We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

Chapter 5

Current and Potential Use of Phytophagous Mites as Biological Control Agent of Weeds

Carlos Vásquez, Yelitza Colmenárez,
José Morales-Sánchez, Neicy Valera,
María F. Sandoval and Diego Balza

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/59953

1. Introduction

Biological control of weeds by using phytophagous mites may help to contain infestations and reduce their spread in time. Although, eradication is not the goal due to the vastness of the areas, the most desirable scenario is achieved when weeds are no longer a concern and no other control is necessary. However, biological control should not be considered the unique strategy to face weed problems, thus commonly; other methods are still required to attain the desired level of control.

There is an increasingly interest in using mites for biological control of weeds, primarily those belonging to Eriophyidae because of they are host-specific and often weaken the host plant affecting plant growth and reproduction. Although eriophyid mite species impact the fitness of their host plant, it is not clear how much they have contributed to reduction of the population of the target weed. In some cases, natural enemies, resistant plant genotypes, and adverse abiotic conditions have reduced the ability of eriophyid mites to control target weed populations. Besides, susceptibility of eriophyids to predators and pathogens may also prevent them from achieving population densities necessary to reduce host plant populations.

In addition to eriophyid mites, tetranychid mites are also being considered as an alternative for weed control. The gorse spider mite, *Tetranychus lintearius* Dufour, has shown to reduce shoot growth on gorse (*Ulex europaeus* L.) by around 36% in impact studies conducted over 2.5 years in Tasmania. New colonies expand rapidly and cause severe damage to gorse plants, but often do not persist in large numbers.

Since the use of phytophagous mite species is a safe alternative for controlling weeds, in this chapter we will review some examples of biological control programs using eriophyid and tetranychid mites worldwide.

2. The problem with weeds

Weeds can be defined as plants growing out of place. For example, water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is widely planted as a water ornamental but when environmental conditions are suitable it spreads rapidly obstructing lakes, rivers and rice paddy fields, affecting adversely human activities (fishing, water transport) and biodiversity [1]. Similarly, morning glory is beautiful in the garden, but also it can cause 30% yield loss [2].

Invasive non-native plants are a serious threat to native species, communities, and ecosystems since they can compete with and displace native plants, animals, and other organisms that depend on them, alter ecosystem functions and cycles significantly, hybridize with native species, and promote other invaders [3]. However, according to these authors, reversion, halting or slowing of plant invasion and even restoring badly infested areas to healthy systems dominated by native species is possible but actions to control and manage those invasive plants are required.

Details of weed management approaches will obviously vary from crop to crop. For instance, although weed control remains a major concern in organic agriculture, producers have limited tools for managing weeds [4].

3. Weed control techniques

Weed control techniques can be grouped in the following categories:

1. Prevention: it consists in avoiding introduction of weeds within an area based on cultural and mechanical practices (such as clean seed use, sanitation of mechanical implements) that ensure sanitary conditions and minimize weed introduction.
   a. Cultural: cultural practices promoting vigorous, dense crops are the most important and least recognized means of preventing weed establishment and encroachment. Also soil fertility, humidity and chemical properties (pH, electrical conductivity, etc.) may favor one plant species over another. Other cultural means of control involve covering a weed infested area with mulches to exclude light.
   b. Mechanical (physical): mechanical control of weeds involves hand pulling or various types of tractor-powered tillage operations.
2. Chemical: One of the major contributing factors to the advancement of man's way of life during the 20th century has been the development of chemical compounds for pest control. The first major selective pest controlling compound used was a lime-copper-

http://dx.doi.org/10.5772/59953

sulfur mixture known as the Bordeaux mixture, which also was used for broadleaf weed control.

3. Biological: Biological methods use weeds' natural antagonists as control agents. The objective of biological control is not weed eradication, but rather the reduction of the population below a level of economic or aesthetic injury.

4. Biological control: A weed management approach

Definition: Weed biocontrol strategies are based on the use of natural enemies to suppress the growth of a weed or to reduce its population [5].

Main strategies of Biological Control: There are two basic strategies for implementing the biological control of weeds:

- The classical biological control which involves the introduction of foreign biological control organisms, and
- Non classical biological control including augmentative strategies, where the biological control agent is already present (native or introduced) and their population is increased by mass rearing [6] and also inundative strategies which includes releasing of large number of the agent to control the target weed. Ex. mycoherbicides [7].

The classical biological control has three disadvantages, such as: high initial costs, limited number of natural enemies for each target weed species and inability to control the biological control agent dissemination after being released in nature [8]. In addition, successful weed control is strongly dependent on favorable conditions promoting biological control agent population increasing, thus stimulating the establishment of epiphytotics to reduce the target weed population [6].

5. Classical biological control of weeds: The beginning

The first intent of classical biological control of a weed species is documented in southern India in 1863 and in Sri Lanka in 1865 with introduction of a cochineal mealybug *Dactylopius ceylonicus* Green against the cactus *Opuntia vulgaris* Mill. [9]. Although it failed, it was followed by the release in 1914 of another strain which resulted in the successful control of *O. vulgaris* [10]. After that, introduction of up to 30 separate insect species rendered in the successful control of common pest pear *Opuntia stricta* (Haw.) Haw. by the moth *Cactoblastis cactorum* (Berg), and of other cacti by this moth and different *Dactylopius* species [10]. Later, the first significant program of classical biological control, involving the import of agents following a search in the country of origin of the weed, was the program against *Lantana camara* L. in Hawaii. For this, 23 different insect species from Mexico were shipped to Hawaii, of which 14 were released and eight of these established to give adequate control of lantana in most areas [11].

