

Review Article

Biological control of noxious pigweeds in Europe: a literature review of the insect species associated with *Amaranthus* spp. worldwide

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ABSTRACT

The results of a comprehensive literature review are presented on insects associated with *Amaranthus* spp. worldwide. The aim was to collect information on species showing some potential for the biological control of pigweeds in Europe. Some 241 insect species are recorded from 21 different *Amaranthus* species. Most of them belong to the Coleoptera and Lepidoptera. In spite of the relatively large number of records, few of the known species seem to have potential as biological control agents. Therefore, additional surveys within the native range of the genus *Amaranthus* are indispensable.

INTRODUCTION

The genus *Amaranthus* comprises about 60 species worldwide, occurring from the tropics to temperate regions. Several species are cultivated as vegetables (*A. tricolor*, *A. dubius*, *A. lividus*, *A. palmeri* and *A. cruentus*) or as “pseudo-cereals” (*A. hypochondriachus*, *A. caudatus*, *A. cruentus*) (Stallknecht and Schulz-Schaeffer 1993), and yet others as ornamental plants (*A. caudatus*, *A. cruentus*, *A. sinensis*, *A. ascendens*) (Dittmar 1995; Tawfik *et al.* 1976).

The taxonomy of genus *Amaranthus* is not well defined, indicated by the fact that the number of species recorded for Europe differs between 10 (Jauzein 1995) and 30 (Hanf 1984). In Europe, cultivation of amaranths is not widespread, but certain species are serious weeds in several summer crops. The most aggressive species are *A. retroflexus* and, on a smaller scale, *A. hybridus*, *A. cruentus* and *A. bouchonii*, which are weeds of local importance. According to Tutin *et al.* (1993) the area of origin of *A. retroflexus* seems to be South America. It was introduced into Europe during the last century via North America (Hanf 1984). Today *A. retroflexus* (redroot pigweed) is naturalized and occurs in several non-crop habitats (along roads, rivers, railways and in rangeland) as well as in crops (Horvath and Csiba 1990). A European survey showed that redroot pigweed is one of the ten most economically important weeds. It is especially a problem in sunflowers, soyabeans, maize, sorghum, vegetables, sugarbeet, potatoes, vineyards and orchards (Schroeder *et al.* 1993).

It is difficult to control these weed populations at a satisfactory level by conventional weed control methods, especially because they are resistant to the most commonly used herbicides such as s-triazines, carbamates and uraciles (LeBaron and Gressel 1982; Schori and Fossati 1990). The cost involved in developing new herbicides, the inefficiency of hand or other mechanical weeding, and the public pressure for environmentally safe pest control are the main reasons for investigating the potential of biological control (Schroeder and Müller-Schärer 1995).

In Europe, basic investigations aimed at the biological control of *Amaranthus* spp. started in 1994. The aim of this alternative approach is to use living organisms such as host-specific arthropods, pathogens or nematodes to keep weed populations below their economic injury level (Schroeder and Müller-Schärer 1995). The first step in any biological weed control programme is a comprehensive literature review (Schroeder 1992). The aim of the literature review presented was to collect information on insect species associated with *Amaranthus* spp. worldwide, and which of these show potential as biological control agents.

RESULTS

The review comes in part from previous literature reviews, the first being that of Stegmaier (1950). The more recent reviews by Waterhouse (1994) and Alex and Heal (1994) cover Asia and Canada, respectively. Baloch *et al.* (1981) provided information on field surveys in Pakistan for the United States Department of Agriculture between 1975 and 1980. Records are from all continents, with a majority

Table 1. Insects found on *Amaranthus* spp.: distribution, part of plant attacked, polyphagy level, biological control potential

