International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 6; Issue 7; July 2017; Page No. 4978-4991
DOI: http://dx.doi.org/10.24327/ijcar.2017.4991.0628

Research Article

MICROBIAL TECHNOLOGY IN WEED MANAGEMENT: A SPECIAL REFERENCE OF BIOLOGICAL CONTROL OF HORSE PURSLANE WEED

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A R T I C L E I N F O

Article History:

Received 8th April, 2017
Received in revised form 10th May, 2017 Accepted 25th June, 2017
Published online 28th July, 2017

Key words:

Weed, Mycoherbicides, *Trianthema portulacastrum* L., *Gibbago trianthemae,*

A B S T R A C T

Weed control is still a major issue in modern agriculture in India, despite the development of several tools for weed eradication. The exploration on fungal plant pathogens as weed biocontrol agents have been increased as alternative method to chemical control. *Trianthema portulacastrum* L. was found as a noxious weed plant in many agricultural crops of India and many tropical and sub-tropical countries. The weed abundance was studied in various crop fields to understand the adverse effects of the weed. Simultaneously the epidemic investigation was accomplished to identify the natural enemies of the weed. To understand the significance of mycoherbicides, a critical review on weed management with special reference to biological control of horse purslane weed was attempted.

INTRODUCTION

Weeds are the oldest problem in agriculture since about 10000 B.C. and represented as one of the main limiting factors in profitable crop production (Avery, 1997). They are the most complex and cost effective in management of natural resources and causes significant losses each year in agriculture, forestry, and aquaculture and also cause allergies and other health hazards to human and domestic animals (Handerson and Anderson, 1996). The plants which growing in agricultural fields have more negative values and competing with crops for soil, water, nutrients etc. are known as weeds (Ali *et al*., 2003; Muzik, 1970). Zimmerman (1976) believes that the term “weed” should be used to describe plants that have all the following characteristics: (1) they colonize disturbed habitats (2) they are not members of the original plant community (3) they are locally abundant and (4) they are of little economic value.

Weeds are very common, dominant and wide spread in the crop fields and they are genetically labile and phenotypically plastic; such characters enable them to survive in adverse habitats. They easily invade crop fields which are favourite grounds for their rapid growth. Weeds become of economic significance in connection with agriculture due to damage of crops and toxic to domesticated animals. Weeds are usually undesirable plants that are very abundant, invasive, competitive, harmful, destructive and difficult to control.

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They have short vegetative phase, high reproductive output and limiting the crop yield. Most of the crops infested with serious weeds during the irrigation period due to the adequate supply of nutrients. The factors like irrigation and supply of nutrients causes enormous growth of weeds.

Apart from quantitative losses caused by weeds due to competition for water, light, space and nutrients, they also cause qualitative indirect damage due to unitary seed reduction, contamination of seeds, slowing of tillage and harvesting practices (Anderson, 1983; Asthon and Monaco, 1991). Weed interference is one of the most important factors to decrease the yields of all crops. Weeds are undesirable on account of their competitive and allelopathic behaviour and providing habitats for harmful organisms (Zaman *et al*., 2011). Weeds compete with crop plants for light, moisture and other essential nutrients, resulting reduced quality and yield of crops and increased the cost of production (Samad *et al*., 2008). These unwanted, unuseful, often prolific and persistent, competitive, harmful and poisonous plants that are known as weeds interfere with agricultural operations, increase labour cost and reduce yield (Crafts and Robbins, 1962). Weeds deplete large quantities of mineral nutrients and moisture more efficiently than the crop plants and flourish better over the crops in drought conditions. Weeds not only compete with crop plants for nutrients, soil moisture, space and sunlight but also serve as an alternative hosts for several insect pest and diseases. Wider spacing, frequent irrigations and liberal use of manures and fertilizers provide favourable conditions for the abundant growth of weeds (Mukherjee *et al*., 2012). Weeds are unwanted plants growing along with domesticated crops. They are non-indigenous plants that can invade or negatively alter native plant communities. Weed plants grow faster, spread rapidly, reproduce in high numbers and produce large quantities of seeds which enable them to establish a kingdom of their own within a short period of time (Dangwal *et al.*, 2010). They always act as energy drains in the entire managed ecosystem such as agricultural fields, forestry, horticulture, and aquaculture etc. They decrease the yield of crops by competing for soil, water, nutrients, space, CO_2 and sunlight (Rao, 2000). They provide habitat for harmful insects and may act as alternate host for pathogens and other organisms (Peters, 1955). Parker and Fryer (1975) estimated the losses due to weeds to be as large as 50% in tropical crops and approximately 11.5% of total potential production worldwide. Invasive weeds cause significant environmental damage, because they are free of their natural enemies and competitors, and very often have high populations and are able to displace native species, a problem which has only recently begun to be recognized (McFadyen, 1998).

Biology of weed plants

Weed flora and its composition in a crop are influenced by the type of cultivation, spacing, time or season of cultivation, soil type, soil pH, climatic conditions such as rainfall, temperature; cultivation practices like irrigation, tillage systems, application of fertilizer and weed management (Kiran and Rao, 2013). Weeds show allelopathic effects on agricultural crops by releasing allelochemicals (phytotoxic compounds) in their environment that inhibit the growth and germination of agricultural crops. Moreover, these weeds effectively compete with the crop for nutrients, water, and space and reduce the yield ranging from 12 to 51 %. (Rao and Singh, 1997; Mukharjee and Singh, 2005; Halder and Patra, 2007; Zimdahl, 2007). Exotic weeds (aquatic, terrestrial and parasitic) interfere with the agriculture, loss of biodiversity and ecosystem resilience, loss of potentially productive land, loss of grazing and livestock production, poisoning of humans and livestock, choking of navigational and irrigation canals and reduction of available water in water bodies.

Weed control methods

The biology, ecology and management of weeds cannot remain constant for all the regions. Hence, weed management strategies are different for each agro-ecological condition. Continuous development and improvement of weed management technologies are very essential to reduce production costs, and also in the view of both ever-changing socioeconomic conditions of the farmers and international agricultural trade policies. Weed control is an essential part of crop production systems. According to Tu *et al*. (2001) there are three principal weed control methods: (1) Cultural or Mechanical weed control, (2) Chemical weed control and (3) Biological weed control. Commonly used weed control strategies are water management, hand weeding, mechanical weeding and chemical herbicides. Water management can control certain weed species in irrigated lowlands. Hand weeding is time-consuming and is becoming expensive, while the use of mechanical weeders is known to reduce yields. Weeding, usually by hand, accounts for up to 60% of total pre-harvest labour input in the developing world (Webb and Conroy, 1995). Chemical herbicides, on the other hand, not only are becoming more expensive, but also contribute to environmental hazards. Moreover, the chemical weed control accounts for over $14 billion spent annually on herbicides (Kiely *et al.*, 2004).