6. Mites as biological control agents of weeds

Insects and, in lesser extent, pathogens have long been considered as the main agents of weed control. Specialized literature lists most of the successful using one of these organisms. For example, the search for biological agents to control water hyacinth began in the early 1960s resulting in six arthropod species released around the world including five insect species [*Neochetina bruchi* (Hustache), *N. eichhorniae* (Warner), *Niphograpta albiguttalis* Warren, *Xubida infusellus* (Walker) and *Eccritotarsus catarinensis* (Carvalho)] and only one mite species [*Orthogalumna terebrantis*Wallwork] [12]. As result, the mite and *X. infusellus* have not contributed to control and only *N. bruchi*, *N. eichhorniae* and *N. albiguttalis* have been released in numerous infestations since the 1970s and have contributed to successful control of the weed in many locations [12]. Other classical example of predominance of insects as bio control agent is referred to *L. camara*. First attempts were made with importation of 23 insect species to Hawaii from Mexico. After that, thirty-nine insect species have been deliberately or unintentionally released as biocontrol agents or otherwise associated to lantana worldwide and only 27 of them have established in at least one country or island [13] (see table 1). In contrast, only three fungus species have been used, such as: *Mycovellosiella lantanae* var. *lantanae* (Chupp) Deighton (Mycosphaerellaceae), *Prospodium tuberculatum* (Spegazzini) Arthur (Pucciniaceae) and *Septoria* sp. (Sphaeriopsidaceae) released in South Africa, Australia and Hawaii, respectively [13]. In turn, only one eriophyid species, so called *Aceria lantanae* (Cook) have been reported on lantana [14] (Fig 1).

Biological control agent	Country released
LEPIDOPTERA	
Autoplusia illustrata Guenée	Australia, South Africa
Cremastobombycia lantanella Busck	Hawaii
Diastema tigris Guenée	Zambia, Australia, Micronesia, Fiji, Ghana, Hawaii, St. Helena, Tanzania, Uganda
Ectaga garcia Becker	Australia
Epinotia lantana Busck	Micronesia, Hawaii, Marshall Islands, South Africa, Australia
Hepialus sp.	Hawaii
Hypena laceratalis Walker	Micronesia, Hawaii, South Africa, Fiji, Australia, Guam
Lantanophaga pusillidactyla (Walker)	Micronesia, Hawaii, Hong Kong, Palau, South Africa
Leptostalis sp.	Jamaica
Oxyptilus sp.	Jamaica
Neogalea sunia (Guenée)	Australia, Micronesia, Hawaii, South Africa
Pseudopyrausta santatalis (Barnes and McDunnough)	Micronesia, Fiji, Hawaii
Salbia haemorrhoidalis Guenée	Kenya, Zambia, Uganda, Tanzania
Strymon bazochii (Godart)	Australia, Fiji, Hawaii
Tmolus echion (L.)	Hawaii, Fiji

Biological control agent	Country released
Coleoptera	
Aerenicopsis championi Bates	Australia, Hawaii
Alagoasa parana Samuelson	Australia, South Africa
Apion sp1	Hawaii
Apion sp2	Hawaii
Charidotis pygmaea Klug	Australia, Fiji
Longitarsus spp.	Jamaica
Octotoma championi Baly	Fiji, South Africa, Hawaii, Australia
Octotoma scabripennis Guérin-Méneville	Guam, South Africa, Niue, New Caledonia, India, Solomon Islands, Hawaii, Ghana,Fiji, Cook Islands, Australia
Omophoita albicollis Fabricius	Jamaica
Parevander xanthomelas (Guérin-Méneville)	Hawaii
Plagiohammus spinipennis (Thomson)	Palau, Australia, Hawaii, South Africa, Guam
Uroplata fulvopustulata Baly	Fiji, Australia, South Africa
Uroplata girardi Pic	Trinidad, South Africa, Samoa, Solomon Islands, St.Helena, Tanzania, Ghana, Palau, Uganda, Vanuata, Zambia, Tonga, India, Australia, Cook Islands, Micronesia, Hawaii, Guam, Philippines, Mauritius, New Caledonia, Niue, Northern Mariana Islands, Papua New Guinea, Fiji
Uroplata lantanae Buzzi and Winder	Australia, South Africa
HEMIPTERA	
Aconophora compressa Walker	Australia
Falconia intermedia (Distant)	Australia
Leptobyrsa decora Drake	Guam, Zambia, South Africa, Palau, Hawaii, Fiji, Australia, Cook Islands, Ghana
Orthezia insignis Browne	Hawaii
Phenacoccus parvus Morrison	
Teleonemia bifasciata Champion	Hawaii
Teleonemia elata Drake	Uganda, Australia, Zambia, Cook Islands, South Africa
Teleonemia harleyi Froeschner	Australia
Teleonemia prolixa (Stål)	Australia
Teleonemia scrupulosa Stål	Tonga, Palau, Papua New Guinea Zimbabwe, South Africa, Samoa, Solomon Islands, Tanzania, Northern Mariana Islands, Uganda Vanuata, Zambia, Zanzibar, St. Helena, Hawaii, Niue, Australia, Micronesia, Fiji, Ghana, Guam, Ascension Island, India, Indonesia, Kenya, Madagascar, New Caledonia.
DIPTERA	
Calycomyza lantanae (Frick)	South Africa, Australia, Fiji

Biological control agent	Country released
Eutreta xanthochaeta Aldrich	Australia, South Africa, Hawaii
Ophiomyia camarae Spencer	South Africa
Ophiomyia lantanae Froggatt	Cook Islands, South Africa, New Caledonia, Kenya, India, Hong Kong, Hawaii, Guam, Micronesia, Australia, Fiji
Aceria lantanae Cook	South Africa, Australia

Based on [13, 15-16].