	Location	<i>Amaranthus</i>	Observation	References
COLEOPTERA				
Anobiidae				
<i>Lasioderma serricornis</i> (Fabricius)	Egypt	<i>cau</i>	Stored seeds	Tawfik <i>et al.</i> 1976
Carabidae				
<i>Agonum</i> sp.	USA	<i>ret</i>	SP, poly	Brust 1994
<i>Amara cupreolata</i> Putzeys	USA	<i>ret</i>	SP, poly	Brust 1994
<i>A. impuncticollis</i> (Say)	USA	<i>ret</i>	SP, poly	Brust 1994
<i>A. mercuria</i> Germer	USA	<i>ret</i>	SP, poly	Brust 1994
<i>Harpalus caliginosus</i> (Fabricius)	USA	<i>ret</i>	SP, poly	Brust 1994, Brust & House 1988
<i>H. pennsylvanicus</i> (De Geer)	USA	<i>ret</i>	SP, poly	Brust 1994, Brust & House 1988
<i>Selenophorus</i> sp.	USA	<i>ret</i>	SP, poly	Brust 1994, Brust & House 1988
<i>Stenolophus</i> sp.	USA	<i>ret</i>	SP, poly	Brust 1994
Cerambycidae				
<i>Hippopsis</i> sp.	Colombia	<i>dub</i>		Altieri & Doll 1977
<i>Perissus delbergiae</i> Gard	Pakistan	<i>vir</i>	Leaves (A)	Baloch <i>et al.</i> 1981
Chrysomelidae				
<i>Aulacophora foveicollis</i> Lucas		spp.	amaranthus as host	Wilson 1989
<i>Cassida enervis</i> Boheman	Pakistan	spp.	Leaves (L); C att.	Waterhouse 1994
<i>C. exilis</i> Boheman	Pakistan	<i>vir, hyb, spi</i>	C att.; Leaves (L)	Baloch <i>et al.</i> 1981
<i>C. nigriventris</i> Boheman	Pakistan	<i>vir, hyb, spi</i>	Leaves (L), poly	Baloch <i>et al.</i> 1981
<i>Chaetocnema pulicaria</i> (Melsheimer)	Canada	<i>ret</i>	on plant (A)	Alex & Heal 1994
<i>Diabrotica</i> sp.	Colombia	<i>dub</i>		Altieri & Doll 1977
<i>D. camposi</i> Barber	South America	spp.	SF	Altieri & Doll 1977
<i>D. fenestralis</i> Jacoby	USA, Mexico	spp.	SF	Stegmaier 1950
<i>D. speciosa</i> (Germar)	Peru	<i>cau</i>		Carrasco 1987
<i>D. decempunctata</i> Bechyne	Peru	<i>cau</i>		Carrasco 1987
<i>Disonycha collata</i> (Fabricius)	South America	<i>ret, spi</i>	Leaves (A); C att.	Vogt & Cordo 1976
<i>D. glabrata</i> (Fabricius)	USA, South & Central America	<i>ret, cru, hyp</i> <i>dub, tri(o)</i> <i>cel(o), plu(o)</i>	used as BC agent Leaves (A), Roots (L)	Altieri & Doll 1977 Balsbaugh <i>et al.</i> 1981 Tisler 1990, Julien 1992
<i>D. triangularis</i> Say	USA	spp.	Leaves	Stegmaier 1950
<i>D. xanthomelas</i> (Dalman)	USA	<i>cru, cau, hyp</i>	Leaves (L) (exp. plots)	Wilson 1989
<i>Epitrix cucumeris</i> (Harris)	USA	spp. (c)	Seedlings (A)	Stallknecht & Schulz-Schaefer 1993
<i>Psylliodes punctulata</i> Melsheimer	North America	<i>ret, pow</i>		Alex & Heal 1994
<i>Systema blanda</i> (Melsheimer)	USA	<i>ret</i>	poly + lab tests; C att.	Capinera 1978
<i>S. frontalis</i> (Fabricius)	USA	<i>ret</i>	CP, poly	Bendixen <i>et al.</i> 1981
Cleridae				
unidentified		spp.	Stems (L)	Baloch <i>et al.</i> 1981
Coccinellidae				
unidentified	Switzerland	spp.	on plants	Schmid 1992
<i>Henosepilachna</i> <i>vigintioctopunctata</i> (Fabricius)	India	<i>vir</i>	amaranthus as host	Wilson 1989
Curculionidae				
<i>Baris amaranthi</i> Marshall	India	spp.		Pajni & Kohli 1990
<i>B. scolopacea</i> Germar	USA	<i>ret</i>	Stem (L), poly	Stegmaier 1950
<i>Ceutorhynchus asperulus</i> Faust	India	<i>vir, tri, spi</i>	poly	Waterhouse 1994
<i>Cloenous punctiventris</i> (Germar)	Russia	<i>ret</i>		Stegmaier 1950
<i>Conotrachelus seniculus</i> LeConte	USA	<i>cru (c), cau (c)</i> <i>hyp (c), ret</i>	Stems and roots (L)	Terry & Lee 1990 Wilson 1989
<i>Cosmobaris americana</i> Casey	USA	spp.	highly poly; C att.	Weaver & McWilliams 1980
<i>Gasteroclisus auriculatus</i> Sahlberg	Pakistan	spp.	poly + lab. tests Stems and roots (L)	Waterhouse 1994
<i>Rhodoaenus tredecimpunctatus</i>	Mexico	<i>spi, hyp</i>	lab. tests	Perez-Panduro <i>et al.</i> 1990
<i>Sitona lineatus</i> Linnaeus	USA	<i>ret</i>	poly	Fisher & O'Keefe 1979
<i>Hypolixus nubilosus</i> (Boheman)	Egypt	<i>cau, sin, pan</i>	Stem (A)	Tawfik <i>et al.</i> 1976