Chemical herbicides

Chemical herbicides are effective in some particular weed control and increased the efficiency of farming. Nevertheless, the continuous utilization of chemical herbicides can induce the herbicide-tolerant weed populations and the increase of herbicide residues in soil, water and food products, and also they can affect non-target organisms (Bayot *et al.,* 1994; Schroeder *et al.*, 1993). The herbicide resistance (HR) in various weed species, around the world was reported by researchers and agronomists since last few years. Weed species with multiple herbicide resistance (MHR) were recognized in many countries due to the huge use of chemical compounds in modern agriculture system. The little seed canary grass (*Phalaris minor* Retz.), a troublesome weed in wheat crop has evolved as a multiple herbicide resistance (MHR) in India first time in 1991 (Yadav and Malik, 2005). Because of more negative results of chemical herbicides in farming, there is increased interest on biological control as alternate to chemical methods (McFadyen, 1998).

Biological control of weeds

Biological weed control is an approach using living organisms to control or reduce the population of a selected, undesirable and harmful weed species (TeBeest *et al.*, 1992). Biological control (biocontrol) of weeds has a long history and a good success rate (Julien, 1992). Biological control of weeds is the intentional use of living organisms (biotic agents) to reduce the vigour, reproductive capacity, density, or the impact of weeds on crop (Quimby and Birdsall, 1995). Bioherbicides comprising microbial agents such as obligate fungal parasites, soil borne fungal pathogens, non-phytopathogenic fungi, pathogenic and non-pathogenic bacteria and nematodes. The strategies of biological control can be classified into two broad categories: (i) classical or inoculative, and (ii) inundative or mass exposure. A development of the inundative strategy is the bioherbicide approach, which involves the application of weed pathogens in a manner similar to herbicide applications. Unlike the classical biological control approach, which involves the use of natural enemies, the inundative approach require more than one year for the effective weed suppression. Bioherbicides are ideally most effective for weed management in annual cropping systems. Bioherbicides are considerable unlike chemical pesticides, and contribute to the effective weed management and environmental resilience. Bioherbicides have been developed using selected plant pathogenic fungi which cause anthracnose, leaf blights, leaf spots and rust on weeds. The term mycoherbicide is often used in reference to the fungal biocontrol agents. Since 1980, eight bioherbicides have been registered and more than 100 micro-organisms have been identified as having the potential for weed biocontrol (Charudattan, 2001). Julien and Griffiths (1998) reported a 47% success rate (partial or complete control) in biological control worldwide. Only a few bioherbicides are successful in field-scale control of weeds while the effectiveness of other candidate bioherbicides has been limited by restricted host-range, elaborate formulation requirements, and lack of persistence in the field. Based on the current status of bioherbicides in use, the strategies for broad host ranges, improving formulations for practical use, and improving techniques for enhancement of weed-suppressive activity in conventional and sustainable agricultural systems are needed.

Types of Biological control

According to Mortensen (1986) there are three approaches in biological weed control. They are (1) The classical or inoculative approach (2) The inundative or bioherbicide approach and (3) The system management approach. These three approaches are differing in their ecological response rather than technological aspects. In the classic approach the control of the target host or weed is dependent upon self maintenance and natural dispersal of the biological agent while the inundative approach works faster than the classical approach because of the avoidance of the wait period for inoculum development and pathogen distribution and the system management approach is based on management of a weed pathosystem to maximize the spread and severity of the pathogen (Templeton *et al.*, 1979; Müller- Schärer and Frantzen, 1996; Charudattan, 2001).

The classical approach

This approach involves the introduction and release of one or more natural enemies that attack the target weed where the introduced weed has become a noxious plant because of the absence of its natural enemies in the area of introduction. The objective of the classical biological weed control is generally not eradication of the weed species but the self-perpetuating regulation of the weed population at acceptable low levels (Wapshere *et al.*, 1989). One of the successful examples of the classical approach is the use of *Puccinia chondrillina* Bubak & Sydenham, a rust fungus against *Chondrilla juncea* L., a common weed of wheat in Southeast Australia and the weed infestation was reduced by more than 99% and with benefits estimated at $15 million per year (Butt *et al.*, 2001).

The inundative approach

The inundative approach involves the periodical application of the native agent (usually a fungus) in a high concentration to control the target weed in a method similar to a chemical herbicide (Templeton *et al.*, 1979; Charudattan and Walker, 1982; Auld and McRae, 1997). The inundative biological weed control strategy was first introduced in 1973 to control northern jointvetch (*Aeschynomene virginica* L.) in rice fields with endemic fungal disease (Daniel *et al*., 1973). Successful inundative applications of mycoherbicides include control of yellow nutsedge (*Cyperus esculentus* L.) in the United States with *Puccinia canaliculata* and control of northern jointvetch (*Aeschynomene virginica* L.) in rice in Arkansas with *Colletotrichum gloeosporioides* f. sp. *Aeschynomene* (Charudattan and Dinoor, 2000).

The System management approach

Biological control as a single measure is not an optimal process for weed control. Instead the use of individual method, an integrated approach is more effective in weed management programmes. An integrated weed management strategy combines the use of complementary weed control methods (mechanical, chemical and biological) resulting in more effective and long term weed management outcomes. This strategy requires the fundamental knowledge of the underlying mechanisms of the crop production system and is aligned with the view of modern agro-ecology, in which complete eradication of weeds is not desirable. The system management approach is aimed at managing a weed pathosystem in such a way to stimulate disease epidemics on the target weed population and reducing the competition, exerted by the weed on a crop (Müller-Schärer and Rieger, 1998).

Mycoherbicides

Mycoherbicides consist of fungal pathogens which can proliferate directly on host weed. For example, the rust fungus *Puccinia canaliculata*, a foliar pathogen of yellow nutsedge (*Cyperus esculentus* L.) is a candidate of mycoherbicide. Usually indigenous plant pathogens are applied as a massive dose of inoculum (spores or mycelium) to reduce weed populations. In the case of fungal pathogens, the inundative approach became known as 'the mycoherbicide approach' (Charudattan and Walker, 1982). The inundative biological weed control strategy was first introduced by Daniel *et al.* (1973) who applied an inundative dose of an endemic, indigenous pathogen *Colletotrichum gloeosporioides* (Penz.) Sacc. f.sp. *aeschynomene* to destroy the annual weed northern jointvetch (*Aeschynomene virginica* L.). Bioherbicides such as Devine® and Collego® have been available since the 1960s in the USA and China. As stated by Charudattan and Dinoor (2000) several biological, technological, and economical constraints may restrict the development and practical use of bioherbicides. For example, moisture and temperature conditions existing under field conditions are often insufficient in meeting the environmental requirements of the bioherbicide candidate for spore germination and host penetration. Biocontrol formulations constitute mixture of the spores and adjuvants have been improved to enhance biocontrol efficacy of mycoherbicidal agents in weed control strategy. According to Templeton *et al.* (1979) the application of bioherbicides is especially advantageous for controlling parasitic weeds which are difficult to control by the use of chemical treatments, moreover, the biological agents are host specific. In addition, the development of biological agents is less expensive whereas the chemical herbicides are too expensive. Therefore, the bioherbicide can be produced more cheaply than chemical herbicides (Mortensen, 1986) by means of various natural enemies such as pathogenic fungi.