Table 1. List of biological control agents associated to *L. camara* worldwide

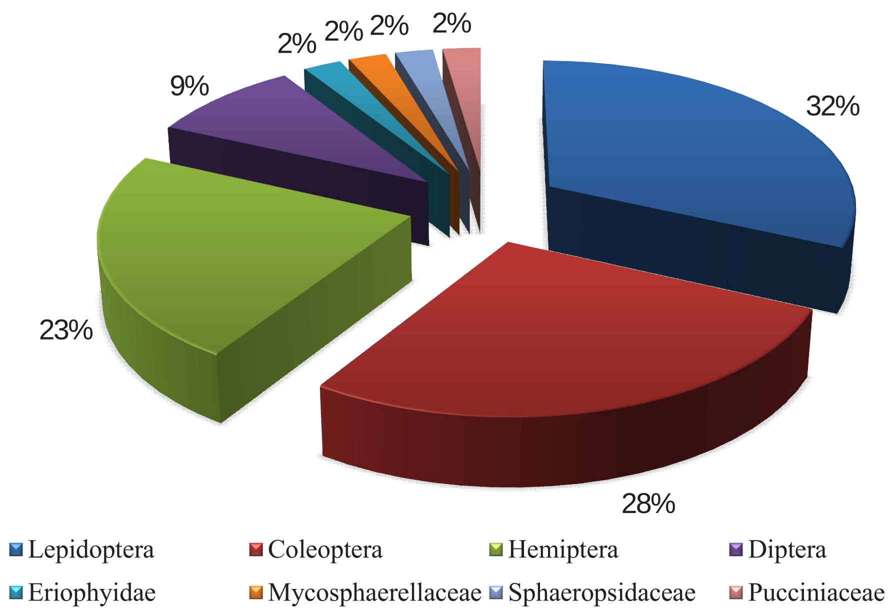

Figure 1. Percentage of different groups of biological control agents used against *L. camara*.

In regard to pathogens, Australia led the world with the first deliberate introduction of a plant pathogen as a biocontrol agent, i.e. the rust *Puccinia chondrillina* Bubak & Syd., released in 1971 to control skeleton weed *Chondrilla juncea* L. [10]. Furthermore, several fungal pathogens with mycoherbicide potential (*Sclerotinia sclerotiorum* (Lib.) de Bary in Hyakill™ and *Cercospora rodmanii* Conway, named ABG-5003) have been discovered on diseased water hyacinth plants, but none has become commercially available in the market [8].

7. Eriophyoid as biological agents of weed control

Eriophyoid mites have long been thought to have a high potential as a source for biological control agents of weeds [17-20] because of their typically high degree of host plant specificity [21]. Also, eriophyoid mites can substantially damage vegetative and reproductive plant parts, thus reduce fitness of the target weed, have high reproductive rates, and disperse widely by wind, which all favor their potential to be effective biological control agents [18, 22-23]. Despite those desirable features exhibited by eriophyoid mites, relatively few species have been introduced as classical biological control agents [19]. This could be account for the fact that relatively few species of Eriophyoidea are considered economic pests [23], which suggests that the impact of most species would be limited by host plant resistance or tolerance, natural enemies, and adverse abiotic conditions, affecting the efficacy of biological control agents [24].

There are about 4,000 recognized eriophyoid mite species, and about 80% of currently known species have been recorded in association with a single species of host plant [21], suggesting that there should be a large number of prospective agents available to discover. By far, species from the genus *Aceria* have been widely used in biological control of weeds (Fig 2), probably due to together with *Eriophyes* include about one-third of the known Eriophyoidea revealing high species diversity.

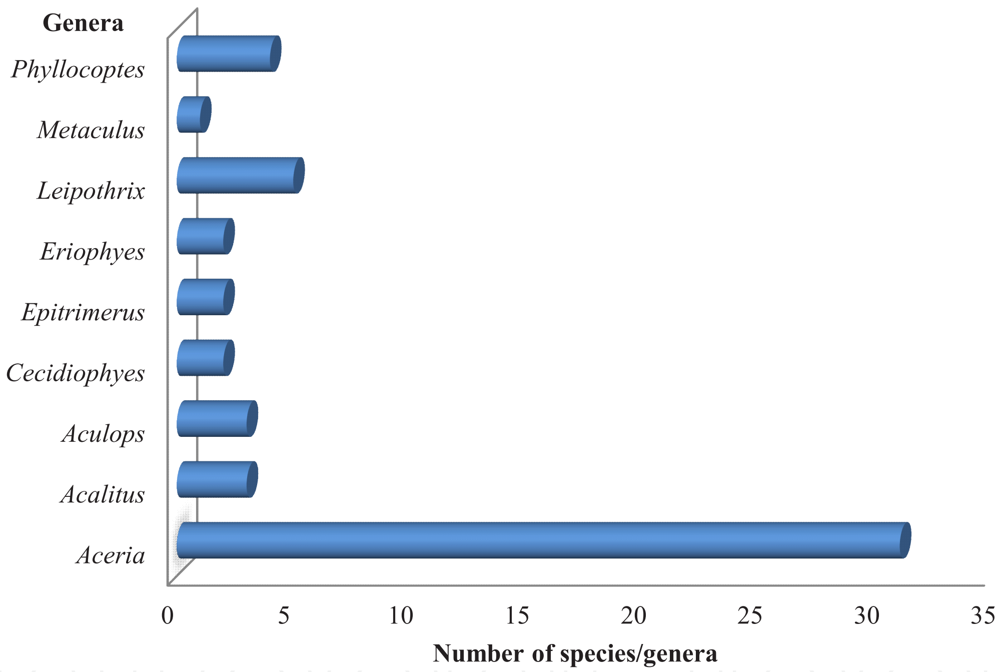

Figure 2. Number of Eriophyidae species used as biological control agents of weeds.

The oldest cases of attempts to use eriophyid mites for biological control include *Aceria chondrillae* Canestrini, *A. malherbae* Nuzzaci and *Aculus hyperici* Liro. *Aceria chondrillae* is native to Europe and has been introduced to control *C. juncea* (rush skeletonweed, Asteraceae) in Australia, USA and Argentina [25] and it is considered to be the most effective of the three biological control agents that were released [26].

Aceria malherbae is native to Europe and forms galls on developing leaves and stems of *Convolvulus arvensis* L. (Convolvulaceae) [27]. *Aceria malherbae* has been released in the USA in 1989 [17], in Canada in 1989 [28] and in South Africa in 1995 [29].

Aculus hyperici, native to Europe, was introduced to control *Hypericum perforatum* L. (Clusiaceae) in Australia [18]. By mid 1994, a total of 245 releases of *A. hyperici* had been made throughout New South Wales and Victoria, being mite populations confirmed at 108 sites. Although the mite significantly reduced shoot and root biomass, field weed populations has not been significantly impacted [18, 30].