Table 1. Continued

	Location	<i>Amaranthus</i>	Observation	References
		<i>asc</i>	potential BC agent	Kolaib <i>et al.</i> 1986
<i>H. truncatulus</i> (Fabricius)	India, Thailand	<i>vir, tri, cau</i>	used as BC agent	Waterhouse 1994
	Pakistan	<i>spi, grae, hyb</i>	poly, stem (L+G)	Agarwal 1985
<i>Hypurus</i> sp.	India	<i>dub, tri</i>	lab. tests	Beevi & Abraham 1986
<i>Hypurus portulacae</i> Marshall	Pakistan, India	<i>vir</i>	Seedlings (A)	Baloch <i>et al.</i> 1981
<i>H. ritsemae</i>	Vanuatu	<i>spi</i>		Waterhouse 1994
<i>Lixus ascanii</i> Linnaeus	Russia	<i>ret</i>	C att.	Stegmaier 1950
<i>L. brachyrhinus</i> Boheman	South India	spp.		Stegmaier 1950
<i>L. camerunus</i> Kolbe	Nigeria	<i>hyb</i>	poly	Okiwelu <i>et al.</i> 1988
<i>L. subtilis</i> Sturn	Ukraine, Russia	<i>ret</i>	SP	Volovnik 1994
Elateridae				
<i>Limonius californicus</i> Mannerheim	USA	<i>ret</i>	CP	Stegmaier 1950
Meloidae				
<i>Epicauta cinerea</i> Förster	USA	<i>ret</i>	Leaves (A)	Stegmaier 1950
<i>E. lemniscata</i> (Fabricius)	USA	<i>ret</i>	Leaves (A)	Stegmaier 1950
<i>E. leopardina</i> Haag	Paraguay	spp.	potential BC agent	Schuester 1987
<i>E. marginata</i> (Fabricius)	USA	<i>ret</i>	C att.	Stegmaier 1950
<i>E. pennsylvanica</i> (De Geer)	USA	<i>ret, hyb</i>	Flowers (A)	Stegmaier 1950
<i>E. vittata</i> (Fabricius)	USA	<i>cru, cau</i>	PH; SP; C att.	Wilson 1989
		<i>hyp</i>	Leaves damaged	
<i>Nemognatha immaculata</i> Say	USA	<i>ret</i>	Seedhead	Stegmaier 1950
Melyridae				
<i>Astylus lineatus</i> Germar	Brazil	<i>spi</i>		Waterhouse 1994
Mordellidae				
<i>Mordellistena pustulata</i> Melsheimer	USA	<i>ret, hyb</i>	Stems (L+A)	Stegmaier 1950
Scarabaeidae (Rutelidae)				
<i>Anomala</i> sp.	Pakistan, India	<i>vir</i>	(A) on plants	Baloch <i>et al.</i> 1981
<i>Lachnosterna farcta</i> LeConte	USA	spp.		Stegmaier 1950
<i>Ligyris gibbosus</i> (De Geer)	USA	<i>pal, ret</i>	PH ; C att.	Stegmaier 1950
Silphidae				
<i>Blitophaga opaca</i> (Linnaeus)	USA	spp.		Stegmaier 1950
<i>B. undata</i> Müller	USA	spp.		Stegmaier 1950
DIPTERA				
Agromyzidae				
<i>Amauromyza abnormalis</i> Mall.	Canada, USA	spp.	Stem (A)	Spencer 1969
<i>Haplomyza togata</i> Mel.	Canada	spp.	Leaf miner; poly	Spencer 1969
<i>Haplopedes minutus</i> (Frost)	USA	spp., <i>vir, spi</i>	Leaf miner; poly	Spencer & Steyskal 1986
<i>Liriomyza bryoniae</i> Kaltenbach	Europe	spp.		Hering 1957
<i>L. huidobrensis</i> (Blanchard)	Colombia	<i>vir, ret</i>	Highly poly; C att.	Spencer 1973
<i>L. sativae</i> Blanchard	Venezuela	<i>vir</i>	Highly poly; C att.	Spencer 1973
<i>L. strigata</i> (Meigen)	Europe	Amaranthaceae	poly	Spencer 1973
<i>L. trifolii</i> Burgess		<i>pal</i>		Chandler & Chandler 1988
<i>Melanagromyza</i> sp.	Colombia	<i>dub</i>	Leaf miner	Altieri & Doll 1977
<i>Melanagromyza consueta</i> Spencer	Venezuela	<i>dub</i>	Oligophagous Leaves (L), Stems (P)	Spencer & Havranek 1989
<i>Phytomyza atricornis</i> (Meigen)	Europe	spp.	Leaf miner (L)	Hering 1957
<i>Phytomyza minuta</i> Frost	USA	<i>ret, hyb</i>	Leaf miner (L)	Stegmaier 1950
Anthomyiidae				
<i>Chortophila betarum</i> Lintner	USA	<i>ret</i>	Leaf miner; C att.	Stegmaier 1950
<i>Delia echinata</i> Séguy		spp.	Leaf and stem miner	Hering 1957
<i>Pegomyia hyoscyami</i> (Panzer)	USA	<i>ret</i>	Leaf miner; C att.	Stegmaier 1950
<i>P. ruficops</i> Stein	USA	<i>ret</i>	Leaves (L)	Stegmaier 1950
<i>P. vicina</i> Lintner	USA	<i>ret</i>	Leaf miner; C att.	Stegmaier 1950
<i>Phorbia loecosa</i> Mead	USA	<i>ret</i>	Leaf miner; C att.	Stegmaier 1950
Cecidomyiidae				
<i>Cecidomyia palmeri</i> Cockerell	USA	<i>pal</i>	Stem (G)	Barnes 1948
<i>Asphondylia amaranthi</i> Felt	USA	<i>bli</i>	Stem (G)	Barnes 1948

