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Review Article

Organisms associated with the family Convolvulaceae and their potential for biological control of *Convolvulus arvensis*

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Abstract
This review catalogues the organisms that have been recorded in association with the family Convolvulaceae worldwide. It selects promising organisms and provides basic information on these potential biological control agents. In total, 328 organisms associated with the Convolvulaceae have been reported in the 270 references cited. Wasps, bees and flies are excluded where they are only casual and transient visitors to the plants. Although a relatively large number of species has been recorded from the Convolvulaceae, only a small number (47 species, 14.3%) seem to have the potential for biological control of *Convolvulus arvensis*. Of these, *Melanagromyza albocilia* (Dipt., Agromyzidae), *Longitarsus pellucidus* and *Hypocassida subferruginea* (Col., Chrysomelidae), *Spermophagus sericeus* (Col., Bruchidae), *Emmelia trabealis* (Lep., Noctuidae) and *Emmelina monodactyla* (Lep., Pterophoridae) appear to be the most promising.

Keywords: Field bindweed: *Convolvulus arvensis*: Convolvulaceae: phytophagous insects: biological control: agent selection

1. Introduction

Field bindweed (*Convolvulus arvensis* L.) and hedge bindweed (*Calystegia sepium* (L.) R. Br.), both from the family Convolvulaceae, are very important weeds in world agriculture. They are deep-rooted perennials and thus they can escape chemical or mechanical weed control [1, 2]. In addition, the abundant reserves stored in the roots enable the plants to survive repeated defoliation [3]. Moreover, fragmentation and dispersal of underground parts leads to vegetative propagation [4]. In this context, biological control appears to be a promising alternative strategy against bindweeds.

Bindweed relatives in the Convolvulaceae include *Ipomoea batatas* (L.) Lam. (sweet potato) and ornamental species in the genus *Ipomoea*. Sweet potato, a widely grown plant, is a staple food for much of the population in many parts of the world [5]. Because sweet potato and some ornamental *Ipomoea* species are often subjected to attack by insects associated with bindweeds, conflicting interests is the major problem to solve in the search for biological control agents for bindweeds [6]. Species feeding on sweet potato have value for biological control of bindweeds only in areas with no significant production of sweet potato [7]. However, any organisms which curtail weed growth or reproduction may be used as biological control agents [8]. Thus, the search for natural enemies should encompass all organisms associated with the target plants [9], including pathogens [10].

The first step in any biological weed control programme is a comprehensive literature survey [11, 12]. Mohyuddin [13] listed 125 species of insects and mites known to attack *Convolvulus* spp. and *Calystegia* spp., found by him in Canada and by others throughout the world. Thirty-five species of insect and two species of mite were found in association with *Convolvulus* spp. in Pakistan [14]. The insect fauna noted on *C. arvensis* in Egypt consisted of 13 species [15]. In Mediterranean Europe, 139 species of phytophagous arthropods were collected from *C.*

arvensis and its close relatives [5]. Weaver & Riley [1] summarized organisms collected from *C. arvensis* in Canada and the USA in a list of 28 insect species. Field surveys of phytophagous insects associated with *Convolvulus* spp. were also carried out in Slovakia to evaluate their potential use in biological control programmes. During the study 108 organisms were collected from *C. arvensis* [16]. Other authors highlighted promising biological control candidates: Mohyuddin [17] in Canada, Baloch [18, 19] in Pakistan, Tyurebaev [20] in Central Asia, Gorenshtein [21] in Russia, and Wang & Kok [7] and Julien [22] worldwide.

This review catalogues all organisms that have been recorded from the Convolvulaceae worldwide. It then identifies species with potential for use in biological control of bindweeds, particularly *C. arvensis.* It summarizes available biological information for each of these species, and discusses the prospects for and limitations to their use in biological control programmes.

2. Organisms Associated with the Family Convolvulaceae

Organisms which have been recorded on Convolvulaceae worldwide are listed in Table 1. Wasps, bees and flies where they are only casual and transient visitors to the plants have been excluded. In total 328 organisms associated with the Convolvulaceae have been recorded. These represent ten orders and 58 families. The majority of species belong to the insect orders Coleoptera (43.7% species), Lepidoptera (33.9%) and Hemiptera (13.6%) (Table 2). Numbers of species and families represented in each order are also given in Table 2.

The Palaearctic fauna (46.8% species) was noticeably richer compared to other regions of the world. The greatest diversity of insect fauna associated with *C. arvensis* was found in Eurasia and North Africa, reflecting the plant's Eurasian origin. On the other hand, organisms feeding on sweet potato were reported from tropical and subtropical regions. The exact origin of the sweet potato is not known, but a New World origin is generally accepted [251]. This is probably why the majority (more than 56%) of species feeding on sweet potato were recorded in the Americas.

The most commonly listed feeding habit was external or internal feeding on leaves (about 54.0% of the 328 recorded species). This was followed by feeding on roots (8.0%), seeds (4.9%), flowers (3.3%) and stems (3.3%). The feeding habit of 87 species (26.5%) was not specified in the literature (Table 3).

The organisms included in this review may be divided into two main groups: polyphagous species (45.7%), and species whose feeding was restricted to the Convolvulaceae (54.3%). There seemed to be just 22 strictly monophagous species (6.5%), feeding on only *C. arvensis* or *Calystegia sepium*. A group of about 47 species (14.3%) was specific to *Convolvulus* spp. A group of oligophagous insects (feeding on a relatively large number of plants in different genera within the Convolvulaceae) contained 59 species (17.6%). Sweet potato was reported as a host for 56 species (16.6%).

3. Potential Biological Control Agents

Although a relatively large number of species has been recorded from the Convolvulaceae, only a small number of them (47 species, 14.3%) seem to have potential as biological control agents. Of these, only *Tyta luctuosa* (Denis & Schiffermüller) (Lep., Noctuidae) and *Aceria malherbae* Nuzzaci (Acari, Eriophyidae) have so far been used in the classical biological control of bindweeds [33].

This estimate of the number of potential biological control agents is probably not entirely accurate. It can be difficult to determine whether or not a species is suitable for biological control. For example, *Longitarsus pellucidus* (Foudras) (Col., Chrysomelidae) has been recorded as a polyphagous species [96]. However, feeding tests have shown that it fed only on species in the Convolvulaceae [16].

On the basis of field surveys and laboratory testing, 12 species were selected as promising biological control agents in Slovakia [16]. Rosenthal & Buckingham [5] selected nine promising species for the same purpose in Mediterranean Europe, and Baloch [19] identified four species in Pakistan. Wang & Kok [7] stated that there were seven promising candidates worldwide. However, according to the feeding tests conducted by Mohyuddin [13], none of the leaf-feeding insects studied was suitable for biological control in sweet potato growing areas.

