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Review Article
Management of Horse Purslane (*Trianthema portulacastrum* L.): An Overview

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Abstract
Trianthema portulacastrum L. (Horse purslane) is an annual broadleaf troublesome weed of tropical and subtropical areas throughout the world. In India, it has been observed as a problematic weed in many states. Remarkable biological and ecological behavior of this weed has enabled its easy and rapid spread and naturalization in a wide range of habitats. Various pre and post-emergence herbicides are used for controlling this weed. With increasing global concern about pesticide residues in the biosphere and public demand for pesticide free-food, alternative pesticides, such as bioherbicides are becoming important. Presently, there are over 17 mycoherbicides against different weeds, which are commercially being used in the developed countries. Of these, 8 are registered in the USA, 4 in Canada, 2 in South Africa and 1 each in Netherland, Japan and China. A total of 9 fungal pathogens have been reported on this weed around the globe. Of these, *Gibbago trianthemae* has the potential to be developed as a mycoherbicide of horse purslane in the USA and India. In this study, attempts have been made to present distribution, menace and management of horse purslane, a notorious agricultural weed by mechanical, chemical and bioherbicidal means.

Key words: Horse purslane, weed, chemical control, biological control, biocontrol, mycoherbicides/bioherbicide

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The genus *Trianthema*, a member of the family Aizoaceae is represented by 12 species and of these *T. portulacastrum* L. (syn. *T. monogyna* L.) enjoys the weed status. It is commonly known as blackpig weed, carpet weed, gudbur, hog weed, itcit, santha and horse purslane. It is a strong competitor with all types of upland crops and causes substantial yield reduction on account of competition in several cultivated crops. It needs argent attention due to one of the most troublesome terrestrial weed not only of Northwest India, but of many parts of the world[1-4]. Over 14 billion dollar spent annually on chemical weed control[5], excluding immense indirect costs to producers, consumers and the environment. Although, herbicides have played a vital role in improving crops yield and overall production efficiency, overreliance and repetitive use of the herbicides belonging to the same can lead to the development of herbicide resistant weed biotypes. Moreover, persistent residues of dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) highly poisonous to humans have been found in vegetables, milk, butter, meat as well as in mother's milk[6]. Many chemical herbicides are unavailable in the market due to lack of re-registration, competition from other herbicides and development of numerous genetically modified crops with resistance to broad-spectrum herbicides[7]. Besides, *T. portulacastrum* is difficult to control effectively with chemicals when they grow with broadleaf crops like onion, eggplant and other vegetables[8]. Indiscriminate and excessive use of chemical herbicides has led to several environmental and health related problems. Chemical weed control is not an ideal option in organic cropping system. Practical use of biological control agents, particularly fungal pathogens has gained acceptance as a safe and environmentally friendly approach which minimizes risks resulting from herbicides[9].

ECOLOGY AND DISTRIBUTION

Horse purslane is a fast-growing, prostrate, profusely branched, succulent, rainy season, annual broadleaf weed in cultivated and wastelands. It produces numerous small white flowers and is a strong competitor with all types of upland crops[1,10,11]. Plant grows rapidly and reaches peak growth within 40-45 days of its emergence. Maximum seedling emergence takes place during rainy season, when conditions for growth i.e., both temperature and relative humidity are optimum[10]. The hard seed coat appears to be the primary mechanism of horse purslane dormancy, thus making it a problem for several years and infesting the crops raised subsequently[10,12].

Horse purslane, an indigenous plant to South Africa, occurs in India, Pakistan, Bangladesh, Srilanka, West Asia, Africa and tropical America[10,13]. In India, it is a very common weed of various farm crops, non-crop lands, grasslands and wastelands. It grows along roadsides on earthen roofs of old buildings in open waste, vacant and wetlands. It has been observed as a problematic weed in various agricultural crops in the states of Uttar Pradesh, Punjab, Haryana, Rajasthan and Delhi[3,11]. Heavy infestations of this weed has been reported in pearl millet[14], soybean[4,10], black gram[15], maize[1,16], cotton[2,17], mungbean[18,19], sugarcane[20,21], onion[8], pearl millet[22,23], pigeonpea[24], peanut[25] and arhar, maize, mustard, onion, potato, soybean and sugarcane[3]. It is a common weed of maize, cotton and vegetables all over Pakistan[26]. It is also reported to be a major weed of garden land representing 85% of weed population[27].