As related by [19], since Rosenthal's review in 1996, 13 species have undergone some degree of pre-release, so named: *Aceria genistae* (Nalepa), *A. lantanae*, *Aceria* sp. [boneseed leaf buckle mite, BLBM], *A. salsolae* De Lillo & Sobhian, *A. sobhiani Sukhareva*, *A. solstitialis* de Lillo et al., *A. tamaricis* (Trotter), *A. thalgi Knihinicki et al.*, *A. thessalonicae* Castagnoli, *Cecidophyies rouhollahi* Craemer, *Floracarus perrepae* Knihinicki & Boczek, *Leipothrix dipsacivagus* Petanović & Rector and *L. knautiae* (Liro), but only four of them have been authorized for introduction (*A. genistae*, *Aceria* sp., *C. rouhollahi* and *F. perrepae*). However, there are much more species have been considered for biological control of weeds [19] (Table 2).

Biological control agent	**Target plant**	**Country**
Aceria species		
A. acacifloris Meyer	*Acacia saligna* (Labill. Wend. (Fabaceae)	Australia
A. angustifoliae Denizhan et al.	*Elaeagnus angustifolia*	Turkey
A. artemisiae (Canestrini)	*Artemisia vulgaris* L. (Asteraceae)	Italy
A. bicornis (Trotter)	*Solanum elaeagnifolium* Cav. (Solanaceae)	Argentina
A. boycei (Keifer)	*Ambrosia artemisiifolia* L. (Asteraceae)	U.SA.
A. burnleya Keifer	*A. saligna*	Australia
A. sobhiani Sukhareva	*Acroptilon repens* (L.) DC. (Asteraceae)	Uzbekistan
A. centaureae (Nalepa)	*Centaurea diffusa*, *C. stoebe* L. (Asteraceae)	Austria (presumed)
Aceria chondrillae Canestrini	*Chondrilla juncea* L. (Asteraceae)	USA and Argentina
A. convolvuli (Nalepa)	*Convolvulus arvensis* L. (Convolvulaceae)	Austria
A. cynodoniensis Sayed	*Cynodon dactylon* (L.) Pers. (Poaceae)	Egypt
A. dissecti Petanović	*Geranium dissectum* L. (Geraniaceae)	Serbia
A. drabae (Nalepa)	*Cardaria draba* (L.) Desv. (Brassicaceae)	Austria
A. eleagnicola Farkas	*Elaeagnus angustifolia* L. (Elaeagnaceae)	Hungary
A. galiobia (Canestrini)	*Galium mollugo* L., *G. verum* L. (Rubiaceae)	Italy
A. geranii (Canestrini)	*Geranium dissectum*	Italy
A. imperata (Zaher & Abou-Awad)	*Imperata cylindrica* (L.) Beauv.	Egypt
A. jovanovici Petanović	*Lythrum salicaria* L. (Lythraceae)	Serbia
A. meliae (Dong & Xin)	*Melia azedarach* L. (Meliaceae)	China
A. mississippiensis Chandrapatya & Baker	*Geranium carolinianum* L. (Geraniaceae)	Mississippi
A. salsolae de Lillo & Sobhian	*Salsola tragus* L. (Chenopodiaceae)	Turkey
A. salviae (Nalepa)	*Salvia pratensis* L., *S. verticillata* L. (Lamiaceae)	Austria

Biological control agent	Target plant	Country
A. solcentaureae de Lillo et al.	*Centaurea solstitialis* L. and *C. virgata* ssp. squarrosa Lam. (Willd.) Gugler (Asteraceae)	Turkey
A. solstitialis de Lillo, Cristofaro & Kashefi	*Centaurea solstitialis* and *C. virgata* ssp. Squarrosa	Turkey
A. spartii (Canestrini)	*Spartium junceum* L. (Fabaceae)	Italy
A. squarrosae de Lillo et al.	*Centaurea virgata* ssp. Squarrosa	Turkey
A. striata (Nalepa)	*Chromolaena odorata* (L.) King & H. Robinson (Asteraceae)	Barbados
A. tamaricis (Trotter)	*Tamarix gallica* L. and *T. ramosissima* Ledeb. (Tamaricaceae)	Turkey
A. thalgi Knihinicki et al.	*Sonchus oleraceus* L., *S. asper* (L.) Hill, *S. hydrophilus* Boulos (Asteraceae)	West Australia
A. thessalonicae Castagnoli	*Centaurea diffusa* Lam. (Asteraceae)	Greece
A. tribuli (Keifer)	*Tribulus terrestris* L. (Zygophyllaceae)	Sudan
A. vitalbae (Canestrini)	*Clematis vitalba* L. (Ranunculaceae)	Italy
Acalitus species		
A. essigi (Hassan)	*Rubus* sp. (Rosaceae)	California (USA)
A. mikaniae Keifer	*Mikania micrantha* Kunth (Asteraceae)	Florida (USA)
A. osmia (Cromroy)	*Chromolaena odorata*	Puerto Rico
Aculops species		
A. euphorbiae (Petanović)	*Euphorbia seguierana* Neck. And *Euphorbia* spp. (Euphorbiaceae)	Serbia
A. toxicophagus (Ewing) (=*Aculops rhois*) (Stebbins)	*Toxicodendron radicans* (L.) Kuntze (Anacardiaceae)	Florida (USA)
Aculus species		
Aculus hyperici Liro	*Hypericum perforatum* L. (Clusiaceae)	Australia
Cecidophyes species		
C. caroliniani Chandrapatya & Baker	*Geranium carolinianum*	Mississippi (USA)
C. galii (Karpelles)	*Galium aparine* L. (Rubiaceae)	Austria (presumed)
Epitrimerus species		
E. heterogaster (Nalepa)	*Clematis vitalba*	Austria (presumed)
E. lythri Petanović	*Lythrum salicaria*	Serbia
Eriophyes species		
E. cuscutae (Molliard)	*Cuscuta epithymum* (L.) L. (Cuscutaceae)	France
E. rubicolens (Canestrini)	*Rubus fruticosus* L. (Rosaceae)	Italy
Leipothrix species		
L. coactus (Nalepa)	*Plantago* spp. (Plantaginaceae)	Germany
L. dipsacivagus Petanović & Rector	*Dipsacus fullonum*, *D. laciniatus*	Serbia