Table 1. Continued

	Location	<i>Amaranthus</i>	Observation	References
<i>Dasyneura</i> sp.	India	spp.		Barnes 1948
Drosophilidae				
<i>Scaptomyza adusta</i> (Loew)	USA	ret	Leaf miner; poly	Stegmaier 1950
<i>S. (Drosophila) graminum</i> Fallén	Europe, N. Africa	spp.	Leaf miner	Hering 1957
Lauxaniidae				
<i>Homoneura</i> sp.	Canada	ret	on plant (A)	Alex & Heal 1994
Muscidae				
<i>Piezura</i> sp.	Canada	ret	on plant (A)	Alex & Heal 1994
Otitidae				
<i>Tetanops myopaeformis</i> (Röder)	USA	spp.	Roots; poly	Stegmaier 1950
Psychodidae				
<i>Phlebotomus papatasi</i> (Scopoli)		ret	lab. tests	Schlein & Yuval 1987
Tephritidae				
<i>Tupanea femoralis</i>	USA	grae	Fruits	Foote & Blanc 1963
<i>Neotephritis finalis</i> (Loew)	Mexico	spi, hyp	lab. tests	Perez-Panduro <i>et al.</i> 1990
HETEROPTERA/HEMIPTERA				
Coreidae				
<i>Cletus fuscescens</i> Walker	Nigeria	dub, cru, hyp, spi		Waterhouse 1994
<i>C. signatus</i> Walker	Pakistan, India	spp. (C)	Leaves (A)	Baloch <i>et al.</i> 1981
<i>Cletomorpha hastata</i> Fabricius	Pakistan, India	spp. (C)	Leaves (A)	Baloch <i>et al.</i> 1981
<i>Leptocoris actua</i> Thunburg	Asia	spp.	Seeds (A + L); CP	Kranz <i>et al.</i> 1979
Cydnidae (Corimelaenidae)				
<i>Corimelaena pulicaria</i> (Germar)	USA	ret	poly	Stegmaier 1950
Lygaeidae				
<i>Geocoris bullatus</i> Say	USA	ret	poly; C att.	Stegmaier 1950
<i>Germalus unipunctatus</i>	Vanuatu	spi		Waterhouse 1994
<i>Nysius</i> sp.	Vanuatu, Pakistan	spi, hyb	Shoots (A)	Waterhouse 1994
<i>N. angustatus</i> Uhler	USA	ret	Seeds	Stegmaier 1950
<i>N. nemorivagus</i> White	USA	spp.	Leaves; poly	Stegmaier 1950
<i>N. nigriscutellatus</i> Usinger	USA	spp.	Leaves; poly	Stegmaier 1950
Miridae				
<i>Horcias nobilellus</i> (Berg)	Brazil	spi	poly	Waterhouse 1994
<i>Lygus elisus</i> Van Duzee	USA	ret	on plants	Wilson & Olson 1990
<i>L. hesperus</i> Knight	USA	ret	on plants	Wilson & Olson 1990
<i>L. lineolaris</i> Palisot de Beauvois	USA	ret, cru (c) cau (c), hyp	Flowers ; lab. tests	Weaver & McWilliams 1980 Terry & Lee 1990
<i>L. pratensis</i> Linnaeus	USA	ret, hyb	Leaves & Seeds(A); CP	Stegmaier 1950
<i>Rhinacloa forticornis</i> Reuter	USA	ret	CP	Bendixen <i>et al.</i> 1981
<i>Spanogonicus albofasciatus</i> Reuter	USA	cau(c), cru(c), hyp(c), ret	CP	Wilson 1989 Bendixen <i>et al.</i> 1981
Pentatomidae				
<i>Eysarcoris guttiger</i> (Thunberg)	Pakistan, India	spi, vir	Leaves (A)	Baloch <i>et al.</i> 1981
<i>Murgantia histrionica</i> (Hahn)	USA	ret		Stegmaier 1950
Piesmididae				
<i>Piesma cinereum</i> (Say)	Brazil, USA	spi, ret, hyb, cau	poly, CP, Stem & Leaves	Waterhouse 1994
<i>P. quadrata</i> Fieber	Germany	ret		Stegmaier 1950
HOMOPTERA/HEMIPTERA				
Aleurodidae				
<i>Bemisia tabaci</i> Gennadius	Egypt, Iran	cau, ask	poly, CP	Bendixen <i>et al.</i> 1981
Aphididae				
<i>Aphis abbreviata</i> Patch		ret	poly	Anonymus 1938
<i>A. amaranthi</i> Holmann		spp.	poly	Eastop & Lambers 1976
<i>A. craccivora</i> Koch	Iran	ret	poly	Bendixen <i>et al.</i> 1981
<i>A. euonymi</i> Fabricius		ret	poly	Anonymus 1938
<i>A. fabae</i> Scopoli	cau, pan	poly		Anonymus 1938
<i>A. gillettei</i> Cowen		ret	poly	Anonymus 1938
<i>A. gossypii</i> Glover	Bulgaria, USA	vir, ret	poly, CP	Stegmaier 1950