Competitive studies have reported heavy reduction in yields due to *Trianthema* in different crops such as 16-94% in pearl millet[14,28], 50-60% in mungbean[1,14] and 32% in maize grain[29]. *Trianthema portulacastrum* has emerged as a great threat to the sustainability of the soybean production system[4,10]. Singh *et al.*[30] reported 97% reduction in rice yield due to *T. portulacastrum* along with *Echinochloa colonum* and *Cyperus iria*. It takes up the major portion of added nutrients especially nitrogen and crops suffer due to inadequate plant nutrient supply[31]. An overall powerful allelopathic inhibition in germination and seedling growth of rice occurred by pre-soaking in leaf extract of *T. portulacastrum* indicating that there might be inhibitory compounds in aquatic leaf extract, which delayed the germination process of rice seeds[32].

CONTROL

Horse purslane has drawn the attention of agriculturalists, plant pathologists and weed control scientists all over the world because of its high infestation amongst various important crops. Attempts are being made to control this weed by all possible strategies i.e., mechanical, chemical and biological.

Mechanical: Mechanical methods of weed control include basic hand tools to sophisticated tractor driven or self-propelled devices[33]. Mechanical weed control by harrowing is one of the direct non-chemical weed control methods[34]. It involves cutting and ranking off the weeds. Hand hoeing is a common practice of controlling this weed in most of the developing countries around the globe, but it is quite expensive and time consuming. Moreover, these methods are ineffective as new seeds germinate after every hoeing and re-infest the crop, thus depleting soil nutrients. Hoeing is not possible during rainy season and due to labor shortage further accentuates the problem[2].

Chemical: The use of herbicides is the most effective and immediate solution to control horse purslane. Hence, control of this weed alone and/or with other weeds with pre and post-emergence herbicides in different agricultural crops have been carried out around the world. Tamilnadu Agricultural University, Coimbatore, Punjab Agriculture University (PAU), Ludhiana and Haryana Agricultural University (HAU), Hisar are the three major centres where herbicidal control of *Trianthema* is conducted[11,14,23,35,36]. Some of the notable studies carried out on the control of horse purslane by herbicides are summarized in Table 1. Out of various pre-emergence herbicides, Walia *et al.*[36] reported that pre-sowing application of fluchloralin (0.35 or 0.45 kg ha^{-1}), pre-emergence application of pendimethalin (0.2 or 0.3 kg ha^{-1}) and oxadiazon (0.2 or 0.25 kg ha^{-1}) showed significant reduction in *T. portulacastrum* populations. Balyan *et al.*[23] reported that post-emergence application of atrazine (0.25 or 0.50 kg ha^{-1}) at 7 or 14 d.a.s. proved highly effective in controlling the two most competitive and aggressive weeds *T. portulacastrum* and *Echinochloa colonum*.

Biological: Biological weed control is the deliberate use of mainly host specific arthropods and fungal pathogens to reduce the population density of a weed below its economic or ecological damage level[37]. It has gained acceptance as environmentally beneficial method applicable to agro-ecosystems due to the best long-term solution of weed problem[9,38-42]. Biological control of weeds is approached by two strategies, the classical (or inoculative) and bioherbicidal (or inundative, mycoherbicidal) strategy. The classical strategy is directed principally at plants that have been introduced into a new region or country and become weedy in the absence of their natural enemies. Classical biocontrol has been widely used to control invasive exotic plants[43,44]. Pathogens are sought from the geographic origin of plants for introduction into new regions, increase in epiphytotic levels and eventually become endemic when the weed is suppressed to subeconomic levels[45]. The inoculative pathogens are usually fungi because of their desirable characteristics to be a biological control agent[46]. It can be a highly effective and cost-efficient approach to control invasive weeds. However, classical biological control requires a time period of one to several years to achieve adequate control. Some of the notable successful examples of the classical approach to control weeds are: The use of *Puccinia*