Biological control agent	Target plant	Country
L. eichhorniae (Keifer)	*Eichhornia crassipes* (Mart.) Solms (Pontederiaceae)	Brazil
L. knautiae (Liro)	*Dipsacus fullonum* L., *D. laciniatus* L. (Dipsacaceae)	Finland
L. taraxaci (Liro)	*Taraxacum officinale* F. H. Wigg. (Asteraceae)	Finland
Metaculus species		
M. lepidifolii Monfredo & de Lillo	*Lepidium latifolium* L.	Turkey
Phyllocoptes species		
P. cruttwellae Keifer	*Chromolaena odorata*	Trinidad
P. euphorbiae Farkas	*Euphorbia cyparissias* L. (Euphorbiaceae)	Hungary
P. gracilis (Nalepa)	*Rubus tomentosus* Borkh. (Rosaceae)	Germany (presumed)
P. nevadensis Roivainen	*Euphorbia esula* L., *E. cyparissias* (Euphorbiaceae)	Spain

Table 2. Eriophyid mites species used in biological control worldwide.

8. *Aceria lantanae* vs. *Lantana camara*

The lantana flower gall mite, *A. lantanae* is native to the Gulf of Mexico and it causes to its host plant to produce vegetative galls instead flowers. This tiny mite is about 0.15 mm long, beige and white in color. Mite feeding induces the flower bud develop into a 20-mm-diameter green gall and in high population levels mites form a mildew-like swarm on the surface of the gall. These galls act as nutrient sinks, which causes stunt vegetative growth and up to 90% reduction in seed production in susceptible varieties [31].

Also, two leaf vagrant eriophyid mites, *Shevtchenkella stefneseri* Craemer and *Paraphytoptus magdalenae* Craemer, were described from *L. camara* in Paraguay and Jamaica, however, so far only *A. lantanae* has shown to cause symptoms that could be used to control this plant [32].

9. *Floracarus perrepae* vs. *Lygodium microphyllum*

The Old World climbing fern, *Lygodium microphyllum* (Cav.) R. Br. (Lygodiaceae) is native to wet tropical and subtropical regions of Africa, Asia, Australia, and Oceania [33] and over recent decades has become a hugely problematic and rapidly spreading invasive weed of natural areas across much of southern Florida in the United States [34].

Management of *L. microphyllum* using fire or mechanical control have been ineffective, meanwhile chemical control is expensive, and not economically sustainable over the large areas already infested [35]. Thus, biocontrol is thought to be a more promising strategy for long-term management [33] and *Neomusotima conspurcatalis* Warren (Lepidoptera: Crambidae) has successfully established in Florida as a biological control of *L. microphyllum* [36-37].

http://dx.doi.org/10.5772/59953

Also, the leaf galling mite, *Floracarus perrepae* Knihinicki & Boczek (Eriophyidae) has been commonly found causing damage to this fern species during extensive foreign exploration within its native range [38]. Since then, several studies have been conducted to evaluate potentiality of this eriophyid mite to effectively control fern. Although *F. perrepae* successful colonized *L. microphyllum* field populations in Florida, the observed incidence was unexpectedly low [37]. According to these authors, only 10% of *L. microphyllum* plants showed mite-induced leaf galls, and mite populations died out resulting in only 3% of infested plots after 12-14 months. However, the low rate of *F. perrepae* establishment was not due to failure of mites to transfer onto field plants but a variety of factors such as:

a. *Propagule*: introductions of biocontrol agents can fail to result in establishment if too few individuals are released.

b. *Environmental conditions*: climatic dissimilarity between source areas and areas of introduction can result in the failure of biocontrol agents to establish. Moreover, persistent and heavy rainfall has shown to be the most important factor dislodging the dispersing *F. perrepae* as they attempted to settle and induce leaf rolls [38].

c. *Plant phenology*: a lack of host plants of the appropriate phenological stage can also hamper agent establishment.

d. *Nutritional status of the plant*: nitrogen limitation can affect establishment of biocontrol agents against invasive weeds.

e. *Biotic interference*: predators or pathogens cause mortality or interfere with introduced weed biocontrol agents.

f. *Plant susceptibility*: differences in susceptibility to eriophyid mite pests exist among different varieties of the same crop species and among eriophyid weed biocontrol agents to biotypes or geographic races of their target weeds.

Distinct haplotypes of *L. microphyllum* and *F. perrepae* from populations across Southeast Asia and Australasia have been revealed from genetic testing of the fern and mite and these different genetic strains of mite and genetic forms of *L. microphyllum* mapped out together according to their geographic origin [39]. Thus, bioassays indicated that strains of *F. perrepae* performed best (were most able to induce leaf galls) on the local forms of *L. microphyllum* from which they were collected and presumably were best adapted [39].

High specificity and variations in mite performance and host plant resistance could make eriophyid agents may have difficulty suppressing all forms of a weed throughout its adventive range when both resistant and susceptible weed genotypes are present [25].

Limited broader establishment of *F. perrepae* strains would appear related to the apparent role of fern resistant genotypes, reflecting difficulties in weed biocontrol programs using this eriophyid mite. Hence it seems unlikely that *F. perrepae* will contribute substantially to suppression of *L. microphyllum* in Florida [36].

10. Could *Aceria solstitialis* be a prospective biological control agent versus *Centaurea solstitialis*?

Yellow starthistle, *Centaurea solstitialis* L. (Asteraceae), is native to the northern half of the Mediterranean and currently it has invaded the western USA displacing native plant communities, reducing plant diversity and forage production for livestock and wildlife [40]. The origin site of this plant species has been explored for prospective biological control agents. Recently an eriophyid mite, *Aceria solstitialis* de Lillo, Cristofaro & Kashefi was discovered damaging *C. solstitialis* in Turkey [41]. However, it is still unclear if *A. solstitialis* could be an effective biological control agent of yellow starthistle, since field and laboratory studies did not yield conclusive results on host specificity and damage level on this host plant [42]. According to these authors, mites remained live on *C. solstitialis*, *Centaurea cyanus* L., *Centaurea diffusa* Lam., *Carthamus tinctorius* L., and *Cynara scolymus* L. 60 days after the start of the experiment. This fact would suggest that *A. solstitialis* is not specific to feed on *C. solstitialis*. Moreover, although young and old *Ce. solstitialis* infested plants became yellow and withered, most of them produced flowers and seeds. Also, damage symptoms by mite feeding was verified on *C. scolymus*, a cultivated species thus hindering possibility of use this eriophyid mite in biological weed control programs. However more detailed studies should be addressed to determine the relationship of mite population size and time of infestation to damage host plants.