Successful incorporation of bioherbicides into conventional agriculture will be achieved if they are able to suppress multiple weeds of economic importance on a very large scale in successful manner (Charudattan, 1990). Fungal pathogens containing different strains or sub-species have mycoherbicide activity against several weeds effectively and consistently. Fungal pathogens, with broad host-range pathotypes against multiple weed targets are achieved through selective screening or through genetic recombination or hybridization (Charudattan, 1990; Sands and Pilgeram, 2001). Formulation of a bioherbicide is the key for successful biological control and can be defined as the mixing of the biologically active pathogens with inert carriers and other adjuvant to increase efficacy of the pathogen on to the target weed (Rhodes, 1990; Boyette *et al.*, 1996; Connick *et al.*, 1998). The main types of formulations are emulsions, organosilicone surfactants, hydrophilic polymers, alginate, starch and cellulose encapsulated granules. Oil suspension emulsions of mycoherbicides have been investigated as less expensive, easy to prepare and they can be applied with conventional spray equipment and effectively used at relatively reduced volumes. Formulation and delivery systems can greatly improve the field performance of a given dose of a mycoherbicide (Hall and Menn, 2001). Formulation of a bioherbicide should be an ideal product with low cost, long shelf-life, no difficulty of application, effectiveness, stability in the environment and be environmentally safe (Amsellem *et al*., 1991; Auld *et al*., 2003).

Bioherbicide products

Currently, five fungi and one bacterium are registered as bioherbicides in Canada, Japan, South Africa and the United States (Charudattan and Dinoor, 2000).

DeVine®

The product is based on *Phytophthora palmivora*, a fungul pathogen of *Morrenia odorata*, a noxious plant infesting citrus groves. It is sold as liquid suspension of chlamydospores (around 6 x 10^5 spores/ ml) to be applied on the soil surface. It causes stem necrosis and plant death within 1-6 weeks after the application depending on the plant age.

Collego®

This is a commercial product based on the fungus *Colletotrichum gloeosporioides* f.sp. *aeschynomene*. It is used in the United States for biological control of *Aeschynomene virginica*, a legume weed, infesting rice and soybean crops. It consists of dried spores which are applied in liquid suspension.

BioMal®

It contains spores of *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *malvae*. It is used to control *Malva pusilla* (round-leaved mallow) in Canada and USA. The most effective period of application is at an early stage of the weed, although it can be effective at any stage of weed growth. The wettable powder formulation disperses easily in water and applied as a spray to the weed. BioMal® is formulated by using silica gel as a carrier. It provides over 90% control of the target weed.

Dr. Bio Sedge®

It contains the active ingredient *Puccinia canaliculata* for control of yellow nutsedge. It causes a rust disease on its host plant *Cyperus esculentus* L. one of the most terrible weed. The fungal pathogen has been reported to be effective in controlling the target weed using the inundative approach. Dr. Bio Sedge has been developed and registered for sale.

Stompout®

It has been developed in South Africa based on *Cylindrobasidium leave* to control *Acacia* species introduced from Australia. The basidiospores are packaged in small bags, and are suspended in sunflower oil before application. 1-2 ml of inoculum is applied with a brush on the cut surface of weeds. The fungus within 6-12 months is able to colonize the weed and causing death.

Camperico®

An isolate of *Xanthomonas campestris* pv. *poae,* a wilt-inducing bacterium, isolated from *Poa annua* was registered in Japan as the bioherbicide to control annual bluegrass on golf courses. The bacterium in Camperico® is applied immediately after golf course grasses mowing. The number of mycoherbicides that have reached the market is quite low due to a number of constraints include technological problems such as difficulties in producing large amounts of inoculum, formulations that ensure high stability, commercial limitation and biological constraints imposed by climatic conditions after application. Most of these constraints can be reduced or eliminated by appropriate formulation (Greaves *et al*., 1998).

Bioherbicides in integrated weed management

The bioherbicides have an important role in managing invasive weeds which spreading naturally in natural ecosystems and producing significant changes in terms of composition, structure, or ecosystem processes (Masters and Sheley, 2001). Many of the weeds inhabiting rangelands, forests, and crop field areas and considered as invasive weeds. The control of invasive weeds is an emerging management challenge in view of economic, agricultural, ecological and conservation standpoint. Bioherbicides have a significant value for the management of alien weeds in areas where herbicides are not effective. And the applications of bioherbicides are very effective where a primary management goal is the preservation of the environment by restoration of native ecosystems. A farming system that utilizes an array of inter-dependent cultural, biological and herbicidal weed control practices is generally referred as Integrated Weed Management (IWM). As an expanded and long-term approach of weed control, integrated weed management programme including all available strategies such as tillage, cultural practices, herbicides, allelopathy, and biological control to reduce the weed population and minimize the competition with desired plants (Aldrich and Kremer, 1997). Like chemical herbicides, bioherbicides may be most effective as a component in an overall management program rather than as a single tactic approach. This may be the most promising situation for bioherbicides as a practical management option in cropping systems. The integrated weed management offers several opportunities for integration of bioherbicides (Aldrich and Kremer, 1997). The combination of herbicides and pathogens has been suggested as an alternative strategy for weed control (Weaver and Lyn, 2007). The bioherbicides with the combination of herbicides selected for the control of multiple weed is a logical approach (Kremer, 2005). Integration with reduced rates of herbicides can successfully improve the activity of mycoherbicides toward weeds (Heiny, 1994).