Within families, the species identified as promising tended to be those attacking the roots or stems. For example, the species of Cerambycidae (Coleoptera), Sesiidae (Lepidoptera) and Cecidomyiidae and Agromyzidae (Diptera) noted to have the most potential as biological control agents all fed on roots or shoots. Given the tremendous amount of root material produced by *C. arvensis*, it is surprising that more organisms do not utilize roots as a food source. Species of Bruchidae (Coleoptera) were suggested as prospective agents for their ability to destroy seeds and seedlings in five of eight studies dealing with potential biological control agents [1, 5, 7, 16, 20]. Flea beetles and tortoise beetles (Chrysomelidae), whose adults are leaf feeders, were suggested as promising species for biological control purposes in 16.5% of 79 studies, because of their restricted host range, larval damage concentrated in the roots or leaves and high adaptability to different ecological situations. Lepidopteran and coleopteran leaf-feeding species were suggested as potential biological control agents usually only if they were monophagous. The promising species are identified in Table 1.

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
NEMATODA					
TYLENCHATA					
Tylenchidae					
Ditylenchus dipsaci (Kühn) Filipjev	Europe	EXT, R	POLY		23
Heteroderidae					
Meloidogyne hapla Chitwood	Germany	EXT, R	POLY		24
Meloidogyne incognita ssp. *acrita* (Kofoid & White) Chitwood	South Africa, Egypt, Nigeria	EXT, R	CONVOL		25, 26, 27
Meloidogyne javanica (Treub) Chitwood	Egypt, South Africa	EXT, R	POLY, IB		25, 27
Meloidogyne sp.	Europe	EXT, R	POLY		23
Hoplolamidae					
Rotylenchulus reniformis Linford & Oliveira	India	EXT, R	POLY		28
ARACHNOIDEA					
ACARI					
Eriophyidae					
Aceria malherbae Nuzzaci	Europe, North Africa	EXT, L, St	CC	*	23, 29 – 33
Eriophyes altus Nalepa [*Aceria altus*]	Indonesia	EXT, L	ID		30
Eriophyes gastrotrichus Nalepa [*Aceria gastrotrichus*]	Philippines	EXT, L	IB, IS		30, 34
Eriophyes lepistemonis Nalepa [*Aceria lepistemosis*]	Indonesia	EXT, L	LB		30
Eriophyes merremiae Nalepa [*Aceria merremiae*]	Indonesia	EXT, L	MG		30
Eriophyes sp.	Italy, Spain	EXT, L	C		5
Phylocoptes convolvuli (Nalepa) [*Aceria convolvuli*]	Europe	EXT, L	CA		23, 30
Tegonotus convolvuli (Channabasavanna)	India	EXT, L	I		30, 35
Tetranychidae					
Tetranychus cinnabarinus Boisduval	Italy	EXT, L	POLY		36
Tetranychus urticae Koch	Canada, Italy, South Africa, Poland	EXT, L	POLY		13, 27, 36, 37
INSECTA					
COLLEMBOLA					
Sminthuridae					
Sminthurus viridis (L.)	Italy	EXT, L	POLY		38
ORTHOPTERA					
Acrididae					
Syrbula admirabilis (Uhler)	–	–	POLY		13
Gryllidae					
Gryllus burdigalensis Latreille [*Modicogryllus burdigalensis*]	–	–	POLY		13
Melanogryllus desertus Pallas	–	–	POLY		13
THYSANOPTERA					
Thripidae					
Scirtothrips aurantii Faure	–	–	POLY		13

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Scolothrips sp.	Italy	EXT, L	C		5
Thrips tabaci Lindeman	Egypt, Italy	EXT, L,F	POLY		15, 39
HEMIPTERA: HETEROPTERA					
Pentatomidae					
Aelia acuminata (L.)	Spain	EXT, SC	POLY		40
Carpocoris mediterraneus Tamanini	Spain	EXT, SC	POLY		40
Cosmopepla bimaculata Thomas	Canada	EXT, L	CONVOL		13
Dryoderes umbraculatus (F.)	Spain	EXT, SC	POLY		40
Eurydema oleraceum (L.)	Spain	EXT, SC	POLY		40
Euschistus variolarius (Palisot de Beauvois)	Canada	EXT, L	CONVOL		13
Holcostethus strictus (F.)	Spain	EXT, SC	POLY		40
Nezara viridula (L.)	Spain, Italy, Egypt	EXT, L, SC	POLY, CP		15, 39
Tingidae					
Corythucha sp.	Canada	EXT, L	CONVOL		13
Miridae					
Adelphocoris lineolatus (Goeze)	Canada	EXT, L	CONVOL		13
Halticus tibialis Reuter	Papua New Guinea	EXT, L	IB		41
Lygus lineolaris Palisot de Beauvois	USA	EXT, L	CONVOL		42
Poecilocapsus lineatus (F.)	Canada	EXT, L	CONVOL		13
HEMIPTERA: AUCHENORRHYNCHA					
Cixiidae					
Hyalesthes obsoletus Signoret	France, Germany, Slovakia	EXT, R, L	POLY		43 – 46
Delphacidae					
Asiraca clavicornis (F.)	Austria, Yugoslavia	EXT, L, St	POLY		47
Cercopidae					
Cercopis sanguinolenta (Scopoli)	Yugoslavia	EXT, L, F	POLY, CP		48
Philaenus spumarius L.	Europe, Canada	EXT, St	POLY, CP		13, 23, 49
Membracidae					
Ceresa bubalus F.	–	–	POLY		13
Cicadellidae					
Cicadella viridis (L.)	Italy	EXT, St	POLY, CP		48
Empoasca spp.	Peru	EXT, L	IB		50
Petalocephala sp.	–	–	POLY		13
Platymetopius sp.	Spain	EXT, St	C		5
Selenocephalus pallens Lindberg	Italy, Yugoslavia	EXT, St	POLY		5, 51, 52
HEMIPTERA: STERNORRHYNCHA					
Psyllidae					
Trioza sp.	Italy	EXT, L	C		5
Aleyrodidae					
Aleyrodes spiraeoides Quaintance	–	–	POLY		13
Bemisia tabaci (Gennadius)	Egypt, Uganda	EXT, L	POLY, CP		13, 15, 53, 54
Aphididae					
Aphis convolvuli Kaltenbach [*Myzus persicae* Sultzer]	Europe	EXT, L	CA		52