11. Other mite groups used in biological control of weeds

Tetranychid mites: Gorse, *Ulex europaeus* L. (Fabaceae), is a thorny shrub native to the temperate Atlantic coast of Europe. Gorse has proven to be an aggressive invader, forming impenetrable, largely monotypic stands that reduce access of grazing animals to fodder, modify native ecosystems and ecosystem processes, and outcompete trees in developing forests [43], mainly in Australia, Chile, New Zealand and the USA [44-46].

The gorse spider mite, *Tetranychus lintearius* (Dufour) is one of the few tetranychid mite species being used for the biological control of gorse in Australia and it is now widespread in Tasmania and Victoria and has become well established in South Australia and Western Australia [47]. Mite populations have shown rapidly increases in the countries where it was released, with colonies forming massive webs over gorse and causing severe bronzing of the foliage. However, populations of the gorse spider mite rarely cause severe damage to the target weed [48]. As previously discussed, natural control mechanisms can interfere with the establishment and development of high population densities that are considered desirable for classical biological control agents [49]. Probably, predators are the main contributors to biotic resistance of spider mites [50]. In this regard, although presence of mite colonies on gorse bushes over a period of 2.5 years from the time of release reduced foliage dry weight by around 36% in Tasmania [51], predation of *T. lintearius* colonies by *Stethorus* sp. and *Phytoseiulus persimilis* Athias Henriot [52], has limited efficacy of control of *T. lintearius* on gorse.

Oribatid mites: The water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), is native of the Amazon basin [53] and whose capacity for growth and propagation causes major conservation problems with considerable socioeconomic repercussion [54]. Also, it has invaded fresh water bodies causing significant economic and ecological losses, being considered to be the worst aquatic weed in South Africa [55]. Several biocontol agents have been used to diminish ecological impact of the plant species, being *Orthogalumna terebrantis* Wallwork (Acari: Oribatida) one of seven biocontrol agents used against the water hyacinth in South Africa and it is currently established at 17 out of the 66 recorded water hyacinth infestation sites across the country [56]. Field observations in South Africa indicate that during summer certain water hyacinth infestations may have more than 50% of the leaf surface area damaged by mite herbivory [56]. Feeding by the nymphs of this mite forms galleries between the parallel veins of the lamina which cause leaf discoloration and desiccation when high mite populations are reached, however it has not contributed to control of the weed [12].

12. Conclusions

Various studies dealing with effectiveness of mites as biological agents of weed have shown variable results; however some of them clearly have the potential to play a significant role in the classical biological control. Field and laboratory observations have shown the debilitating effect of some mite species on its target plant, opening a gate to be explored in the future. Furthermore, additional aspects as plant genotype interaction with those biological control agents and also interaction with other biological control agents such as pathogens should be addressed to complement the action of the mite agents currently established on susceptible weedy varieties in order to improve biological control programs.

Author details

Carlos Vásquez[1*], Yelitza Colmenárez[2], José Morales-Sánchez[1], Neicy Valera[1], María F. Sandoval[3] and Diego Balza[1]

*Address all correspondence to: carlosvasquez@ucla.edu.ve

1 Department of Life Sciences. Faculty of Agronomy. Universidad Centroccidental Lisandro Alvarado. Barquisimeto, Lara State, Venezuela

2 CABI South America. UNESP-Fazenda Experimental LageadoBotucatu, São Paulo State, Brazil

3 National Institute of Agricultural Research. Plant Production Unit. Laboratory of Entomology. Maracay, Aragua State, Venezuela

References

[1] Ruiz-Téllez T, Rodrigo-López E, Lorenzo-Granado G, Albano-Pérez E, Morán-López R, Sánchez-Guzmán J. The water hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). Aquatic Invasions 2008;3(1): 42-53.

[2] Ampong-Hyarko K, De Data SK. A handbook for weed control in rice. International Rice Research Institute. Manilam Philipines;1991.

[3] Tu M, Hurd C, Randall JM. Weed Control Methods Handbook: tools and techniques for use in natural areas. The Nature Conservancy. 2001. http://tncweeds.ucdavis.edu (accessed 20 June 2014).

[4] Mennan H, Uzun S, Kolören O, Kaya-Altop E, Işık D. 2011. General information about organic agriculture and physical and cultural weed control in Turkey. March 28-30. 9th EWRS Workshop on Physical and Cultural Weed Control. Samsun, Turkey; 2011.

[5] McFadyen REC. Biological control of weeds. Annual Review of Entomology 1998; 43:369-393.

[6] El-Sayed W. Biological control of weeds with pathogens: current status and future trends. Z. Pflanzenkrankh Pflanzenschutz 2005; 112: 209-221.

[7] Hasan S, Ayres PG. The control of weeds through fungi: principles and prospects. New Phytologist 1990; 115: 201-222.

[8] Dagno K, Lahlali R, Diourté M, Jijakli MH. Present status of the development of mycoherbicides against water hyacinth: successes and challenges: a review. Biotechnology, Agronomy, Society and Environment 2012;16(3): 360-368.

[9] McFadyen R, Willson B. A History of Biological Control of weeds. In: Julien MH, White GG (eds.) Biological Control of Weeds: theory and practical application. Canberra, Australian Centre for International Agricultural Research; 1997.

[10] McFadyen R. Benefits from biological control of weeds in Australia. Pakistan Journal of Weed Science Research 2012; 18: 333-340.