The sustainable agricultural systems involve a range of technological and management options to reduce costs, protect health and environmental quality, and enhance beneficial biological interactions and natural processes (National Research Council, 1989). Bioherbicides may be most effective in managing weeds as a component in a biological weed management system that is associated with sustainable agriculture. Biological weed management involves the use of diversity of biological agents such as bioherbicides, biopesticides and biological approaches including allelopathy, crop competition and other cultural practices to obtain similar dramatic reduction in weed densities often associated with herbicide use (Cardina, 1995). Bioherbicide technology used in appropriate integrated weed management is a diversified cropping system may aid in restoring fertility and productivity of the crop and conservation of ecosystems through avoiding the increase of herbicide resistance in invasive weeds. Bioherbicides appropriately integrated into agricultural and environmental restoration systems can play a major role in reclaiming and restoring natural resources and biodiversity. Mycoherbicides are considered as complementary components of current Integrated Weed Management (IWM) systems rather than as alternatives to chemical herbicides. The mycoherbicides to control weeds are considered as an environment-friendly approach. Generally most mycoherbicides have no effect on non-target organisms and do not contaminate soil or ground water (TeBeest and Templeton, 1985). From scientific and practical perspectives, inundative control of weeds with indigenous fungi is a successful and promising technology. The future development of mycoherbicides as a component of integrated pest management systems is dependent on research directed to: (a) the innovation of the endemic pathogens on major weeds (b) the strategies used for the mass production of spores or inoculum (c) studying disease cycles to understand the principal constraints to epidemic build-up of the disease (d) advances in technology with the public support, the financial aid and more scientific research will contribute in the progress of the 'Science of Biological Weed Control'.

Biological control (Biocontrol): Ecofriendly approach

Today most countries are faced with the need to develop alternatives to conventional weed control methods. As alternate to pesticides, biological weed control involves using the living organisms, such as insects, nematodes, bacteria or fungi to reduce weed populations and contamination of environment. Biological control of weeds using plant pathogens is a practical and environmentally sound method of weed management. A variety of herbaceous, woody, climbing, aquatic, and parasitic weeds have been shown to be capable of being controlled by plant pathogens. Biological control with plant pathogens is an effective, safe, selective and practical means of weed management that have gained considerable importance recently (Charudattan, 1986, 1991; Flint and Thomson, 2000; Pemberton and Strong, 2000; Bouda *et al*., 2001). The increasing awareness of public about the influence of different herbicides on food crops and the environment has encouraged researchers to develop alternative weed control approaches such as biological control of weeds (Charudattan, 2001). Weed control using this approach can complement and be integrated with traditional cultural and chemical methods of weed control. The introduction of specific and potential natural enemies is the principal technique for the control of exotic weeds through biological control (Andreas *et al.,* 1976; Simmonds, 1970). Recently biological control has received more attention as an eco-friendly approach and it is considered as the most important component of Integrated Pest Management (IPM). Biocontrol of weeds using plant pathogens consists of two strategies: (1) the classical strategy, that involves an initial inoculation of self-sustaining agent onto weed population (2) the augmentative or inundative approach, that utilizing the annual application of endemic or foreign bioherbicidal agents. The highly virulent pathogens always make the most effective bioherbicides, but this concept has been effectively challenged (Hallett, 2005). Pathogen-mediated biocontrol of weeds generally employs a potential pathogen or insect to manage a weed population. When the plant pathogens are fungi, these bioherbicides are often called "mycoherbicides".

Fungal Biological Control Agents

Plant pathogens are utilized as biocontrol agents with tremendous potential, as shown by the success of DEVINE® and COLLEGO® in controlling specific target weeds in USA. DeVine, a liquid formulation of *Phytophthora palmivora* (Butl.) Butl. was registered in 1981 for the control of strangler vine (*Morrenia odorata* (H. & A.) Lindl.) in Florida citrus groves. Collego, a powder formulation of *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. f.sp. *aeschynomene* was registered in 1982 for the control of northern jointvetch (*Aeschynomene virginica* (L.) Britton, Sterns & Poggenburg) in rice and soybeans in Arkansas, Louisiana and Mississippi (Watson, 1991). Many examples of weed control with pathogens exist, such as the control of hamakua pamakani weed [*Ageratina riparia* (Regel) R. M. King & H. Rob.] by the *Entyloma compositarum* (Trujillo *et al.*, 1988), milkweed vine or strangler vine [*Morrenia odorata* (H. & A.) Lindl.] by DeVine (*Phytopthora palmivora*) (Kenney, 1986), musk thistle (*Carduus nutans* L.) by *Puccinia carduorum* (Baudoin *et al*., 1993), sicklepod (*Cassia obtusifolia* L.) by *Alternaria cassiae* (Walker and Riley, 1982; Charudattan, 1986), skeleton weed (*Chondrilla juncea* L.) by *Puccinia chondrillina* (Supkoff *et al*., 1988), yellow nutsedge (*Cyperus esculentus* L.) by *Puccinia canaliculata* (Phatak *et al*., 1987) and wild persimmon (*Diospyros virginiana* L.) by *Cephalosporium diospyri* (Griffith, 1970).

Limiting factors of bioherbicide adoptions and use

Factors like the narrow host range, specific requirements for culturing and formulation of the biotic agents and the release of potent mammalian and avian toxins by some fungal agents have limited commercial development of bioherbicides (Kremer, 2005). It is estimated that there are over 200 plant pathogens under evaluation for their potential as bioherbicides (Charudattan, 2001). The most frequent constraint of a mycoherbicide is imposed by environmental conditions after the field applications and the effectiveness of the primary infection of the mycoherbicide relying on temperature and humidity (McRae and Auld, 1988; Makowski, 1993; Shabana, 1997; Zhang and Watson, 1997; Pfirter and Defago, 1998). Researchers have shown that some of these constraints can be overcome through formulation based approaches. Boyette (2006) found that a surfactant greatly improved the bioherbicidal potential of the pathogen *Colletotrichum gloeosporioides* for control of sicklepod (*Senna obtusifolia*), a serious weed pest. The uses of various crop oils and invert emulsions have resulted in improved bioherbicide efficacy and performance of several biocontrol fungi (Auld, 1993; Egley and Boyette, 1995; Ghorbani, 2000; Sandrin *et al*., 2003; Boyette, 2006; Amsellem *et al*., 1990; Boyette *et al*., 1993; Womack *et al.*, 1996; Shabana, 2005).