Table 1. Continued

	Location	<i>Amaranthus</i>	Observation	References
	Egypt	<i>cau, ask</i>		Kolaib <i>et al.</i> 1986
<i>A. helianthi</i> Monell		spp.	poly	Anonymus 1938
<i>A. maidi-radicis</i> Forbes		<i>ret, spi, hyb</i>	poly	Anonymus 1938
<i>A. medicaginis</i> Koch		spp.	poly	Anonymus 1938
<i>A. middletonii</i> Thomas		<i>ret</i>	poly	Anonymus 1938
<i>A. rumicis</i> Linnaeus	Europe	<i>ret, cau</i>	poly; galls in leaves	Houard 1908
<i>A. sorbi</i> Kaltenbach	USA	<i>ret, pan</i>	poly	Stegmaier 1950
<i>A. spiraeola</i> Patch		spp.	poly	Anonymus 1938
<i>Macrosiphum gei</i> Koch		<i>ret, pan, spi</i>	poly	Anonymus 1938
<i>M. schranki</i> Theobald		spp.	poly	Anonymus 1938
<i>Myzus achyranthes</i> Monell	USA	<i>ret</i>	poly; CP	Stegmaier 1950
<i>M. persicae</i> Sulzer	Malawi, Thailand	<i>spi, ret</i>	highly poly; CP	Bendixen <i>et al.</i> 1981
<i>M. pseudosolani</i> Theobald		<i>ret, spi</i>	poly	Anonymus 1938
<i>Pemphigus fuscicornis</i> (Koch)	Bulgaria	<i>ret</i>	poly, rarely found	Bendixen <i>et al.</i> 1981
<i>Trifidaphis phaseoli</i> (Passerini)	World	<i>gra, ret</i>	highly poly	Anonymus 1938
Cicadellidae				
<i>Agallia sanguinolenta</i> Provancher	USA	<i>ret</i>	poly, C att., Leaves(A)	Stegmaier 1950
<i>Crucifer temellus</i> Baker	USA	spp. (c)	disease transmission	Stallknecht & Schulz-Schaefer 1993
<i>Draeculacephala mollipes</i> (Say)	USA		Leaves	Stegmaier 1950
<i>Endria inimica</i> (Say)	USA	<i>ret</i>		Stegmaier 1950
<i>Empoasca decipiens</i> Paoli	Egypt	spp.	Leaves, CP	Kolaib <i>et al.</i> 1986
<i>E. fabae</i> Harris			second host	Lamp <i>et al.</i> 1984
<i>E. solana</i> DeLong	USA	<i>ret, hyb</i>	Stem & Leaves, C att.	Stegmaier 1950
<i>Gyponana</i> sp.	USA	<i>ret</i>		Stegmaier 1950
<i>Macrosteles</i> sp.	USA	<i>ret</i>		Stegmaier 1950
<i>Neokolla hieroglyphica</i> (Say)	USA	<i>ret</i>	Leaves, lab. tests	Stegmaier 1950
<i>Norvellina seminuda</i> (Say)	USA	<i>ret</i>	Leaves, lab. tests	Stegmaier 1950
<i>Paraphlepsius irroratus</i> (Say)	USA	<i>ret</i>	Leaves	Stegmaier 1950
Coccidae (Diaspididae)				
<i>Aonidiella aurantii</i> Maskell	Egypt	<i>cau</i>	CP	Tawfik <i>et al.</i> 1976
Membracidae				
<i>Micrutalis calva</i> (Say)	USA	<i>ret</i>	Stems & Leaves	Stegmaier 1950
Pseudococcidae				
<i>Planococcus lilacinus</i> Cockerell	India	<i>gra</i>	CP, poly	Bendixen <i>et al.</i> 1981
HYMENOPTERA				
Apidae (Anthophoridae)				
<i>Melissodes thelypodii</i> Cockerell	USA	<i>pal</i>	Pollen collection	Cane <i>et al.</i> 1992
Formicidae				
<i>Pogonomyrmex barbatus</i> (F. Smith)	USA	spp.	SP	Pulliam & Brand 1975
<i>Crematogaster lineolata</i> (Say)	USA	<i>ret</i>	Stem as home by (A)	Stegmaier 1950
<i>Lasius</i> sp.	USA	<i>ret</i>	SP, poly	Brust & House 1988
<i>Pheidole</i> sp.	USA	<i>ret</i>	SP, poly	Brust & House 1988
<i>Veromessor pergandei</i> (Mayr)	USA	<i>ret</i>	SP, poly	Tevis 1958
ISOPTERA				
Rhinotermitidae				
<i>Reticulitermes</i> sp.	USA	<i>ret</i>	Roots	Stegmaier 1950
LEPIDOPTERA				
Arctiidae				
<i>Diacrisia maculosa</i> Stoll	Nigeria	<i>hyb</i>	poly	Okiwelu <i>et al.</i> 1992
<i>D. obliqua</i> Walker	Pakistan, India	<i>hyb, spi, vir</i>	Leaves (L)	Baloch <i>et al.</i> 1981
<i>Estigmene acraea</i> Drury	USA	<i>ret, hyb</i>	Leaves (L); C att.	Stegmaier 1950
Coleophoridae				
<i>Coleophora amaranthella</i> Braun	USA	<i>ret</i>	SP	Stegmaier 1950
<i>C. lineapulvella</i> Chambers	USA	<i>ret, hyb</i>	SP	Weaver & McWilliams 1980
<i>C. versurella</i> Zeller	Pakistan	<i>spi, hyb, gra</i>	Flowers; poly	Waterhouse 1994