Table 1: Herbicides used to control *Trianthema portulacastrum* in different crops

Herbicide	Crops	Dosage (kg ha^{-1})	Time of application	Duration of control	References
Acifluorfen	Peanut	0.3	Early post-emergence	21 d.a.t[a]	Grichar[61]
Acifluorfen+bentazon	"	0.3+0.6	"	"	"
Acifluorfen+2, 4DB	"	0.3+0.3	"	"	"
Alachloral	Sesame	1.5-1.75	Pre-emergence	-	Subramanian and Sankaran[35]
Atrazine	Pearl millet	0.25-0.50	Post-emergence	7-14 d.a.s[b]	Balyan[14] and Balyan *et al.*[23]
	Fodder Maize	1.0-1.5	Pre-emergence	-	Singh and Prasad[11]
	Maize	0.5	Pre-emergence	-	Balyan and Bhan[62]
Fluchloralin	Berseem	0.35-0.45	Pre-emergence	-	Walia *et al.*[36]
	Pigeon pea	1.5	PPI[c]	-	Chauhan *et al.*[24]
	Cotton	1.5	Pre-emergence	-	Panwar and Malik[63]
Fomesafen	Mungbean	250-350 (g ha^{-1})	Post-emergence	-	Balyan and Malik[1]
Isoproturon	Blackgram	0.5	Pre-emergence	-	Ali and Durai[15]
Lactofen	Peanut	0.2	Post-emergence	26 d.a.t	Grichar[61]
Metolachlor	"	1.0	Pre-emergence	20-40 d.a.s	Sandhu *et al.*[19]
Oxyfluorfen	Onion	0.125-0.25	Before transplanting crop	-	Singh *et al.*[8]
Paraquat	Berseem	0.2	Post-emergence	-	Walia *et al.*[36]
Pendimethalin	Fodder maize	1.5	Pre-emergence	-	Singh and Prasad[11]
	Berseem	0.2-0.3	Pre-emergence	-	Walia *et al.*[36]
	Pigeon pea	1.5	Pre-emergence	1 d.a.s	Chauhan *et al.*[24]
Pendimethalin	Cotton	0.75, 1.50, 2.25	Pre-emergence	30 d.a.s	Brar *et al.*[2]
Pendimethalin	Cotton	1.5	Pre-emergence	-	Panwar and Malik[63]
Pyrivate+2,4 DB	Peanut	1.0+0.3	Early post-emergence	26 d.a.t	Grichar[61]
Trifluralin	Pigeon pea	2.0	PPI	-	Chauhan *et al.*[24]

[a]Days after treatment, [b]Days after sowing and [c]Pre plant incorporation

chondrillina Bubak and Syn., imported from Mediterranean South Europe for the control of *Chondrilla juncea* L. in Australia and the USA, *Phragmidium violaceum* (Schultz) winter from Europe for the control of *Rubus constrictus* P.J. Mull. and Lefevre and *R. ulmifolius* Schott in Chile and *Maravalia cryptostegiae* from Madagascar for the control of *Cryptostegia grandiflora* Roxb. in Australia[47-51]. In South Africa, 63 biological control agents have been successfully accepted on 44 invasive exotic plant species since 1913 and 25% of the target exotic weeds have been completely controlled[52].