[11] Waterhouse DF, Norris KR. Biological Control: Pacific Prospects. Melbourne: Inkata Press; 1987.

[12] Julien MH. Biological control of water hyacinth with Arthropods: a review to 2000. In: Julien MH, Hill MP, Center TD, Jianqing D (eds.) Biological and integrated control of water Hyacinth, *Eichornia crassipes*. 9-12 October 2000, Beijing, China. Canberra: Australian Centre for International Agricultural Research; 2001.

[13] Day MD, Zalucky MP. *Lantana camara* (Verbenaceae). In: Muniappan R, Reddy GVP, Raman A (eds.) Biological control of tropical weeds using arthropods. New York: Cambridge University Press, 2009. p211-243.

[14] Boczeck J. 1995. Eriophyid mites (Acari: Eriophyoidea) as agents of biological weed control. In: Kropczyńska D, Boczek J, Tomczyk A. (eds) The Acari: physiological and ecological aspects of Acari: host relationships. Dabor, Warsawa, Poland.

[15] Baars JR, Hill MP. The phytophagous organisms associated with *Lantana* L. species in Jamaica and their potential use as biological control candidates of weedy varieties of *Lantana camara* L. (Verbenaceae) in South Africa. Entomotropica2010;25(3): 99-108.

[16] Thomas S.E., Ellison C.A. A century of classical biological control of *Lantana camara*: Can pathogens make a significant difference?, 4-14 July 1999. Proceedings of the X International Symposium on Biological Control of Weeds 97, Montana USA. Neal R. Spencer [ed.]. 2000. p97-104.

[17] Rosenthal SS. *Aceria*, *Epitrimerus* and *Aculus* species and biological control of weeds. In: Lindquist EE, Sabelis MW, Bruin J (eds.) Eriophyoid mites: their biology, natural enemies and control, vol 6. Amsterdam: Elsevier; 1996. p729-739.

[18] Briese DT, Cullen JM. The use and usefulness of mites in biological control of weeds. In: Halliday RB, Walter DE, Proctor HC, Norton RA, Colloff MJ (eds.) Acarology: Proceedings of the 10th International Congress. Melbourne, CSIRO Publishing.

[19] Smith L, de Lillo E, Amrine JW Jr. Effectiveness of eriophyid mites for biological control of weedy plants and challenges for future research. Experimental and Applied Acarology 2010; 51(1-3):115-149.

[20] Gerson U, Smiley RL, Ochoa R. Mites (Acari) for pest control. Oxford: Blackwell Science Ltd.; 2003.

[21] Skoracka A, Smith L, Oldfield G, Cristofaro M, Amrine JW. Host-plant specificity and specialization in eriophyoid mites and their importance for the use of eriophyoid mites as biocontrol agents of weeds. Experimental and Applied Acarology 2010; 51:93–113.

[22] Rosen D, Huffaker CB. An overview of desired attributes of effective biological control agents, with particular emphasis on mites. In: Hoy MA, Cunningham GL, Knutson L. (eds.) Biological control of pests by mites. Berkeley: University of Caliornia; 1983. p2-11.

[23] Lindquist EE, Sabelis MW, Bruin J. In: Lindquist EE, Sabelis MW, Bruin J (eds.) Eriophyoid mites: their biology, natural enemies and control, vol 6. Amsterdam: Elsevier; 1996.

[24] Smith L Prospective new agents for biological control of Yellow Starthistle, 12–14 January, 2004. Proceedings 56th Annual California Weed Science Society Sacramento, USA, 2004.

[25] Cullen JM, Briese DT. Host plant susceptibility to eriophyid mites used for weed biological control. In: Halliday RB, Walter DE, Proctor HC, Norton RA, Colloff MJ (eds)

Acarology: Proceedings of the 10th International Congress. Melbourne: CSIRO Publishing; 2001.

[26] Piper GL, Coombs EM, Markin GP, Joley DB. *Eriophyes chondrillae* (=*Aceria chondrillae*) In: Coombs EM, Clark JK, Piper GL, Cofrancesco AF Jr (eds.) Biological control of invasive plants in the United States. Oregon: Oregon State University Press; 2004.

[27] Littlefield JL. Spatial distribution and seasonal life history of *Aceria malherbae* (Acari: Eriophyidae) on *Convolvulus arvensis* in Montana, USA. In: Cullen JM, Briese DT, Kriticos DJ, Lonsdale WM, Morin L, Scott JK (eds.) Proceedings of the XI international symposium on biological control of weeds, 4–8 May 2003, Canberra, Australia: CSIRO Entomology; 2004.

[28] McClay AS, De Clerck-Floate RA. *Convolvulus arvensis* L. field bindweed (Convolvulaceae). In: Mason PG, Huber JT (eds.) Biological control programmes in Canada, 1981–2000. Wallingford: CABI Publishing; 2002. p331-337.

[29] Craemer C. Host specificity, and release in South Africa, of *Aceria malherbae* Nuzzaci (Acari, Eriophyoidea), a natural enemy of *Convolvulus arvensis* L. (Convolvulaceae). African Entomology 1995; 3(2):213-215.

[30] Mahr FA, Kwong RM, McLaren DA, Jupp PW. Redistribution and present status of the mite *Aculus hyperici* for the control of St. John's wort, *Hypericum perforatum*, in Australia. Plant Protection Quarterly 1997; 12(2) 84-88.

[31] Besaans L. *Aceria lantanae*, lantana flower gall mite. ARC-PPRI Fact sheets on invasive alien plants and their control in South Africa. 2012. http://www.arc.agric.za/arc-ppri/Fact%20Sheets%20Library/Aceria%20lantanae,%20the%20lantana%20flower%20gall%20mite.pdf. Accessed August 04 2014.

[32] Craemer C. Eriophyoidea (Acari) associated with *Lantana camara* L., with descriptions of two new species. African Plant Protection 1996; 2(1): 59-66.

[33] Pemberton RW. The potential of biological control to manage Old World climbing fern (*Lygodium microphyllum*), an invasive weed in Florida. American Fern Journal 1998; 88: 176-182.