Table 1. Continued

	Location	<i>Amaranthus</i>	Observation	References
Cossidae				
<i>Zeuzera</i> sp.	Pakistan, India	spp.	Stems (L)	Baloch <i>et al.</i> 1981
Gelechiidae				
<i>Chrysoesthia sexguttella</i> (Thunberg)	Europe, N. Africa	spp.	Leaf miner	Hering 1957
<i>Dichomeris famulata</i> Meyrick	Colombia	<i>dub</i>	CP	Ciro <i>et al.</i> 1992
<i>Eurysaca melanocampta</i> (Meyrick)	Peru	<i>cau</i>		Carrasco 1987
Geometridae				
<i>Scopula</i> sp.	Pakistan	<i>hyb, spi, vir</i>	Leaves (L)	Baloch <i>et al.</i> 1981
Hesperiidae				
<i>Pholisora catullus</i> Fabricius	North America	<i>ret, hyb</i>	Leaves (L)	Alex & Heal 1994
Lycaenidae				
<i>Zizeeria knysna</i> (Trimen)	Pakistan	<i>spi, hyb, vir</i>	leaves (L)	Waterhouse 1994
<i>Z. krupta</i> Trimen	Pakistan	<i>spi, hyb, vir</i>	leaves (L)	Waterhouse 1994
Noctuidae				
<i>Agrotis ipsilon</i> Hufnagel	USA	<i>ret</i>		Weaver & McWilliams 1980
<i>A. segetum</i> Denis & Schiffermüller	Bulgaria, India	<i>ret, spi</i>	poly + lab. tests; CP	Bendixen <i>et al.</i> 1981
<i>Anticarsia gemmatalis</i> Hübner	Canada	<i>ret</i>	Leaf miner	Alex & Heal 1994
<i>Autoplusia egena</i> Guenée	USA	<i>ret</i>		Weaver & McWilliams 1980
<i>Diataraxia oleracea</i> (Linnaeus)	Bulgaria	<i>ret</i>	poly; C att.	Bendixen <i>et al.</i> 1981
<i>Eublemma silicula</i> Swinhoe	Pakistan	<i>hyb, spi, vir</i>	Fruits (L)	Baloch <i>et al.</i> 1981
<i>Eumichtis</i> sp.	Peru	<i>cau</i>		Yabar-Landa 1987
<i>Heliothis titicae</i>	Peru	<i>cau</i>		Yabar-Landa 1987
<i>H. virescens</i> Fabricius	New World	<i>ret</i>	C att.; poly	Kranz <i>et al.</i> 1979
<i>Helicoverpa zea</i> (Boddie)	USA	<i>cau, cru, hyp</i>	C att.; poly	Wilson 1989
<i>Papaipema nebris</i> Guenée	USA	<i>ret</i>	Stem (L); CP	Alvarado <i>et al.</i> 1989
<i>Peridroma ambrissoides</i>	Peru	<i>cau</i>		Yabar-Landa 1987
<i>Plusia californica</i> Speyer	USA	<i>ret</i>		Weaver & McWilliams 1980
<i>Pseudoplusia includens</i> Walker	Peru	<i>cau</i>		Carrasco 1987