Trianthema portulacastrum L. (Horse purslane)

Trianthema portulacastrum L. is a noxious annual weed belonging to family Aizoaceae (Fig.1). It is indigenous to South Africa but widely distributed in India and Sri Lanka (Balyan and Bhan, 1986; Javed *et al.,* 2000). It has become a noxious weed due to competition for soil, water and nutrients and spreads rapidly in various agricultural crops such as maize, mustard, pigeon pea, mung bean, potato, onion, cotton, soybean, pearl millet and sugarcane during crop growth and causing 50-90 % yield reduction (Balyan, 1985; Balyan and Bhan, 1986; Balyan and Malik, 1989). Enormous seedling capacity or very little dormancy allows the mature seed to germinate immediately, thus producing multiple generations in the same season. In Pakistan and India, horse purslane is a common weed during summer season in the major field crops such as pulses, cotton, sugarcane, direct seeded rice and maize. Its infestation in cotton, maize and direct seeded rice, especially in rainy season is a matter of great concern and could reduce crop yields by 32-60% (Baylan and Malik, 1989). Significant losses in maize and peanut yield are also attributed to this weed (Grichar, 2008). The weed plants *Trianthema portulacastrum* L. and *Cynodon dactylon* (L.) Pers. are the most economically important weeds of rainy season crops in India (Balyan, 1985). *T. portulacastrum* generally emerges before soybean or along with soybean and eventually growing faster than soybean and mungbean (Balyan and Malik, 1989). The carpet weed (*T. portulacastrum*) and barnyard grass weeds competed severely with soybean and caused yield reduction from 29 to 87% (Mishra *et al.*, 1990) and horse purslane reduced mung bean [*Vigna radiata* (L.) R. Wilcz.] yield up to 50 to 60% when left untreated (Balyan, 1985; Balyan and Malik, 1989). Horse purslane and barnyard grass are troublesome weeds of leguminous crops grown in semiarid regions of the world (Balyan and Bhan, 1986). *T. portulacastrum* is a serious weed by means of its allelopathic potential. Allelopathic growth inhibition of crop plants owing to horse purslane has also been reported (Sethi and Mohnot, 1988). The presence of different allelochemicals and other compounds of *T. portulacastrum* may inhibit seed germination and vigour of seedlings of other weed plants and crops including sorghum, pumpkin, eggplant, radish, several pulses and wheat. The extracts of *T. portulacastrum* and *Sesuvium portulacastrum* L. significantly inhibited the root length, shoot length and seedling vigour of crop plants. These weed species and interaction of weed extracts significantly affected the germination of crops such as millet, sorghum, maize, wheat, mung bean, guar and sunflower (Asghar *et al.*, 2013). In India, horse purslane has been reported in the states of Uttar Pradesh, Punjab, Haryana, Rajasthan and Delhi. It was considered as a serious terrestrial weed by virtue of its infestation in various agricultural and vegetable crops such as mustard, maize, pigeon pea, mung bean, potato, onion, cotton, soybean, pearl millet and sugarcane especially during the rainy seasons (Balyan and Bhan, 1986). Recently, interference of horse purslane with economic crops and the heavy losses of yield due to its competition with field crops reported around the world. Despite, many negative effects of *T. portulacastrum* (horse purslane) as an economically important terrestrial weed in India, the control methods are not well developed. Currently, *T. portulacastrum* has turned into a harmful weed due to its competition with various agricultural and vegetable crops such as mustard, maize, pigeon pea, soybean, potato and onion in Northern India. Therefore, the management of horse purslane should be needed in various crops and the control methods should be more effective and eco-friendly in view of the conservation of natural habitats.

Scientific classification (Shivhare *et al.*, 2012)

Kingdom	: Plantae
Sub Kingdom	: Tracheobionta
Division	: Spermatophyta
Sub Division	: Magnoliophyta
Class	: Magnoliopsida
Sub class	: Caryophyllidae
Order	: Caryophyllales
Family	: Aizoaceae
Genus	: *Trianthema* Linnaeus
Species	: *Trianthema portulacastrum* L.

Geographical distribution

Trianthema portulacastrum L. (Horse purslane) is a weed plant of Aizoaceae. It is known as Hand Qooqi in Arabic, Dewasapt in Persian and Horse purslane in English. It is an annual indigenous plant of South Africa and found in tropical and subtropical countries of the world and widely distributed in India, Sri Lanka, Baluchistan, West Asia, Africa and Tropical America (Kirtikar and Basu, 2003). In India and neighbouring countries, it is a serious weed during summer season in the major field crops such as pulses, cotton, sugarcane, direct seeded rice and maize. Its infestation in cotton, maize and direct seeded rice especially in rainy season is a matter of great concern and could reduce crop yields by 32-60% (Baylan and Malik, 1989). *Trianthema* comprises about 17 species and is closely related to *Sesuvium* and *Cypselea*. These three genera are thought to link the Aizoaceae to the Portulacaceae.

Vernacular Names

Trianthemae portulacastrum L. have several common names (also known as Vernacular names) worldwide. The common names of horse purslane in different languages listed below (Ibn Baitar, 2000; Prajapati and Kumar, 2003; Kirtikar and Basu, 2003; Shanmugam *et al.*, 2007; Anonymous, 2007).

Arabic :Hand Qooqi
Bengali :Sabuni/Gadabani
Chinese :Jia Hai Ma Chi
English :Horse purslane/ Carpetweed/ Giant pigweed
Hindi :Salasabuni/ Sabuni/ Vishakhapara/Lal-sabuni/Santhi/ Svet-sabuni
Kannada:Muchchugoni/ Pasalaesoppu.
Malayalam:Pasalikeera
Marathi :Pundharighentuli
Oriya :Sweta Puruni
Persian :Dewasapt
Punjabi :Biskhapra/ Itsit
Sanskrit :Chiratika/Dhanpatra/Vishakha/Shvetapunarnava/ Shvetamula/ Upothaki.
Sindhi :Narmah
Spanish :Verdolaga
Tamil :Sharunnai/Shavalai/Shaaranaj
Telugu :Ambatimadu/ Atikamamidi/ Galijeru.
Unani :Lotoos Aghryoos
Urdu :Biskhapra

Taxonomic description (Gamble *et al*., 1967; Pullaiah and Chennaiah, 1997).
Syn. *T.monogyna* L. Mant.

Family: Aizoaceae

Annual or perennial herbs; leaves simple, often fleshy, opposite, alternate or falsely whorled; stipules scarious or 0; flowers regular, hermaphrodite or rarely polygamous, in cymes or fascicles, rarely solitary; calyx of 4-5, sepals free or rarely adnate to the ovary, usually persistent; petals usually 0, when present small; stamens perigynous or hypogynous, definite or indefinite, sometimes with staminodes; filaments free or connate; anthers oblong; ovary free, 2-5 celled, syncarpous or rarely apocarpous; ovules many in each carpel, axile or solitary basal; styles as many as the carpels; fruit usually capsular, dehiscing loculicidally or circumscissile, some times of indehiscent cocci; seeds many or 1 in each carpel, usually reniform, compressed; testa membranous or

crustaceous, often pitted or tuberculate; curved or annular embryo.
Syncarpous fruit;
Calyx tube elongate;
Stamens inserted on the calyx tube;
Capsule circumsciss;
Petals 0;
Ovary and capsule 1-2 celled...............***Trianthema***
Leaves obovate;
Flowers solitary, sessile, sheathed by the base of the petiole;
Style 1; stamens 10 or 15;
Capsule top mitriform, enclosing at least 1 seed, the lower part 3-5 seeded; Seeds with concentric muriculate lines..................***T. portulacastrum***