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Aphis fabae ssp. *euonymi* F.	–	–	POLY		13
Aphis fabae Scopoli	Europe	EXT, L	POLY		23
Aphis gossypii Glover	USA, Canada	EXT, L	POLY		1, 34
Aphis nerii Boyer de Fonscolombe	USA, Canada	EXT, L	POLY		1
Aphis spiraecola Patch	–	–	POLY		13
Aulacorthum solani (Kalenbach)	Yugoslavia	EXT, L	POLY, CP		47
Aulacorthum speyeri Börner	Italy	EXT, L	*Convall*., C		5, 55
Macrosiphum euphorbiae Thomas	Canada, Peru, Europe	EXT, L	POLY, CP		13, 39, 50, 56
Macrosiphum gei (Koch)	–	–	POLY		13
Macrosiphum ludovicianae Oestlund [*Macrosiphoniella ludovicianae*]	–	–	POLY		13
Medoralis althae Kittel [*Aphis lavaterae*]	Europe	–	POLY		56
Myzus persicae Sultzer	Europe, Egypt, Canada	EXT, L	POLY, CP		13, 23, 34, 39, 56
Rhopalosiphoninus latysiphon Davidson	–	–	POLY		13
Ortheziidae					
Orthezia sp.	Italy	EXT, L	C		5
Pseudococcidae					
Phenacoccus sp.	Italy	EXT, R	C		5
Planococcus sp., prob. *citri* (Risso)	Italy, Spain	EXT, R	POLY, CP		57
Pseudococcus comstocki (Kuwana)	Canada	EXT, L	CONVOL		13
Pseudococcus longispinus (Targioni-Tozzetti)	Spain	EXT, R	POLY, CP		57
Rhizoecus falcifer Künckel d'Herculais	–	–	POLY		13
HYMENOPTERA					
Formicidae					
Acromyrmex octospinosus (Reich)	Canada	EXT, L	IB		58
Tenthredinidae					
Ametastegia glabrata (Fallén)	USA, Canada	–	CONVOL		1, 13
COLEOPTERA					
Scarabaeidae					
Chasmatopterus sp.	Portugal	EXT, F	C		5
Maladera matrida Argaman	Israel	–	IB		59
Oxythyrea funesta (Poda)	Spain	EXT, F	POLY, CP		60
Phyllophaga ephilda (Say)	USA	EXT, R	IB		61
Tropinota hirta Poda [*Epicometis hirta*]	Spain	EXT, F	POLY, CP		60
Buprestidae					
Trachys puncticollis Abeille var. *obscurella* Obenberger	Europe	EXT, L; INT, L	CC	*	5, 62, 63
Trachys puncticollis ssp. rectilineata Abeille de Perin	Slovakia, Austria	EXT, L; INT, L	CA	*	16, 64
Trachys spp.	Uzbekistan Tajikistan	INT, L	CA		21
Elateridae					
Adrastus limbatus (F.)	Yugoslavia	EXT, L	C		5, 65
Conoderus amplicollis (Gyllenhal)	USA	–	IB		66
Conoderus falli Lane	USA	EXT, R	IB		67

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Conoderus rudis Brown	USA	EXT, R	IB		68
Conoderus scissus (Schaeffer)	USA	–	IB		66
Conoderus vespertinus (F.)	USA	EXT, R	IB		67
Conoderus spp.	USA	–	IB		69
Dermestidae					
Attagenus scalaris (Pic)	Egypt	EXT, F	CA		15, 70
Dasytidae					
Astylus variegatus (Germar)	Brazil	–	IB		71
Nitidulidae					
Conotelus obscurus Erichson	–	–	POLY		13
Meligethes solidus (Kugelann)	Spain	EXT, F	POLY		72
Meligethes spp.	Austria, Italy	EXT, F	C		5
Phalacridae					
Olibrus spp.	Italy	EXT, F	CC		5
Stilbus sp.	Italy	EXT, F	CC		5
Coccinellidae					
Subcoccinella vigintiquatuorpunctata (L.)	Italy	EXT, L	POLY, CP		60
Meloidae					
Epicauta ferruginea Say	USA, Canada	EXT, L	POLY		1, 13
Epicauta leopardina Haag	Paraguay	–	I		73
Epicauta trichrus Pallas	USA, Canada	EXT, L	POLY		1, 13
Epicauta vittata (F.)	USA, Canada	EXT, L	POLY		1, 13
Macrobasis immaculata Say	–	–	POLY		13
Macrobasis unicolor (Kirby) [*Epicauta murina* (LeConte)]	–	–	POLY		13
Lagriidae					
Lagria hirta (L.)	Italy	EXT, L	C		5
Lagria villosa F.	Brazil	–	IB		71
Tenebrionidae					
Gonocephalum pusillum (F.)	Italy	EXT, L	POLY, CP		60
Stenosis angusticollis (Reiche)	Italy	EXT, L	POLY, CP		5
Cerambycidae					
Nupserha apicalis (Fairmaire) [*Nupserha apicata*]	Africa	INT, St	C	*	74
Nupserha quadrioculata Thunberg	South East Asia	INT, St	C	*	75
Chrysomelidae					
Agrioconota bivittata (Say)	North America	–	C, I		76, 77
Altica oleracea (L.) or nr.	Italy, Spain	EXT, L	POLY, CP		60
Aspidomorpha difformis (Motschulsky)	Japan	–	CJ		13
Aspidomorpha furcata (Thunberg)	Burma, India, Indonesia	EXT, L	IB, IT		78
Aspidomorpha indica Boheman	South East Asia, Pakistan	EXT, L	C, I	*	19, 79
Aspidomorpha miliaris (F.)	South East Asia	–	C, I	*	79
Aspidomorpha transparipennis (Motschulsky)	South East Asia, USA	EXT, L	CONVOL	*	80, 81
Aspidomorpha sp.	Papua New Guinea	–	IB		41

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Aulacophora calva Anand & Cox	India	–	IB		82
Calligrapha praecelsis Rogers	North America	–	CS, I		83
Cassida atrata F.	Italy	EXT, L	CA, CS, *Salvia*	*	5, 84
Cassida circumdata Herbst	South East Asia	–	C, I	*	80, 82
Cassida enervis Boheman	Pakistan	EXT, L	C	*	19
Cassida indicola (Duvivier) [*Rhytidocassis indicola*]	Pakistan, India	EXT, L	CA, CM	*	19, 85
Cassida nebulosa L.	–	EXT, L	POLY		13
Cassida rubiginosa Müller or nr.	Italy, Kazakhstan	EXT, L	POLY, CA	*	20, 60
Cassida sanguinolenta Müller	Egypt	EXT, L	CA		15
Cassida vespertina Boheman	–	EXT, L	POLY		13
Cassida vittata Villers or nr.	Yugoslavia	EXT, L	POLY, CP		60
Cassida wienmanni Chapuis	Italy	EXT, L	C		5
Cassida sp.	Portugal, Spain	EXT, L	C		5
Cassida sp.	Papua New Guinea	EXT, L	IB		41
Chaetocnema apricaria Suffrian	Brazil	–	IB		71
Chaetocnema basalis Baly	Philippines	EXT, L	IB		34
Chaetocnema confinis Crotch	USA	EXT, R	IB		67, 69
Chaetocnema pulicaria (Melsheimer)	–	–	POLY		13
Charidotella sexpunctata (F.)	Puerto Rico	EXT, L	IB		86
Chelymorpha cassidea (F.)	USA, Canada	EXT, L	CONVOL	*	17, 87–90
Chirida guttata (Olivier) [*Deloyala guttata*]	North and Central America	EXT, L	CONVOL	*	17, 77, 91
Chrysolina banksi (F.) or nr.	Yugoslavia	EXT, L	POLY, CP		60
Colasposoma sellatum Baly	Australia, Papua New Guinea	EXT, L, St, R	IB		92
Colasposoma subopacum Jacoby	India	–	IB		82
Coptocephala chalybea Germar or nr. [*Stolas chalybea*]	Portugal	EXT, L	C		5
Coptocycla aurichalcea F.	North America	–	C		76
Cryptocephalus sp.	Italy	EXT, L	C		5
Deloyala guttata (Olivier)	USA, Canada	EXT, L	CA		1, 90
Diabrotica balteata LeConte	USA, Taiwan	EXT, R	IB		67, 93, 94
Diabrotica duodecimpunctata F.	–	–	POLY		13
Diabrotica speciosa (Germar)	Brazil	–	IB		71
Diabrotica undecimpunctata ssp *howardi* Barber	USA	EXT, R	IB		67
Diabrotica spp.	USA	–	IB		69, 95
Epitrix parvula (F.) [E. *fasciata* Blatchley]	–	–	POLY		13
Exosoma lusitanicum (L.) [*Exora lusitanica*]	Italy, Spain	EXT, F	POLY		96
Galeruca rufa Germar	South and Central Europe, Southern Russia and Asia Minor	EXT, L	CA, CS	*	97, 98
Gastrophysa polygoni (L.)	Italy, Spain	EXT, L	POLY, CP		60
Glyphocassis trilineata (Hope)	Pakistan	EXT, L	CA	*	19
Hypocassida meridionalis (Suffrian)	Italy, Morocco	EXT, L	CC	*	96