<i>Spodoptera eridania</i> Cramer	Nicaragua	<i>ret, dub, spi</i>	PH; C att.	Wilson 1989
	Colombia			Waterhouse 1994
<i>S. exigua</i> Hübner	Nicaragua, USA	<i>cru, cau, spi</i> <i>hyp, ret</i>	poly, C att. Leaves (L)	Kranz <i>et al.</i> 1979 Wilson 1989; Waterhouse
1994				
<i>S. frugiperda</i> J.E. Smith	USA	<i>ret</i>	poly	Stegmaier 1950
<i>S. littoralis</i> Boisduval	Egypt	<i>cau, ask</i>	Oviposition; C att.	Kolaib <i>et al.</i> 1986
<i>S. litura</i> Fabricius	Philippines, Korea	<i>ret, spi, man</i>	highly poly; C att.	Choo <i>et al.</i> 1992
<i>S. ornithogalli</i> (Guenée)	USA	<i>ret</i>	poly	Stegmaier 1950
<i>S. sunia</i> Guenée	Nicaragua	<i>spi</i>	poly	Waterhouse 1994
<i>Trichoplusia ni</i> Hübner	USA	<i>cau, cru, hyp</i>	CP; lab. tests	Weaver & McWilliams 1980
Pyralidae				
<i>Herpetogramma bipunctalis</i> (Fabricius)	Colombia, USA	<i>dub, ret, hyb</i>	highly poly; CP	Altieri & Doll 1977
<i>Hymenia recurvalis</i> Fabricius	Pakistan, Australia Vanuatu, USA, India Colombia, Japan	<i>spi, vir, liv</i> <i>grae, hyb</i> <i>dub</i>	poly Leaves (L) Leaf roller	Benedixen <i>et al.</i> 1981 Miyahara 1990 Waterhouse 1994
<i>Loxostege</i> sp.	Argentina	spp.	genus includes pests Seed heads	Waterhouse 1994
<i>L. commixtalis</i> Walker	USA	<i>ret</i>	PH; poly + lab. tests	Capinera <i>et al.</i> 1981
<i>L. bifidalis</i> (Fabricius)	USA	<i>ret</i>	PH but C att.; Flowers	Stegmaier 1950
<i>L. nudalis</i> Hübner	Egypt, Pakistan	<i>cau, grae</i>	Flowers and leaves (L)	Tawfik <i>et al.</i> 1976 Baloch <i>et al.</i> 1981
<i>L. similalis</i> (Guenée)	USA	<i>ret, hyb</i>	poly; Leaves (L+P)	Stegmaier 1950
<i>L. sticticalis</i> Linnaeus	USA	<i>ret</i>	CP	Stegmaier 1950
<i>Ostrinia ainsliei</i> (Heinrich)	USA	<i>ret, hyb</i>	Stems; C att.	Stegmaier 1950
<i>O. nubilalis</i> Hübner	USA	spp.	lab tests	Weaver & McWilliams 1980
	Italy, Poland, Hungary	<i>ret</i>	CP	Ciampolini <i>et al.</i> 1985
Scythrididae				
<i>Eretmocera impactella</i> Walker	Pakistan	<i>spi, vir</i>	Flowers (L); C att.	Baloch <i>et al.</i> 1981