Macroscopic description: (Morphology)

Plants are diffuse, prostrate, branched herbs; glabrous or papillose; thickened and flattened at the nodes; Root- a taproot system with fibrous hairs; Stem - more or less angular, glabrous or pubescent, much branched; Leaves - petioled, opposite, unequal, one of the lower pair much smaller than the other, entire, sub-fleshy; leaf blade obovate to orbicular, or oblong, 1.5-3.5 X 1-3 cm, sub-succulent, purplish on margins, base cuneate, margin entire, apex obtuse, apiculate, petioles of each pair connected at the base by stipuliform membranous; Flowers - small, white or bright pink, axillary, solitary in pouch or between forks of branches; bracts membranous as are the 2 bracteoles; calyx tube short or long; lobes 5, coloured within, mucronate on the back near the tip; petals 0; stamens 5, 10, or 15, inserted near the top of the calyx-tube, filaments white, glabrous; Ovary free, sessile, usually truncate at apex, 1-2 celled; ovules 1 or more in each cell, from a basal placenta; styles 1 or 2, papillose. Fruit - a capsule, capsules circumscissile, glabrous, partly concealed in the petiolar hood; the upper part carrying away 1-2 seeds, the lower 2-many seeded. Flowering - June to October; Fruiting - July to December; Seeds are reniform, muriculate and dull black in colour with epigeal germination (Kirtikar and Basu, 2003). The production of flowers and seeds of *T. portulacastrum* starts 20 - 30 days after germination of the seeds. Enormous seeding capacity or very little dormancy allows the mature seed to germinate immediately thus, producing multiple generations in the same season. Cotyledons are elliptic and have epigeal germination. Seeds of *T. portulacastrum* germinate between 20- 45°C, with an optimum at 35°C. More than 50% of fresh seeds germinate within 4-8 days of incubation.

Microscopic description (Anatomy)

Mature root shows anomalous secondary growth; cork 5 to 8 layered; secondary cortex narrow zone consisting of round to polygonal, tangentially elongated, thin-walled, parenchymatous cells; a few cells containing groups of prismatic crystals of calcium oxalate; below secondary cortex five concentric bands of vascular tissue; vessels of varying sizes occurring along with xylem fibres and phloem; phloem composed of thin walled cells having intercellular spaces, a few cells containing prismatic crystals of calcium oxalate; a few rows of polygonal, thin walled, parenchymatous cells occur in rings; medullary rays prominent in middle of the cortical region and in the second or third vascular bundle ring; centre mostly occupied by a single vascular bundle strand with two isolated groups of phloem (Anonymous, 2007).

Weed properties

Trianthema portulacastrum L. is a common weed in fields and open sunny localities such as road sides. It is often found on clay soils and muddy coastal zones of the sea up to 200 m altitude. It is an annual herb which spreads on the ground in circle and not more than 4-6 ft in length. The plant is found in tropical and subtropical countries of the world, and almost throughout India as a weed in cultivated and waste lands. In India both red and green biotypes grow profusely under partial shade and flourish in neutral to alkaline soils that are low in organic matter. The plant is one of the problematic terrestrial weed by virtue of its competitiveness as a C_4 species. Significant losses in maize and peanut yield are also attributed to this weed (Grichar, 2008). It shows allelopathic effects on other weeds and crops including sorghum, pumpkin, eggplant, radish, several pulses and wheat by inhibiting seed germination and vigour of seedlings. Interestingly it is also autotoxic as plant extracts reduce its seed germination, shoot length and vigour. Allelopathic growth inhibition of crop plants owing to horse purslane has also been reported (Sethi and Mohnot, 1988). Horse purslane causes heavy losses to agriculture worldwide (Aneja *et al.*, 2000; Balyan and Bhan, 1986; Saeed *et al.*, 2010; Simmons, 1986). Balyan and Malik (1989) reported that horse purslane is a strong competitor and reducing the yield of mung bean [*Vigna radiata* (L.) R. Wilczek] by 50 to 60% when left untreated. Significant losses in maize, soybean, and peanut (*Arachis hypogaea* L.) yield are also attributed to this weed (Grichar, 1993, 2008; Hazra *et al.*, 2011; Saeed *et al.*, 2010). Up to 60-70% infestation of this weed has been reported in pigeon pea and soybean fields and 80-90% in maize and brassica fields (Aneja *et al.*, 2000). Negative allelopathic effects of extracts of horse purslane on seed germination, seedling vigour, and productivity in soybeans and other crops also reported (Sethi and Mohnot 1988; Umarani and Selvaraj, 1995). High seed production and short dormancy allow the mature horse purslane seed to germinate rapidly, thereby producing multiple generations in a single season.

Economic importance

Leaves of *Trianthema portulacastrum* L. used in dropsy, edema and ascites. Decoction of herb used as an antidote in alcohol poisoning, also used in rheumatism and as a vermifuge. It is also used as alternative cure for bronchitis, heart disease, anaemia, inflammation and piles (Kirtikar and Basu, 2003; Ambasta, 1986). The young tops and leaves of horse purslane are used as cooked vegetable and also preparation of soups in several regions such as Africa, Ghana, Cameroon, Tanzania and South-East Asia. However, the plant may cause diarrhoea or paralysis, particularly when older leaves are eaten. Moreover, the fodder (foliage of the weed) can produce similar effects on domestic animals, because of this deadly effect most animals are refused to eat. The seeds are harmful contaminants in food grains and other crop seeds. The plant has a potential value as a source of organic matter. In Africa, the Philippines, Thailand and India roots of horse purslane are used to relieve obstructions of the liver and to relieve asthma. The leaves are diuretic and are applied in the treatment of edema, jaundice, painful discharge of urine and dropsy. A decoction of the herb is used as a vermifuge and also utilized for the cure of rheumatism. And it is considered as an antidote to alcoholic poisoning. The fleshy nature of the leaves makes them suitable for use as a wound-dressing or bandage.