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Hypocassida subferruginea Schrank	South and Central Europe, Turkey, Kazakhstan, Uzbekistan, Tajikistan	EXT, L	CC	*	5, 20, 21, 84, 96, 99
Jonthonota nigripes (Olivier)	North America	–	CONVOL		76, 77
Laccoptera quadrimaculata (Thunberg)	South East Asia	–	C, I		80, 82
Leptinotarsa decemlineata Say	North America	EXT, L	POLY		1
Longitarsus aeruginosus (Foudras)	France	–	POLY		100
Longitarsus codinai Madar & Madar	France	EXT, L	C		100
Longitarsus longipennis Kutschera	From Central and East Europe to Central Asia	EXT, L; INT, R	POLY, CONVOL		16, 60, 100, 101
Longitarsus nasturtii (F.)	Portugal, Italy	EXT, L	POLY, CP		60
Longitarsus nigrocillus Motschulsky	Mediterranean region	EXT, L	CONVOL		100
Longitarsus pellucidus (Foudras)	Europe, North Africa, Central Asia, Mongolia, India	EXT, L; INT, R	POLY, CONVOL	*	5, 16, 21, 84, 96, 100, 102–112
Longitarsus rubiginosus (Foudras)	Europe, North Africa, Iran, Caucasus, Siberia	EXT, L; INT, R	CA,CS, *Calystegia tricolor*, CL		84, 100, 103–105, 110, 113–117
Metriona australica (Boheman) [*Cassida australica*]	Pakistan, India	EXT, L	CONVOL	*	19
Metriona bicolor (F.) [*Charidotella sexpunctata*]	North America	EXT, L	CONVOL		1, 17, 88, 90
Metriona purpurata (Boheman) [*Charidotella purpurata*]	North America	EXT, L	CA		1, 118
Metriona tuberculata (F.) [*Charidotella tuberculata*]	USA	–	CA, IB		81
Oulema melanopus (L.)	Italy	EXT, L	POLY, CP		60
Phyllotreta consobrina (Curtis)	Europe, North Africa	EXT, L	POLY, CP		60, 100
Physonota jamaicensis (L.) [*Eurypepla jamaicensis*]	Puerto Rico	–	IB		86
Podagrica malvae (Illiger) or nr.	Europe	EXT, L	POLY, CP		60, 100
Psylliodes glabra L.Redtenbacher or nr.	Italy	EXT, L	C		5
Psylliodes punctulata Melsheimer	–	–	POLY		13
Psyllioides sp.	Italy	EXT, L	C		5
Sphaeroderma testaceum (F.)	Spain	EXT, L	POLY, CP		60
Smaragdina sp	Portugal	EXT, L	C		5
Strobiderus sp.	India	–	IB		82
Systena blanda (Melsheimer)	North America	EXT, R	IB		67, 119
Systena elongata (F.)	USA	EXT, R	IB		67
Systena frontalis (F.)	USA	EXT, R	IB		67
Systena sp.	Brazil	–	IB		71
Systena sp.	USA	–	IB		69, 95
Typophorus nigritus (F.)	Brazil	–	IB		71
Typophorus viridicyaneus (Crotch)	–	–	POLY		13
Bruchidae					
Megacerus discoidus Say	USA, Canada	EXT, F; INT, S	CS, IP, ITR	*	17, 90, 120–124
Megacerus impiger (Horn)	USA	INT, S	CC	*	125
Spermophagus calystegiae (Lukjanovič & Ter-Minasjan)	Europe, Turkey, Iran	EXT, F; INT, S	CS	*	84, 126–128

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Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Spermophagus kuesteri (*küsteri*) Schilsky	Europe, Turkey, Iran, Israel, Syria, North Africa, Mongolia	EXT, F; INT, S	C	*	84, 126, 127, 129–131
Spermophagus rufiventris Boheman	Japan	EXT, F; INT, S	CJ	*	132
Spermophagus sericeus (Geoffroy)	Europe, North Africa, Iran, Iraq, Turkey, Mongolia, Uzbekistan, Tajikistan	EXT, F; INT, S	CC	*	21, 84, 126, 127, 129–135
Spermophagus variolosopunctatus Gyllenhal	East and South Europe, South Russia, Turkey, North Africa.	EXT, F; INT, S	C	*	48, 126, 127, 136
Spermophagus sp.	Italy, Spain	EXT, F; INT, S	C		5
Curculionidae					
Alcidodes chaudoiri (Chevrolat) [A. *karelinii* (Boheman)]	Uzbekistan, Tajikistan	EXT, S	CA	*	21
Alcidodes fabricii (F.)	Pakistan	EXT, S	CA, I	*	19, 137
Apion basicorne Illiger	Yugoslavia	EXT, L	POLY		138
Apion pisi (F.)	Italy	EXT, L	POLY, CP		60
Apion sp.	Italy	EXT, L	C		5
Calomycterus setarius Roelofs	–	–	POLY		13
Ceutorhynchidius [*Ceutorhynchus*] *baldensis* Schultze [*Trichosirocalus baldensis*]	Italy	EXT, L	POLY		139
Ceutorhynchidius [*Ceutorhynchus*] *maculaalba* (Herbst) [*Neoglocianus maculaalba*]	Italy	EXT, L	POLY		60
Cylas formicarius F.	India, Japan, Taiwan, Kenya, South Africa, Papua New Guinea	EXT, R	IB		27, 82, 140–143
Cylas formicarius ssp. *elegantulus* (Summers)	Japan, Australia	EXT, R	IB		144, 145
Cylas puncticollis Boheman	South Africa, Nigeria	EXT, R	IB		27, 146
Diaprepes abbreviatus L.	USA, Caribbean islands	–	POLY, IB, CP		147
Euscepes postfasciatus (Fairmaire)	Japan	INT, St, R	IB		148 – 150
Hypera postica (Gyllenhal)	Italy	EXT, L	POLY		60
Limnobaris pilistriata (Stephens)	Italy	EXT, L	POLY		139
Lixus iridis Olivier	Italy	EXT, L	POLY, CP		60
Otiorhynchus sp.	Italy	EXT, L	C		5
Pachnaeus litus (Germar)	Cuba	INT, R	IB		151
Pachytychius squamosus (Gyllenhal)	Italy	EXT, L	POLY, CP		60
Sitona limosus (Rossi)	Italy	EXT, L	POLY, CP		60
Sitona lineatus (L.)	Portugal	EXT, L	POLY, CP		60
Strophomorphus sp. nr. *porcellus* (Schönherr)	Italy	EXT, L	C		5
Tanymecus palliatus (F.)	Italy	EXT, L	POLY, CP		13, 16, 60
LEPIDOPTERA					
Nepticulidae					
Stigmella freyella (Heyden)	Europe	INT, L	CA, CAL, CS	*	5, 16, 52, 152–157
Stigmella sp.	Austria, Italy, France, Spain, Portugal	INT, L	CC		5
Psychidae					
Apterona helicinella (Herrich-Schäffer)	Europe	INT, L	POLY		154