In bioherbicidal tactic, plant pathogenic microorganisms are developed and used to control weeds in a way chemical herbicides are used. When the microorganism used is a fungus, the product is called as a mycoherbicide. However, the use of pathogens other than fungi as bioherbicides is limited. Therefore, the term "mycoherbicide" has often been used interchangeably with "bioherbicide"[6]. Mycoherbicides are formulations of highly specific disease inducing phytpathogenic fungi that attacks the target weed in large proportion without harm to the crop or any non-target species in the environment[53]. Presently, there are over 17 mycoherbicides, which are commercially being used in the developed countries of the world[54]. Of these, 8 are registered in the USA, 4 in Canada, 2 in South Africa and 1 each in Netherlands, Japan and China[9,55]. The first commercial mycoherbicide appeared in the USA market in the early 1980s with the release of the product DeVine, a formulation of *Phytophthora palmivora* in 1981 to control milkweed vine in Florida citrus grooves. It was followed by the release in the next year i.e., 1982 of the product Collego, a formulation of *Colletotrichum gloeosporioides* f.sp. *aeschynomene* to control northern jointvetch, a leguminous weed in rice. Other commercially available fungal products are: Casst (a formulation of *Alternaria cassiae*) to control *Cassia obtusifolia* in the USA, BioMal (formulation of *C. gloeosporioides* f.sp. *malvae*) for control of *Malva pusilla* in Canada, Biochon (*Chondrostereum purpureum*) for control of *Prunus serotina* in Netherland, Lubao (*C. gloeosporioides* f.sp. *cuscutae*) for *Cuscutta* spp. in China and ABG 5003 (*Cercospora rodmanii*) for control of *Eichhornia crassipes* in the USA[9,54].

A literature study reveals that not much study has been done on the biocontrol of *T. portulacastrum* by fungal pathogens, except the study of Mitchell[56] and Aneja *et al.*[3]. A total of 10 plant pathogens (9 fungi, 1 virus) and 2 insects have been recorded on this weed around the globe (Table 2). *Gibbago trianthemae* is the only fungal pathogen, which has been evaluated for its biocontrol potential. *Gibbago trianthemae* is a phaeodictyoconidial hyphomycetous fungus. It causes leaf spots on horse purslane (Fig. 1). It was first of all isolated from the diseased plants in 1986 from the USA[57] followed by its 2nd isolation from Kurukshetra (India)[58] and 3rd isolation from Faisalabad (Pakistan) in 2013[59].

Mitchell[56] studied the biocontrol efficacy of *G. trianthemae* for the control of horse purslane in green house conditions. It was reported 50% reduction in weed growth at the lowest concentration of spores (5×10^4 spores mL^{-1}). It was emphasized that further studies are still needed on the impact of environment and on application technology of the potential of this pathogen to develop it into a bioherbicide. Aneja *et al.*[3] reported that in experimental pots, defoliation started after 20 days of inoculum spraying of *G. trianthemae*. Percent infection on

Table 2: Pathogens/insects reported on *Trianthema portulacastrum* throughout the globe

Pathogens/insects	Diseases	Country	References
Fungus			
Cercospora trianthemae Chiddarwar	Leaf spot	India	Chiddarwar[64]
Gibbago trianthemae Simmons	Leaf spot	USA, Cuba, Venezuela, India, Pakistan	Simmons[57], Aneja and Kaushal[58] and Akhtar *et al.*[59]
Drechslera (*Exserohilum*) *indica* (Rai, Wadhwani and Tewari) Mouchacca (*Bipolaris indica*)	Leaf spot	India, Japan, Australia	Rao and Rao[65], Taber *et al.*[66] and Shivas[67]
Colletotrichum gloeosporioides Penz. and Sacc.	Leaf spot	India	Darshika and Daniel[68]
Fusarium oxysporum Schlecht	Leaf spot	India	Darshika and Daniel[68]
Fusarium semitectum	Leaf spot	India	Darshika and Daniel[69]
Alternaria alternata Keissler	Leaf spot	India	Gupta and Mukherji[70] and Bohra *et al.*[71]
Phoma herbarum Saccardo	Leaf spot	India	Ray and Vijayachandran[72]
Fusarium chlamydosporum Wollenw and Reinking	Leaf spot	India	Aneja *et al.*[73]
Virus			
Trianthema mosaic virus		India	Sastry[74]
Insects			
Spoladea recurvalis (*Hymenia recurvalis*)		Argentina	De Manero and de Argentier[75] and Kedar and Kumaranag[76]
Spodeptera littoralis		Madagascar	Randrianandrianina-Razananaivo[77]