[34] Pemberton, RW, Ferriter AP. 1998. Old World climbing fern (*Lygodium microphyllum*), a dangerous invasive weed in Florida. American Fern Journal 1998; 88: 165-175.

[35] Stocker RK, Miller RE Jr, Black DW, Ferriter AP, Thayer DD. Using fire and herbicide to control *Lygodium microphyllum* and effects on a pine flat-woods plant community in South Florida. Natural Areas Journal 2008; 28: 144-154.

[36] Boughton AJ, Pemberton RW. Establishment of an imported natural enemy, *Neomusotima conspurcatalis* (Lepidoptera: Crambidae) against an invasive weed, Old World climbing fern, *Lygodium microphyllum,* in Florida. Biocontrol Science and Technology 2009; 19: 769-772.

[37] Boughton AJ, Pemberton RW. Limited field establishment of a weed biocontrol agent, *Floracarus perrepae* (Acariformes: Eriophyidae), against Old World climbing fern in Florida: a possible role of mite resistant plant genotypes. Environmental Entomology 2011; 40(6): 1448-1457.

[38] Goolsby JA, Wright AD, Pemberton RW. Exploratory surveys in Australia and Asia for natural enemies of Old World climbing fern, *Lygodium microphyllum*: Lygodiaceae. Biological Control 2003; 28: 33-46.

[39] Goolsby JA, De Barro PJ, Makinson JR, Pemberton RW, Hartley DM, Frohlich DR. Matching the origin of an invasive weed for selection of an herbivore haplotype for a biological control programme. Molecular Ecology 2006; 15: 287-297.

[40] Sheley RL, Larson LL, Jacobs JJ. Yellow starthistle. In: Sheley RL, Petroff JK (eds.) Biology and management of noxious rangeland weeds. Oregon: Oregon State Univ. Press; 1999. p408-416.

[41] de Lillo E, Cristofaro M, Kashefi J. Three new *Aceria* species (Acari: Eriophyoidea) on *Centaurea* spp. (Asteraceae) from Turkey. Entomologica 2003; 36:121–137.

[42] Stoeva A, Harizanova V, de Lillo E, Cristofaro M, Smith L. Laboratory and field experimental evaluation of host plant specificity of *Aceria solstitialis*, a prospective biological control agent of yellow starthistle. Experimental and Applied Acarology 2012; 56:43-55.

[43] Hill RL, Ireson J, Sheppard AW, Gourlay AH, Norambuena H, Markin GP, Kwong R, Coombs EM. A global view of the future for biological control of gorse, *Ulex europaeus* L. In: Julien M (ed) Proceedings of the XII International Symposium on Biological Control of Weeds. 22-27 April 2007. Le Grande Motte, France. Wallindorf: CAB International; 2008.

[44] Hill RL, Gourlay AH, Fowler SV. The biological control programme against gorse in New Zealand. In: Spencer NR (ed.) Proceedings of the X International Symposium on Biological Control of Weeds. 4-14 July 1999. Bozeman, USA. Montana: Montana State University; 2000.

[45] Markin GP, Yoshioka ER, Conant P. Biological control of gorse in Hawaii. In: Moran VC, Hoffman JH (eds) Proceedings of the IX International Symposium on Biological Control of Weed. 19-26 January 1996. Stellenbosch, South Africa: University of Cape Town; 1996.

[46] Norambuena H, Martinez G, Carillo R, Neira M. Host specificity and establishment of *Tetranychus lintearius* (Acari: Tetranychidae) for biological control of gorse (*Ulex europaeus*). Biological Control 2007; 26: 40-47.

[47] TIAR (Tasmanian Institute of Agricultural Research) 2008. Weed Biological Control Pamphlet. Available in: http://www.weeds.org.au/WoNS/gorse/docs/Pamphlet_6_GSM_APR08.pdf

[48] Rees M, Hill RL. Large-scale disturbances, biological control and the dynamics of gorse populations. Journal of Applied Ecology 2001; 38: 364-377.

[49] Pratt PD, Coombs EM, Croft BA. Predation by phytoseiid mites on *Tetranychus lintearius* (Acari: Tetranychidae), an established weed biological control agent of gorse (*Ulex europaeus*). Biological Control 2003; 26: 40-47.

[50] Walter DE, Proctor HC. Mites: Ecology, Evolution and Behaviour. Oxon: CABI Wallingford; 1999.

[51] Davies JT, Ireson JE, Allen GR. The impact of the gorse spider mite, *Tetranychus lintearius*, on the growth and development of gorse, *Ulex europaeus*. Biological Control 2007; 41: 86-93.

[52] Ireson JE, Gourlay AH, Kwong RM, Holloway RJ, Chatterton WS. Host specificity, release and establishment of the gorse spider mite, *Tetranychus lintearius* Dufour (Acarina: Tetranychidae), for the biological control of gorse, *Ulex europaeus* L. (Fabaceae), in Australia. Biological Control 2003; 26: 117-127.

[53] Barrett SCH, Forno IW. Style morph distribution in New World populations of *Eichhornia crassipes* (Mart) Solms-Laubach (water hyacinth). Aquatic Botany 1982; 13: 299-306.

[54] Marlin D, Hill MP, Ripley BS, Strauss AJ, Byrne MJ. The effect of herbivory by the mite *Orthogalumna terebrantis* on the growth and photosynthetic performance of water hyacinth (*Eichhornia crassipes*). Aquatic Botany 2013; 104: 60-69.

[55] Hill MP, Cilliers CJ. A review of the arthropod natural enemies, and factors that influence their efficacy, in the biological control of the water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae) in South Africa. In: Olckers T, Hill MP (eds.). Biological control of weeds in South Africa (1990–1998). Pretoria: The Entomological Society of South Africa; 1999. p103–112.

[56] Byrne M, Hill M, Robertson M, King A, Jadhav A, Katembo N, Wilson J, Brudvig R, Fisher J. Integrated management of water hyacinth in South Africa: development of an integrated management plant for water hyacinth control, combining biological control, herbicidal control and nutrient control, tailored to the climatic regions of South Africa. Water Research Council Report No. TT 454/10. 2010.