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Dissoctena granigerella Staudinger	Portugal, Spain	EXT, F	POLY, C		158, 159
Psychidae sp.	South Korea	EXT, L	IB		160
Bucculatricidae					
Bucculatrix cantabricella Chrétien	Slovakia, France, Spain, Italy, Hungary, Yugoslavia	INT, L	*Convolvulus cantabricus*		154, 157, 161
Bedelliidae					
Bedellia somnulentella (Zeller)	North America, Eurasia, Africa, Australia, Papua New Guinea	INT, L	CONVOL, CP	*	15, 17, 20, 41, 52, 88, 144, 152, 155, 162–165
Ethmiidae					
Ethmia candidella (Alpheraky)	South America, China	–	CA, I		166, 167
Scythrididae					
Scythris lempkei (Bengtsson & Langohr)	France, Spain	EXT, L	POLY		168
Scythris sp.	Italy	EXT, L	C		5
Cosmopterigidae					
Hodgesiella rebeli Krone [*Stagmatophora rebeli*]	Europe	INT, L	C		152, 154
Pebops sp.	Peru	–	IB		169
Gelechiidae					
Brachmia convolvuli (Walsingham) [*Helcystogramma convolvuli*]	Philippines	EXT, L	IB		34
Brachmia triannulella ssp. macroscopa (Meyrick) [*Helcystogramma triannulella ssp. macroscopum*]	South Korea	EXT, L	IB		160
Brachmia sp.	Italy	EXT, L	C		5
Brachmia sp.	Philippines	EXT, L	IB		170
Dichomeris lamprostoma (Zeller)	Spain	INT, L	C		5, 14, 171
Gelechia rhenanella Heyden	Europe	EXT, L	CS		52
Helcystogramma triannulella (Herrich-Schäffer)	Europe, Japan	EXT, L	CONVOL	*	5, 16, 52, 153, 157, 172, 173
Pleurota sp.	Italy	EXT, L	C		5
Trichotaphe sp.	Peru	–	IB		169
Xystophora rhenanella Heyden	Europe	–	C		153, 174
Sesiidae					
Tinthia brosiformis (Hübner)	Russia, East Europe, Turkey	INT, R	C	*	157, 175
Tinthia tineiformis (Esper)	South Europe, Turkey	INT, R	C	*	157, 175
Tortricidae					
Archips crataeganus (Hübner)	Austria	EXT, L	POLY		176
Archips purpuranus Clemens	Canada	EXT, L	CONVOL		13
Argyroploce sp.nr. *arbutella* (L.)	Austria	EXT, L	CONVOL		5
Argyrotaenia ljungiana (Thunberg)	Italy	EXT, L	CONVOL		177
Cacoecimorpha pronubana (Hübner)	Italy, Spain	EXT, L	POLY		176
Celypha rivulana (Scopoli)	Italy	EXT, L	POLY		172
Cnephasia incertana (Treitschke)	Europe	INT, L	POLY		152, 154, 176, 178, 179,
Cnephasia longana (Haworth)	–	–	POLY		13
Epinotia sp.	Canada	EXT, L	CONVOL		13

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Sparganothis pilleriana (Denis & Schiffermüller)	Austria	EXT, L	POLY, CP		176
Pterophoridae					
Emmelina monodactyla (L.)	Europe, Africa, Asia, North and Central America	EXT, L	POLY, CONVOL	*	1, 5, 15–17, 88, 152, 155, 180–191
Ochyrotica fasciata Walsingham	Peru	–	IB		169
Pterophorus ischnodactyla (Treitschke)	South Europe	EXT, L	*Convolvulus cantabricus*		157, 191
Pterophorus jezonicus Matsumura	Asia	–	C, I		192
Pterophorus pentadactyla (L.)	Europe	EXT, L	POLY	*	5, 16, 152, 191, 193–195
Pterophorus sp.	South East Asia	–	C		196
Stenoptilia pterodactyla (L.)	Europe	EXT, L	POLY		52, 152, 159, 195
Pyralidae					
Aporodes floralis (Hübner) [*Noctuelia floralis*]	Syria, Afghanistan, Egypt, India, Europe	EXT, L,St	CC	*	5, 15, 16, 18, 157, 197
Chrysocrambus linetellus (F.)	Europe	EXT, L	CONVOL	*	5, 157
Diastichtis [*Anomostictis*] *fracturalis* Zeller	North America	–	C		88
Eurrhypara hortulata (L.)	Europe	EXT, L	CA, CS		52
Hydrisis ornatalis (Duponchel)	Switzerland, South Europe, Egypt	EXT, L	CONVOL	*	5, 15, 157, 159
Loxostege mancalis (Lederer) [*Hahncappsia mancalis*]	USA, Canada	–	CA		1
Loxostege sticticalis (L.)	Canada, USA, Italy, Yugoslavia	EXT, L	POLY, CP		1, 198, 199
Macrobotys pertextalis (Lederer) [*Herpetogramma pertextalis*]	Canada	–	CONVOL		13
Microthyris anormalis (Guenée)	Peru	EXT, L	IB		169, 200
Omphisa anastomosalis Guenée	Asia, Papua New Guinea, Taiwan	INT, St, R	IB		41, 201, 202
Phlyctaenia coronata (Hufnagel)	Europe	–	POLY		52, 152
Pyrausta despicata (Scopoli)	Italy, Spain	EXT, L	POLY		194, 193, 203
Sitochroa verticalis (L.)	South Europe	EXT, L	POLY		193
Titanio normalis (Hübner)	Eurasia, Africa	INT, L	CC	*	16, 154, 157
Sphingidae					
Coelonia fulvinotata (Butler)	–	–	POLY		13
Deilephila elpenor (L.)	Eurasia, Africa	EXT, L	CS		157, 204, 205
Herse convolvuli L. [*Agrius convolvuli*]	Europe, India, China, Oman, Egypt, Saudi Arabia, Madagascar, South Africa, Japan, Australia, Papua New Guinea, Hawaii	EXT, L	C, POLY, CP		15, 16, 21, 41, 144, 199, 206–216
Hippotion celerio (L.)	Europe	EXT, L	POLY, IB		144, 157
Hippotion scrofa (Boisduval)	Australia	–	IB		144
Theretra nessus (Drury)	South East Asia	–	C		217
Geometridae					
Ascotis selenaria (Denis & Schiffermüller)	Europe, Israel, Japan	EXT, L	POLY, CP		48, 152, 218– 222
Ematurga atomaria (L.)	Italy	EXT, L	POLY, CP		48, 152, 207