Management of Trianthema portulacastrum L. (horse purslane)

The weed plant *T. portulacastrum* often controlled either by uprooting the plants before flowering, or by the application of pre- and post-emergence herbicides such as acifluorfen, alachlor, atrazine, bentazon, fluchloralin, fomesafen, paraquat and pyruvate. Mechanical means of weed control is time consuming and has become labour intensive and the heavy applications of chemical herbicides leads to increase of soil and water pollution. In the view of the increasing global concern about pesticide residues in the biosphere and public demand for pesticide free food, the exploitation of microorganisms especially plant pathogenic fungi is now emerging as an effective and eco-friendly alternative to conventional methods of weed control (Aneja, 2009; Aneja and Kaushal, 1998; Charudattan, 1991). Biological control of weeds has advantages over mechanical and chemical methods and they can be specific to the weed and do not lead to residue problems and accumulation of toxic pollutants in the soil or underground water (Hasan, 1980).

The common weed control methods against this weed include hand weeding, hoeing, inter-row tillage and chemical herbicides (Aneja *et al.*, 2000; Grichar, 2007, 2008). The mechanical removal of plants during traditional weeding does not help in reducing weed infestation. Hand hoeing is costly while inter-row tillage and weedicides cannot be used during rainy seasons. Furthermore, herbicides may enhance soil and environmental pollution. Notwithstanding, the chemical herbicides are the most effective immediate solution to the control of weeds, the increase and indiscriminate use of these chemical herbicides resulted in resistance of several weeds. Moreover, persistent residues of the organochlorine pesticides (Ex: DDT and HCH) which are highly poisonous to human beings have been found in vegetables, milk, butter, meat as well as in mother’s milk. Enormous seedling capacity or very little dormancy allows the mature seed to germinate immediately to produce multiple generations in the same season. The large seed bank of horse purslane and subsequent irrigation facilities in the crop fields allows the profuse growth and infestation of the weed. Hand hoeing is a common practice for horse purslane control in mung bean in India (Balyan and Bhan, 1986). Hand weeding and hoeing are common practices of controlling this weed in the developing countries of the world; but this method is quite expensive and time consuming. New seeds of the weed plant germinate after every hoeing and infest the crops and moreover hoeing is not possible during rainy season. Therefore, mechanical means of weed control is ineffective and has become labour intensive.

The herbicides, Fluchloralin [N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl) benzen-amine], Pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl- 2,6-dinitrobenzenamine](5, 11, 12), Alachlor [2-chloro-N-(2,6 -diethylphenyl) - N -(methoxymethyl) acetamide], or Nitrofen [2,4-dichloro-l-(4-nitrophenoxy)benzene] have been reported to control horse purslane in mung bean (Dhingra *et al.,* 1984). These herbicides can control the weed on a small scale and they are not feasible for large infestation of the weed at environmentally sensitive areas. Further, the increased and indiscriminate use of herbicides has resulted in herbicide resistance and environmental hazard (Van Gessel, 2001; Mamy *et al.,* 2010). Balyan and Bhan(1986) stated that horse purslane seeds have essentially no dormancy and can germinate immediately after maturation. Therefore, multiple post-applications of non-residual herbicides are required for season-long control.

Nowadays allelopathy has been recognized as a natural weed control approach (Hardwood, 1979; Rice, 1984). Different crops possess allelochemicals, which could be utilized for suppressing weeds (Putnam and DeFrank, 1979). Combined application of sorghum, sunflower and *Brassica* sp. residues has potential to suppress germination and seedling growth of horse purslane. Sorghum water extract at higher concentrations suppressed the germination, root and shoot growth of *T. portulacastrum* and this suppression was perhaps due to the presence of allelochemicals in sorghum plant (Randhawa *et al.*, 2002).

Biological control of weeds has advantages over mechanical and chemical methods of weed control. Unlike chemical weedicides, biological control agents (BCAs) are specific to the target weed and do not lead to residue problems and accumulation of toxic pollutants in the soil or underground water (Hasan, 1980). The use of effective bioherbicidal plant pathogens may offer such an alternative to weed control (Cook *et al.,* 2005). Biological control agents (BCAs) are generally perceived by the public to be more environmentally friendly and safer for users and consumers. The fungus *Myrothecium verrucaria* (Alb. & Schwein.) Ditmar has considered as a promising mycobioherbicide for controlling several divergent weed species. In field tests, inoculum treatments of weed with conidia of *M. verrucaria* in 0.2% Silwet caused 90-95% mortality of horse purslane. In addition, the plant mortality affected by these treatments was equivalent to the treatment with the herbicide metribuzin (Boyette *et al.,* 2007). The extensive studies of Mitchell (1988) and Aneja and Kaushal (1998) reported the herbicidal potential of *Gibbago trianthemae* Simmons against horse purslane. Many distinguished characters of the fungal pathogen *Gibbago trianthemae* attracted researchers and agronomists as a promising candidate for biological control of *Trianthema portulacastrum* L. Horse purslane was naturally controlled by Trianthema Mosaic Virus, which causes distinct necrotic lesions on the leaves and fungi such as *Macrophomina phaseolina*, causing dry root rot, and *Colletotrichum capsici*, *Fusarium semitectum*, *Drechslera* sp., *Stemphylium* spp. and *Gibbago trianthemae* cause leaf spot diseases. Earlier studies indicated the potential of biological control of horse purslane using different plant pathogens (Aneja and Kaushal, 1998; Aneja *et al.*, 2000; Bohra *et al.*, 2005; Boyette *et al.,* 2007; Mitchell, 1988). Mycoherbicides are primarily attractive because they can be weed specific, have low environmental impact, and are often cost effective (TeBeest *et al.*, 1992). Mitchell (1988) and Aneja and Kaushal (1998) reported the herbicidal potential of *Gibbago trianthemae* Simmons against horse purslane. Boyette and Abbas (2001) reported the bioherbicide *Myrothecium verrucaria* (Albertini & Schwein) Ditmar. Fr., isolated from sicklepod [*Senna obtusifolia* (L.) H.S. Irwin & Barneby] and the fungus eliminated horse purslane and several other weeds that have seriously interfered with commercially grown tomatoes. Similarly Babu *et al.,* (2004) reported *Paecilomyces variotii* Biourge & Bain. as mycoherbicide against horse purslane in South India. Fungal pathogens namely *Cercospora trianthemae* (Chiddarwar, 1962), *Gibbago trianthemae* (Aneja and Kaushal, 1998; Simmons, 1986), *Drechslera* (*Exserohilum*) *indica* (*Bipolaris indica*) (Taber *et al.*, 1988; Rao and Rao, 1987), *Colletotrichum gloeosporioides* (Darshika and Daniel, 1992), *Fusarium oxysporum* (Darshika and Daniel, 1992), *Fusarium semitectum* (Darshika and Daniel, 1998), *Alternaria alternata* (Bohra *et al.*, 2005; Gupta and Mukherji, 2001) and *Phoma herbarum* (Ray and Lakshmi, 2013) have been reported on this weed around the world (Table 1). Among all the isolates the fungal pathogen, *Gibbago trianthemae* has shown potential to control horse purslane weed (Aneja *et al.*, 2000; Aneja, 2010; Aneja *et al.*, 2013). A total of three leaf spot diseases caused by pathogenic fungi e.g. *Cercospora trianthemae*, *Drechslera indica* and *Gibbago trianthemae*, recorded on this weed; among them only *Gibbago trianthemae* have been evaluated as a potential biocontrol agent.