Fig. 1(a-c): (a) *Trianthema portulacastrum* infected plants, (b) Leaf spots due to *Gibbago trianthemae* and (c) Germinating conidia

leaves ranged between 72 and 84%, 30 days post inoculation with a conidial suspension at concentration of 2.2×10^5 conidia mL^{-1}. Application of inoculum significantly reduced the production of leaves, height and biomass per plant as compared to control. A significant correlation between the growth and sporulation of the pathogen was reported when tested on 10 different culture media. Best sporulation was found on trianthema extract dextrose agar followed by potato dextrose agar and potato dextrose agar+yeast extract (8.6×10^5>8.0×10^5>7.37×10^5 conidia mL^{-1}, respectively). Best sporulation was recorded at 25°C. Conidia germinated between 15 and 35°C, the best recorded at 25°C. Host range studies conducted on 12 plant species (3 weeds and 9 agricultural crops) belonging to 6 families; Aizoaceae, Amaranthaceae, Chenopodiaceae, Poaceae, Cruciferae and Fabaceae revealed that none of these except one i.e., horse purslane showed symptoms of the disease (i.e., susceptible to *G. trianthemae*). Biocontrol studies conducted on the *Trianthema-Gibbago* system revealed that *G. trianthemae* has most of the criteria desirable for development it as a mycoherbicide to control horse purslane; i.e., it can be cultured on a cheap medium (trianthema extract dextrose agar), good sporulation capacity, host specificity, fast growth rate and hence can be mass produced in a short time and infection can take place from conidia and/or mycelial fragments[3,60]. The formulation of the fungus with surfactant has been named gibbatrianth[9].

CONCLUSION

Trianthema portulacastrum L. is emerging as a problematic weed in various crops, especially in tropical and subtropical areas of the world. There are two ways to check the nuisance value of a weed (i) Converting a problematic weed into a resource through its multifarious uses such as its use as a vegetable, fodder, green manure or medicinal and (ii) To control it through integrated pest management strategies. Although, various pre and post-emergence chemical herbicides are available to control this weed but keeping in view the pollution hazards created by chemicals, the need of the hour is to intensify research on to control this weed either through biological agents or with an integrated approach using chemical plus biological agents. *Gibbago trianthemae*, a fungal pathogen reported on this weed from the USA, India and Pakistan is in the process of development as a commercial mycoherbicide and the scientists are hoping for its release in the near future.

There is a significant interest in developing bioherbicides for use in crops, gardens, rights-of-ways, parks and the alike. Literature study reveals several phytopathogenic fungi have been patented as weed-control agents. The phytotoxic components of most agents have been not elucidated and dis-assessment of much microbial agents are limited. A more through study is needed to tackle the problem. Currently, 9 fungal pathogens have been recorded on *Trianthema portulacastrum* around the globe. Of the 9 fungal pathogens, *G. trianthemae* has been found to be a potential biocontrol agent. Before gibbatrianth is commercialized as a bioherbicidal agent to control *Trianthema* weed scientists need to carry out study on *Trianthema-Gibbago* system on the following lines, evaluation of potential fungal biocontrol agents (BCAs) for their synergism to be applied as consortium in multicomponent bioherbicidal system for checking the growth of weed as soon as it emerges from the soil, enhancing the bioherbicidal activity of BCAs either by the application of exogenous cellulose and/or pectinase enzymes or by adding a microbes in the consortium having the ability to produce these enzymes to increase the virulence and hasting the process of pathogenesis. In addition to the study has to be carried out on phytotoxin production by the BCAs and their toxicity to the mammalian system.

SIGNIFICANCE STATEMENTS

This study helps the researchers of biological weed control field in following ways:

- Study explains the ecological distribution and various methods for controlling *Trianthema portulacastrum*
- It explains the present status of herbicides and biological agents used to control this weed
- Some information on total bioherbicides registered throughout the world and classical control strategy

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