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Idaea degeneraria (Hübner)	–	EXT, L	POLY		211
Idaea emarginata (L.)	Europe	EXT, L	POLY		52, 211
Idaea sp.	Italy	EXT, L	C		5
Larentia clavaria (Haworth)	Italy	EXT, L	CC, Malvaceae		5, 206
Lycia florentina (Stephanelli)	Italy, Yugoslavia	EXT, L	POLY, CP		48, 157
Orthonama obstipata (F.)	–	–	POLY		223
Scopula emissaria (Walker)	Korea	EXT, L	IB		160
Scopula emutaria Hübner	Europe	EXT, L	POLY		152
Scopula rubiginata (Hufnagel)	Europe	EXT, L	POLY		152, 223
Semiothisa clathrata (L.) [*Chiasmia clathrata*]	Italy	EXT, L	LEG, CA		5, 206
Notodontidae					
Schizura ipomoeae Doubleday	–	–	POLY		13
Noctuidae					
Acontia lucida Hufnagel	Europe, Asia	EXT, L	POLY		152, 211, 224
Acronicta rumicis (L.)	Italy	EXT, L	POLY		193
Aedia funesta (Esper)	Europe, Turkey	EXT, L	CC	*	16, 152, 157, 225, 226
Aedia leucomelas (L.)	Europe, Turkey, Japan, Korea	EXT, L	CONVOL		52, 157, 160, 172, 173
Agrotis ipsilon (Hufnagel)	Egypt, Italy	EXT, L	POLY, CP		15, 199
Agrotis segetum Dennis & Schiffermüller	Italy	EXT, L	POLY, CP		38
Anepischetos [*Hypena*] *lividalis* (Hübner)	Europe	–	C, *Parietaria*		5, 157, 227
Autographa gamma (L.)	Worldwide	EXT, L	POLY, CP		193, 228
Axylia putris (L.)	Italy, Poland, Russia	EXT, L	POLY		21, 152, 199, 206, 229
Chrysodeixis chalcites Esper	Italy	EXT, L	POLY, CP		230
Discestra trifolii (Hufnagel)	Italy	EXT, L	POLY		48
Elaphria morpheus Hufnagel [*Caradrina morpheus*]	–	–	POLY		13
Emmelia trabealis (Scopoli)	Europe, Asia	EXT, L	CA, CS	*	5, 16, 21, 52, 152, 193, 211, 224, 226
Estigmene acraea (Drury)	–	–	POLY		13
Eublemma baccalix (Swinhoe)	Pakistan	EXT, F	CA, I		18, 137
Euplexia lucipara L.	–	–	POLY		13
Euxoa segetum Denis & Schiffermüller [*Agrotis segetum*]	–	–	POLY		13
Heliothis armigera (Hübner) [*Helicoverpa armigera*]	Italy, Sweden, Canada, USA, India, China, Egypt	EXT, L	POLY, CP		1, 231– 234
Lacanobia oleracea (L.)	Italy, Spain, UK, Bulgaria, Slovakia	EXT, L	POLY, CP		193, 235 – 237
Lycophotia margaritosa (Haworth) [*Peridroma saucia* Hübner]	USA, Canada	–	CONVOL		1
Mamestra brassicae (L.)	Italy, Bulgaria, Yugoslavia, France, Slovakia	EXT, L	POLY, CP		193, 198, 199, 237 – 239
Melanchra pisi (L.)	Europe	EXT, L	POLY		52
Mythimna sp.	Spain	EXT, L	C		5

Table 1. Organisms associated with the family Convolvulaceae worldwide[a].

Taxon[b]	Location	Plant association[c]	Host specificity[d]	Biocontrol candidate[e]	Ref.
Neleucania diffusa (Walker) [*Faronta diffusa*]	–	–	POLY		13
Peridroma saucia (Hübner)	Canada, Italy	EXT, L	POLY, CP		13, 39, 199, 240
Pseudaletia unipuncta (Haworth) [*Mythimna unipuncta*]	Canada, USA	–	CONVOL		13
Rivula sericealis Scopoli	France	EXT, L	POLY		206
Spodoptera eridania Cramer	Brazil, Peru	–	POLY, IB		241, 242
Spodoptera exigua (Hübner)	Europe, Egypt, USA, Canada	EXT, L	POLY, CP		1, 39, 211
Spodoptera littoralis Boisduval	Italy, Egypt	EXT, L	POLY		15
Spodoptera ornithogalli (Guenée)	–	–	POLY		13
Synthymia fixa (F.)	Europe	EXT, L	C, *Psoralea*,		5, 157, 227
Trachea atriplicis (L.)	Europe	–	CS, C		243
Tyta luctuosa (Denis & Schiffermüller)	Europe, Asia, North Africa	EXT, L	CC	*	16, 21, 33, 152, 157, 224 – 226, 244
Xylena vetusta (Hübner)	Austria	EXT, L	POLY		193
Arctiidae					
Arctia caja L.	–	–	POLY		13
Diacrisia virginica (F.) [*Spilosoma virginica*]	USA, Canada	–	POLY		1, 13
Eilema sp.	Italy	EXT, L	CS		5
DIPTERA					
Cecidomyiidae					
Lasioptera convolvuli Felt	North America	INT, St	CA, CS	*	13, 245, 246
Agromyzidae					
Melanagromyza albocilia Hendel	Slovakia, Austria, Hungary, UK, Italy, Israel, Egypt	INT, St, R	CA	*	5, 15, 247 – 249
Melanagromyza convolvuli Spencer	Pakistan	INT, St	CA	*	18, 247, 250
Chromatomyia horticola (Goureau)	Worldwide	INT, L	POLY, CP		154

[a]Families are listed taxonomically, and genera and species within families in alphabetical order. [b]Taxa are largely listed as cited in the references. Where appropriate, preferred synonyms are given in square brackets. [c]EXT: external feeding; INT: internal feeding; L: leaf; St: stem; R: root; S: seed; SC: seed capsule. [d]CA: *Convolvulus arvensis*; CAL: *Convolvulus althaeoides*; CJ: *Calystegia japonica*; CL: *Convolvulus lanceolata*; CM: *Convolvulus microphylus*; CS: *Calystegia sepium*; C: *Convolvulus* spp.; CC: species of *Convolvulus* and *Calystegia*; CONVOL: members of the Convolvulaceae; *Convall.*: *Convallaria*; I: *Ipomoea* sp.; IB: *Ipomea batatas* (sweet potato); ID: *Ipomoea denticulata*; IP: *Ipomoea pandurata*; IS: *Ipomoea staphilina*; IT: *I. tuberosa*; ITR: *Ipomoea tricolor*; LEG: Leguminosae; LB: *Lepistemon binectarifeus*; MG: *Merremia gemella*; POLY: polyphagous species; CP: crop pest. [e]Biological control candidate according to the literature.

3.1. Gall-Forming Mite

Feeding by *Aceria malherbae* Nuzzaci (Acari, Eriophyidae) on young leaf petioles, stems and expanding buds causes abnormal growth or galling. Flowers have never been seen on stems heavily infested with the mites [29, 32]. The symptoms were found only in natural ecosystems and were never recorded in cultivated fields [16]. The mite lived and reproduced only on species in the genera *Convolvulus* and *Calystegia* [31]. In 1989, *A. malherbae* was released in Saskatchewan (Canada) and New Jersey and Texas (USA) where it established [22]. During 1993–98, *A. malherbae* was released and established in southern Alberta (Canada) and Montana (USA). Populations of the mite survived for up to 4 years at some localities and caused slight to severe damage to the weed. The establishment of *A. malherbae* in these areas suggests that it could establish throughout the North American range of *Convolvulus arvensis* [252].