Gibbago trianthemae Simmons - a promising mycoherbicidal agent

Foremost, *Gibbago trianthemae* Simmons, sp. nov., type of a new genus, is described by E.G. Simmons and this fungal pathogen isolated from parasitized leaves of *Trianthema portulacastrum* L. (Aizoaceae) collected in Cuba, USA (Texas), and Venezuela. Genus characters are compared with those of somewhat similar genera *Alternaria*, *Embellisia*, *Stemphylium*, and *Ulocladium*. The isolate *Gibbago trianthemae* has several characteristics similar to those of the genera *Stemphylium* and *Alternaria* but is distinct from them (Simmons, 1986). Between 1989 and 1998 a series of surveys of plant pathogenic fungi associated with naturally infected horse purslane were conducted in the states of Haryana and Punjab. In 1990, a leaf spot disease due to this fungus, causing epiphytotics (foliar disease) was observed for the first time at Kurukshetra in India. Highly infected leaves of *T.*

Table 1 The exploration of microbes on *Trianthema portulacastrum* L. around the world

S. No	Fungal species	Reporting Year	Reporting Country	References
1	*Cercospora trianthemae*	1962	India	Chiddarwar (1962)
2	*Gibbago trianthemae* Simmons	1986	USA	Simmons (1986)
3	*Drechslera* (*Exserohilum*) *indica* (*Bipolaris indica*)	1987	India	Rao and Rao (1987)
4	*Gibbago trianthemae* Simmons	1988	USA	Mitchell (1988)
5	*Drechslera* (*Exserohilum*) *indica* (*Bipolaris indica*)	1988	USA	Taber *et al*. (1988)
6	*Colletotrichum gloeosporioides*	1992	India	Darshika and Daniel (1992)
7	*Fusarium oxysporum*	1992	India	Darshika and Daniel (1992)
8	*Gibbago trianthemae* Simmons	1998	India	Aneja and Kaushal (1998)
9	*Fusarium semitectum*	1998	India	Darshika and Daniel (1998)
10	*Gibbago trianthemae* Simmons	2000	India	Aneja *et al*.(2000)
11	*Alternaria alternata*	2001	India	Gupta and Mukerji (2001)
12	*Myrothecium verrucaria* (Albertini & Schwein) Ditmar. Fr.,	2001	USA	Boyette and Abbas (2001)
13	*Paecilomyces variotii* Biourge & Bain.	2004	India	Babu *et al*. (2004)
14	*Alternaria alternata*	2005	India	Bohra *et al*.(2005)
15	*Alternaria alternata* (Fr.) Keissler	2013	India	Ray and Lakshmi (2013)
16	*Fusarium oxysporum* Schltdl.	2013	India	Ray and Lakshmi (2013)
17	*Phoma herbarum* Westendorp	2013	India	Ray and Lakshmi (2013)
18	*Gibbago trianthemae* Simmons	2013	Pakistan	Akhtar *et al*. (2013)
19	*Fusarium chlamydosporum* Wollenw. & Reinking	2014	India	Aneja *et al*.(2014)
20	*Gibbago trianthemae* Simmons	2014	India	Ratna Kumar and Gaddeyya (2014)

Figure 1 Biological control of horse purslane weed with fungal pathogen *Gibbago trianthemae* (A) Weed plant (B) Leaf spot disease (C) Colony of *G. trianthemae* (D) Conidia of *G. trianthemae* (E) Bioherbicide activity of *G.trianthemae*

portulacastrum collected from various sites yielded a phaeodictyoconidial fungus *Gibbago trianthemae* Simmons (Aneja *et al.,* 2000). In earlier, the reports of Mitchell (1988) supported the candidate *Gibbago trianthemae* as a skilful agent to control horse purslane. Weed plants sprayed with conidia at 1×10^5 spores/ml or more density, killed within 9 days after spore treatment. In host-range studies the fungus was extremely pathogenic only to horse purslane and not to other economically important crops. Result of both pathogenicity and host-range studies demonstrated that this fungus may be a useful agent for the biological control of horse purslane. The fungus *G. trianthemae* was highly recommended by previous studies as biological control agent which causing extensive defoliation of horse purslane followed by the mortality of the weed within short period. However, the extensive study on mycoherbicidal activity was not reported to develop this candidate as a mycoherbicide. The foliar pathogen *Gibbago trianthema*e, a phaeodictyoconidial fungal species was recorded on infected leaves of horse purslane in 1969 at experimental farm, University of Massachusetts by E.G. Simmons for the first time in the world. Leaf spot disease of horse purslane weed due to *G. trianthemae*, causing epiphytotics was recorded by various workers of USA (Simmons, 1986; Mitchell, 1988), India (Aneja and Kaushal, 1998; Ratna Kumar and Gaddeyya, 2014) and Pakistan (Akhtar *et al.,* 2013) and the findings supported the biocontrol potential of the pathogen. The fungal pathogen *G. trianthemae* can be highly aggressive towards horse purslane and it has certain characteristics such as high virulence and host specificity to make a desirable candidate for biological control of horse purslane weed (Fig.1).

CONCLUSION

Gibbago trianthemae, one of the foliar fungal pathogen of *T. portulacastrum* has been identified on highly infected weed plants at agricultural fields of Visakhapatnam District. The pathogenicity and host specificity of the pathogen was confirmed by green house experiments at plant pathology laboratory in Andhra University. Furthermore, the exploitation on mycoherbicide potential of *G. trianthemae* was determined in green house experiments. This study revealed that the horse purslane populations were eliminated by means of the adverse effects caused by *G. trianthemae* at field as well as in greenhouse conditions. The fungal pathogen *G. trianthemae* was highly virulent and host specific and showed potential herbicide activity against horse purslane weed. The quantitative data on disease severity (DS) was revealed the biocontrol potential of *G. trianthemae* as a successful mycoherbicide. The extensive work is required to study pathogenicity, adaptability, and dispersal and survival efficiency of the pathogen for the development of a commercial mycoherbicide.

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How to cite this article:

Gaddeyya G *et al* (2017) 'Microbial Technology in Weed Management: A Special Reference of Biological Control of Horse Purslane Weed ', *International Journal of Current Advanced Research,* 06(07), pp. 4978-4991.
DOI: http://dx.doi.org/10.24327/ijcar.2017.4991.0628

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