chlorimuron, and Trifloxysulfuron could provide effective control of parthenium. Fernandez (2013) has shown that under field condition, Saflufenacil + dimethenamid-P and hexazinone were highly effective and rapid in controlling flowering parthenium, providing 100% control at all evaluation timings (3, 6, 9 weeks after treatment). While in greenhouse, aminocyclopyrachlor + chlorsulfuron, aminopyralid, hexazinone, saflufenacil + dimethenamid-P, 2,4 D provided 100% aboveground dry weight reduction of rosette parthenium at 21 DAT.

Biological control

Biological control can play a significant role to check the growth of Parthenium weed because it would be more sustainable and possibly cost effective (Evans, 1997; Lorraine and Lin, 2015). Several effective biological control agents are already available and can be introduced and released with a minimum of additional research required. Six potential agents have been released for biological control, mainly in Australia. The two most important species that have been established are *Zygogramma bicolorata* (leaf feeding beetle) and *Epiblemma strenuana* (stem galling moth) and they have a significant impact on parthenium in Australia. Only *Z. bicolorata* was released in India where it caused widespread defoliation, permitting local vegetation to grow again. In Australia, *E. strenuana* can exert significant control but erratic rainfall has disrupted the moth populations, reducing them to very low levels. Populations take a long time to build-up again, usually too late to have a significant impact on the weed (Wise *et al.*, 2007). Also; according to Kumar *et al*. (2009) Cladosporium sp. (MCPL-461) affects the embryo development which enhances the sterile seeds formation. Spraying of this sp. has deleterious effects on Parthenium weed only, not to other plant species, which living together under same niche. Due to invasive nature and luxuriant growth capacity of Parthenium in different habitat, Cladosporium sp. as a floral and leaf pathogen may be used as a potential myco-herbicide against this weed. Rezaul Karim (2012) reported that *Puccinia abrupta* is appropriate disease that used to control parthenium.Finally, biological control, using natural enemies from the plant in its native range, would be the most sustainable management intervention and requires further research.

Mechanical control

Control operations should focus on preventing spread, the eradication of small and isolated populations (Wise *et al.*, 2007)**.** Khan *et al*. (2013) reported that manual weeding and tillage are the most common control practices used to control Parthenium weed. According to van der Laan (2006) manual removal of *P. hysterophorus* is often not cost-effective and therefore used on a limited basis. Hand-pulling should ensure the removal of the entire crown to prevent regeneration from remaining lateral shoots. Correspondingly, Patel (2011) stated that manual uprooting of Parthenium before flowering and seed setting is the most effective method. This is easily done when the soil is wet. Uprooting the weed after seed setting will increase the area of infestation. Pulling a plant in flower will aid in the dispersal of pollen grains, resulting in allergic reactions. Mulching with *Gliricidia sepium*, or any other suitable and a cost-effective mulch, coupled with manual weeding before land preparation or ploughing would help suppressing the growth and development of the Parthenium weed and enhance yield of tomato (Nishanthan *et al*, 2013). However, burning of *P. hysterophorus* should be avoided in the agricultural field to enhance overall productivity (Kumar and Kumar, 2010). This could be due to the fact that burning requires large quantity of fuel. Moreover, burning destroys all plants and predators in vicinity.

Botanical control methods

Aqueous and methanol extracts of *Nerium oleander* L. leaves inhibited seed germination (Germination percentage, germination speed, germination value and peak value) and early growth (root hair formation, root and shoot lengths of seedlings) of *Parthenium hysterophorus* L. in a concentration dependent manner. Methanol extracts of white flowered variety showed higher inhibition compared to that of pink flowered variety (at 1:40 dilution of the stock, inhibition was 60% and 23.4% with white and pink, respectively) (Rajyalakshmi *et al*., 2011). Belachew and Tesema (2015) assessed the weed flora composition in Parthenium (*P.hysterophorus L*.) infested area of East Shewa Zone, Ethiopia, and finally investigated three herbaceous species, namely *Cassia tora, Xanthium strumarium* and *Argemone mexicana* which had good association and grow with *P. hysterophrous* in competition and thus, these species are recommended for *Parthenium* eradication. According to Lorraine and Lin (2015) reducing livestock densities to increase grass cover assists to alleviate parthenium infestations.

Root and shoot extracts of the three allelopathic grasses viz., *Dicanthium annulatum* Stapf., *Cenchrus pennisetiformis* Hochest and Sorghum halepense Pers., reduced germination and suppressed early seedling growth of exotic weed Parthenium hysterophorus L. Aqueous extracts of D. annulatum and C. pennisetiformis were more inhibitory than extracts of S. halepense. The highest suppressive ability was exhibited by extracts of C. pennisetiformis where 20% shoot and 25% root extract completely inhibited the germination of *P. hysterophorus.* In general shoot extracts were more inhibitory than the root extracts (Arshad and Tehmina, 2006). In a phytochemical control study, *Cassia occidentalis, Rumex dentatus, Calotropis procera and Withania somnifera* had been evaluated for their herbicidal potential against biochemical activities and mortality percentage of parthenium. The study concluded that the 100%, 9th day aqueous shoot leachates of *Cassia occidentalis* found effective in arresting germination and suppressing seedling growth of parthenium (Jai *et al.*, 2010).Sing *et al.* (2013) studied the effect of leachates of different phenological stages of *Cassia*

occidentalis L. on *P.hysterophorus* L. Accordingly, 100% concentration of leaf leachate from vegetative stage completely inhibited the germination while highest concentration of leaf leachate from vegetative, flowering, fruiting and fruit ripening stages caused the death of the plants.

CONCLUSIONS

The distribution and existence of *Parthenium hysterophorus* L. weed in various environments including crop lands, range lands, road sides, forests, watersheds and other economically important ecosystems has been identified. Its dissemination is progressing at an alarming rate which gives the impression of difficulty to control its distribution in the future.

Some general recommendations arise from the present review.

- A well-planned programme that encourage the participation of all stake holders including universities, research centers, individual researchers, government and non-governmental organizations is needed to develop strategies for controlling further distribution or achieve eradication of this weed.
- A single technology in isolation will not give desired results. Thus, adoption of related controlling methods as an integrated package would provide a synergistic effect.
- Creating public awareness especially in farmers' area about the effect of *Parthenium hysterophorus* on agricultural productivity, ecosystem as well as on strategies control methods.
- By using its potential beneficial effects as opportunity there is a possibility to eradicate this weed through time.

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