3.2. Root and Stem Feeders

Melanagromyza albocilia Hendel (Dipt., Agromyzidae), a native European stem borer of *C. arvensis*, was considered as a very promising candidate for the biological control of bindweed [5, 249]. Larvae bore tunnels in bindweed stems and root crowns, causing the death of infested shoots [247]. The number of infested plants ranged from 46.7% to 99.2% and the number of infested stems from 4.1% to 37.2% in southwest Slovakia [253]. The fly can promote secondary damage due to infection by pathogenic microorganisms [254]. Its feeding habit in stems indicates a high degree of probability that the species

Table 2. Systematic affiliation of organisms associated with the family Convolvulaceae worldwide.

Order	%	Number		
		Species	Families	Biological control candidate species
Tylenchata	1.8	6	3	0
Acari	3.1	10	2	1
Collembola	0.3	1	1	0
Orthoptera	0.9	3	2	0
Thysanoptera	0.9	3	1	0
Hemiptera	13.6	45	13	0
Hymenoptera	0.6	2	2	0
Coleoptera	43.7	143	15	29
Lepidoptera	33.9	111	17	14
Diptera	1.2	4	2	3
Total	100.0	328	58	47

Table 3. Feeding sites of organisms found on the family Convolvulaceae worldwide[a].

External or internal feeding on:	Number of species	%
Leaves	177	54.0
Roots	26	8.0
Seeds, seed capsules	16	4.9
Flowers	11	3.3
Stems	11	3.3
Not specified	87	26.5
Total	328	100.0

[a]If an insect fed on different part of the plants as an adult and as a larva, it is included here in its more destructive stage.

will prove to be strictly monophagous [255]. Its known distribution includes Austria and Hungary [256, 257], Egypt [15], Israel [258], UK, Denmark and Sweden [248], Italy [5] and the Czech Republic [259]. High numbers of *M. albocilia* were recorded only in Slovakia [16].

Melanagromyza convolvuli Spencer was found in *C. arvensis* stems in Pakistan [250]. Larval feeding in the stems or lateral branches considerably weakened the plants. Infested branches dried up under the combined effects of drought and larval attack in areas with limited rainfall [247]. However, the species was able to complete its development on sweet potato and *Ipomoea purpurea* (L.) Roth [19]. For this reason *M. convolvuli* can be used as biological control agent only in areas where sweet potato is not grown as a crop [7].

The adult of the *Convolvulus* flea beetle, *Longitarsus pellucidus* (Foudras) (Col., Chrysomelidae), was found to be a widespread and abundant leaf feeder. The larva fed on roots. Gorenshtein [21] mentioned *L. pellucidus* as highly specialized on *C. arvensis*. In Italy, the adults were found primarily on *Convolvulus* species. Only slight feeding on sweet potato was observed. This species seems to have the most potential as a classical biological control agent for introduction from Mediterranean Europe [5]. *Longitarsus pellucidus* is well synchronized with the host plant and if released as a biological control agent in the classical concept, its population should be able to increase to a size large enough to suppress *C. arvensis*. *Longitarsus pellucidus* is widely distributed in the Old World, from the British Isles to Mongolia and India. It has also been reported from North Africa and the Middle East (Table 1). LeSage [260] reported the species for the first time in North America.

Nupserha apicata (Fairmaire) (syn. *N. apicalis*) (Col., Cerambycidae) in Africa [74] and *Nupserha quadrioculata* Thunberg in southeastern Asia [75] feed in stems of *Convolvulus* spp. forming galls [74]. The species are able to suppress weed populations.

3.3. Seed Feeders

Species from the family Bruchidae (Coleoptera) were frequently associated with *C. arvensis* and *Calystegia sepium*. In the Palaearctic region, *Spermophagus sericeus* (Geoffroy), *Spermophagus calystegiae* (Lukjanoviæ & Ter-Minasjan,, *Spermophagus kuesteri* Schilsky and *Spermophagus variolosopunctatus* Gyllenhal [127] and *Spermophagus rufiventris* Boheman [132] were reared from *Convolvulus arvensis* seeds. *Megacerus discoidus* Say [123] and *Megacerus impiger* (Horn) [125] were reported as native North American seed feeders on *Calystegia sepium*.

In Europe, the most common bruchid species is *S. sericeus*. Adults feed on pollen of different plant species mainly in the Convolvulaceae and larvae feed in seeds [134]. In some cases *S. sericeus* has been able to generate high levels of infestation even after only one generation on the host. More than 50% of *Convolvulus arvensis* seeds were attacked by this insect in Slovakia [16]. In Italy, infestation levels of 40% were found at Rome and 65% at Venice [5]. *Megacerus discoidus* destroyed about 63% of the viable seeds of *Calystegia sepium* at Belleville in Canada [17]. However, the species is not always able to generate high levels of infestation, probably because of parasitism. The egg stage is particularly vulnerable because eggs are laid on the surface of the ripening pod. Bridwell [261] noted that when the trichogrammatid egg parasite *Uscana semifumipennis* Girault was present, only six larvae reached maturity out of 3000 eggs of the bruchid *Caryedon serratus* (Olivier). A similar species, *Uscana spermophagi* Viggiani, was found to be a parasitoid of *S. sericeus* [262].

The newly hatched larvae of *Alcidodes fabricii* (F.) (Col., Curculionidae) bored upwards into the fruits and destroyed all seeds of *Convolvulus arvensis* in Pakistan. The species appeared to be specific to *C. arvensis* although it would infest *Ipomoea* spp. [137]. The larvae of a related species, *Alcidodes karelinii*

(Boheman) (syn. *A. chaudoiri* [Chevrolat]), fed on the reproductive organs of *C. arvensis* in Uzbekistan and Tajikistan [21].

3.4. Foliage Feeders

Galeruca rufa Germar (Col., Chrysomelidae), a European species, feeds only on plant species in the genera *Convolvulus* and *Calystegia* [97]. Moderate populations of this insect can cause defoliation severe enough to reduce *Convolvulus arvensis* flower production and to kill seedlings [98]. Natural populations of *G. rufa* could be expected to occur on *C. arvensis* continuously through the season (with feeding by both adults and larvae) [263]. *Galeruca rufa* was considered by the above authors as a promising biological control agent for *C. arvensis* in the USA.

Tortoise beetles (Col., Chrysomelidae), including *Rhytidocassis indicola* (Duvivier) (syn. *Cassida indicola*) [85], *Aspidomorpha indica* Boheman [19], *Aspidomorpha miliaris* (F.) [79], *Aspidomorpha transparipennis* (Motschulsky) and *Cassida circumdata* Herbst [80] and *Cassida enervis* Boheman, *Glyphocassis trilineata* (Hope) and *Cassida australica* (Boheman) (syn. *Metriona australica*) [18] were found to be promising agents in Pakistan and India. Each of them can defoliate *Convolvulus arvensis* and (or) *Calystegia sepium* severely when their populations are high. However, their value in biological control is limited to areas where sweet potato is not grown, because they all feed on this plant.

Cassida rubiginosa Müller was mentioned as a prospective phytophagous species for the biological control of *Convolvulus arvensis* and *Calystegia sepium* in Kazakhstan [20], and *Cassida atrata* F. was suggested for the same purpose in Italy [5].

Hypocassida subferruginea Schrank and *Hypocassida meridionalis* (Suffrian) (Col., Chrysomelidae), were recorded as specific to the genera *Convolvulus* and *Calystegia* in Eurasia (Table 1). The larvae and adults of *H. subferruginea* almost completely destroyed the leaves of *Convolvulus arvensis* plants in some uncultivated habitats in the warmest localities of Slovakia [16]. Feeding tests showed that 28 newly hatched larvae of *H. subferruginea* fed only 6% as much on sweet potato as control larvae did on *C. arvensis*. Only four of them survived the 5-day test, and none of them completed development on sweet potato [5].

Chelymorpha cassidea (F.) (Col., Chrysomelidae), a frequent defoliator of bindweeds in the USA (Table 1), also showed potential for their control. Larvae and adults were successfully established on *Calystegia sepium* and *Convolvulus arvensis* in rye, maize, grapes, pine and zucchini. This insect fed only on plants within the Convolvulaceae and can be reared in the laboratory [264].

The larvae of *Tyta luctuosa* (Denis & Schiffermüller) (Lep., Noctuidae) generally feed during the night on leaves and flowers of *Convolvulus* or *Calystegia* throughout Europe and Asia (Table 1). The species was released for biological control purposes in the USA (1987) and Canada (1990) but its establishment was not confirmed [22].

On the basis of the results from Slovakia, *Emmelia trabealis* (Scopoli) from the same family is probably more promising than *T. luctuosa*. The larvae of *E. trabealis* fed during the daytime on leaves, but also flowers, where they evidently reduced reproductive capacity in *Convolvulus arvensis* as a result of feeding on pistils and stamens [16]. Larvae fed only lightly and were unable to complete development on sweet potato [5].

In Europe, Syria, Afghanistan, Pakistan, India and Egypt, the larvae of *Noctuelia floralis* Hübner (syn. *Aporodes floralis*) (Lep., Pyralidae) were noted as very promising biological control agents feeding on young leaves and buds, and subsequently the soft, whitish, underground or aerial stems of bindweeds [5, 15, 19, 197].

The plume moth *Emmelina monodactyla* (L.) is a member of the family Pterophoridae, whose larvae are primarily leaf feeders or stem and root borers on a wide range of host plants. First-instar larvae fed gregariously on the leaves and spread out on the plants as they developed [184]. In Slovakia, *E. monodactyla* was selected as a potential agent for biological control because of its distinct preference for *C. arvensis* and high abundance throughout the area [265]. Smith [88], Mohyuddin [17] and Ghani *et al.* [196] also considered its use as a biological control agent of bindweeds. Sweet potato is of North or South American origin [251] and is grown all over the world [266]. *Emmelina monodactyla* is distributed nearly worldwide [191], but only in one case was damage recorded on sweet potato [267]. Generally, sweet potato was free from very serious attack by *E. mondactyla* [120]. However, the moth's ability to complete development on nine sweet potato varieties under laboratory conditions [186] precludes its use as a control agent in the areas where this crop is grown. Nonetheless, Rosenthal & Buckingham [5] recommended *E. monodactyla* for biological control purposes. They considered that larvae could not survive more than 2 weeks on sweet potato and, moreover, they were not able to complete development on this plant. According to Parrella & Kok [268], releases of three and five larvae of *E. monodactyla* per *Calystegia sepium* leaf caused 90% and 100% reduction of foliage in the greenhouse, respectively. A similar test, where *C. sepium* was infested with three larvae of *E. monodactyla* per leaf in field cages, resulted in a decrease in total length of sprouts, and number of leaves or shoots. In this test, average larval leaf consumption was 13 cm^2 at 18.3°C, increasing to 16 cm^2 at 29.4°C. The last-instar larvae consumed over 60% of the leaf area [184]. Inundative releases of ten larvae of *E. monodactyla* per *Convolvulus arvensis* plant caused full defoliation of plants under laboratory conditions. Although the population density of *E. monodactyla* under field conditions

was found to be low [16], a well-managed conservation biological control strategy could provide a method of controlling *C. arvensis* in the field [265].

Larvae of *Helcystogramma triannulella* (Herrich-Schäffer) (Lep., Gelechiidae) were commonly found in rolled leaves of *C. arvensis* and *Calystegia sepium* in Europe [16, 52, 153, 172] and Canada [17]. However, this species was recorded as a foliage feeder on sweet potato in Japan, Korea and the Philippines [34, 160, 170, 173]. Hence, on the world scale, *H. triannulella*'s value is limited to areas with no sweet potato production.

Multiple infestation by larvae of *Bedellia somnulentella* (Zeller) (Lep., Bedelliidae) in a single bindweed leaf generally ends with complete destruction of the leaf, since the mines amalgamate into a single large mine that extends throughout the leaf tissue [15]. The accumulation of frass can result in fungal growth causing more harm to the plant [163]. Although, Tawfik *et al.* [163] suggested *B. somnulentella* for biological control purposes in Egypt, this species feeds on sweet potato [164, 269, 270].

4. Conclusions

This review highlights that organisms associated with the family Convolvulaceae have great diversity even within single families, and only a few species have been studied in detail. In particular, tropical faunas are largely unstudied (apart from organisms feeding on sweet potato) and these are almost certainly greater in size than temperate faunas. So it is still questionable how representative our current knowledge is.

Convolvulus arvensis and other species in the Convolvulaceae have more than one means of reproduction, i.e. seeds and roots. Thus complete biological control of this weed is unlikely to be achieved by using a single species which causes damage limited to one plant part, for example seeds or leaves.

Research efforts should be directed towards continued investigation of phytophagous arthropods attacking the Convolvulaceae, and how suitable species could be effectively combined to put maximum stress on *C. arvensis*. Such efforts may lead to an effective integrated pest management programme. The variety of biological control agents available (identified in Table 1) indicates a reasonable probability of success. From results obtained in Slovakia, we have every reason to believe that *Melanagromyza albocilia, Longitarsus pellucidus, Hypocassida subferruginea*, *Spermophagous sericeus*, *Emmelina monodactyla* and *Emmelia trabealis* are the most promising [16]. These species cause heavy damage to the host plant and their combined influence is evident in each growing season and on each part of *C. arvensis*.

It is clear that insects have considerable success in controlling *C. arvensis* in natural ecosystems, uncultivated areas and vineyards with living green cover. Given this, as well as public concern about environmental problems caused by modern agriculture, the development of new cropping systems could help in managing *C. arvensis*.

Because sweet potato and some ornamental plants in the genus *Ipomoea* are often subjected to attack by insects associated with *C. arvensis*, conflicting interests will be the major hurdle in the search for biological control agents that can be used against the weed on the world scale. However, by finding stenophagous species to control *C. arvensis*, the benefits of control could be more easily reconciled with the economic and ecological value of sweet potato and ornamental *Ipomoea* species.

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