Table 1. Continued

	Location	Amaranthus	Observation	References
	India, Thailand			Moriuti & Yasuda 1983
<i>Scythris trivinctella</i> (Zeller)	USA	ret, hyb	Leaves of heads (L)	Stegmaier 1950
Tineidae				
<i>Oinophila</i> sp.	Canada	ret	on plant (L)	Alex & Heal 1994
Tortricidae				
<i>Amelia pallorana</i> (Robinson)	USA	ret, hyb	Leaves(L+P); C att.	Stegmaier 1950
<i>Archips</i> sp.	Pakistan	spi	Waterhouse 1994	
<i>Epiblema strenuana</i> Walker	Canada	ret	on plant (L)	Alex & Heal 1994
<i>Cnephasia</i> sp.		spp.	Leaf miner	Hering 1957
<i>Platynota flavenda</i> Clemens	USA	ret, hyb	Leaves (L); poly	Stegmaier 1950
<i>Polychrosis</i> sp.	USA	ret, hyb	Stem of heads (L)	Stegmaier 1950
<i>Sparganothis nigrocervina</i> Walsingham	North America	ret	poly; Catt.	Mackay 1962
<i>S. sulfureana</i> Clemens	USA	ret, hyb	Leaves (L); poly	Stegmaier 1950
Plutellidae (Yponomeutidae)				
<i>Plutella xylostella</i> Linnaeus	Pakistan, India	spi, vir	highly poly	Waterhouse 1994
ORTHOPTERA				
Acrididae				
<i>Catantops pingius</i> (Stall)	Pakistan, India	hyb, spi	Leaves (A)	Baloch <i>et al.</i> 1981
<i>Dissosteira carolina</i> Linnaeus	USA	ret	Leaves (A)+lab. tests	Stegmaier 1950
<i>Hieroglyphus banian</i> (Fabricius)	India	liv	CP	Vyas <i>et al.</i> 1983
<i>Melanoplus bivittatus</i> Say	USA	ret	Leaves (A)+lab. tests	Stegmaier 1950
<i>M. differentialis</i> Thomas	USA	ret	Leaves (A)+lab. tests	Stegmaier 1950
<i>M. femur</i> De Geer	USA	ret	Leaves (A)	Stegmaier 1950
<i>Orphulella speciosa</i> Scudder	USA	ret	Leaves (A)	Stegmaier 1950
<i>Schistocerca lineata</i> Scudder	USA	ret, hyb	Flowers (A)	Stegmaier 1950
<i>S. piceifrons</i> (Walker)	Peru	cau	poly	Carrasco 1987
Gryllidae				
<i>Gryllus pennsylvanicus</i> Burmeister		ret	SP; poly	Brust 1994
<i>Oecanthus angustipennis</i> Fitch	USA	ret, hyb	poly, stem (ovi)	Stegmaier 1950
<i>O. nigricornis</i> Walker	USA	ret, hyb	poly, stem (ovi)	Stegmaier 1950
<i>Metioche vittaticollis</i> Stal	USA	spp.	Pollen (A); poly	Stegmaier 1950
Tettigoniidae				
<i>Orchelimum nigripes</i> Scudder	USA	ret, hyb	poly, stem (ovi)	Stegmaier 1950
THYSANOPTERA				
Phlaeothripidae				
<i>Haplothrips longisetosus</i> Anathakrishnan	India	spi, vir, ole	poly	Waterhouse 1994
<i>Haplothrips cottei</i> (Vuillet)	Egypt	cau, ret	poly, CP	Tawfik <i>et al.</i> 1976
				Bendixen <i>et al.</i> 1981
<i>Haplothrips gowdeyi</i> (Franklin)	USA	ret, hyb, vir	Flowers	Stegmaier 1950
Thripidae				
<i>Frankliniella occidentalis</i> (Pergande)	USA	spp.	C att.	Yudin <i>et al.</i> 1988
<i>F. tritici</i> (Fitch)	USA	ret	Seedhead, CP	Stegmaier 1950
<i>F. unicolor</i> Morgan	USA	ret	Highly poly, Seedhead	Stegmaier 1950
<i>Scirtothrips longipennis</i> (Bagnall)	Holland	spp.	in greenhouse	Stegmaier 1950
<i>Taeniothrips orchidii</i> Molt	Holland	spp.	in greenhouse	Stegmaier 1950
<i>Thrips tabaci</i> Lindeman	Egypt	cau, ret, vir	poly, CP	Tawfik <i>et al.</i> 1976
				Bendixen <i>et al.</i> 1981

Amaranthus species:

asc=ascendens Lois., cau=caudatus L., cel=celosia, cru=cruentus L., dub=dubius Ex.Thall., gra=gracilis Poiret, grae=gracizans L., hyb=hybridus L., hyp=hypochondriachus L., liv=lividus L., man=mangostus, ole=oleosa, pal=palmeri S. Watson, pan=paniculatus L., plu=plumosa, pow=powellii S. Watson, ret=retroflexus L., sin=sinensis, spi=spinosus L., tri=tricolor L., vir=viridis L.; (o). ornamental amaranths ; (c). cultivated amaranths

other symbols

(A)=adults; (G)=gall; (L)= larvae; (P)= pupae; (ovi)=oviposition
C att.=crop attacked; CP=crop pest; poly=polyphagous; (exp. plots)=surveys carried out on experimental plots
BC=biological control; SF=specific to family; SP=seed predator; PH=amaranthus are preferred hosts

of information from North and South America and Asia, especially Pakistan and India. The number of records from Europe is small, although *Amaranthus* spp. are weeds of great economic importance in south-central and south-eastern Europe. In contrast, interesting information is available from two African countries, Egypt and Nigeria.

Altogether, records were found for 241 insect species from 21 *Amaranthus* species. The insect records presented in Table 1 concern species which

- (i) were used as biological control agents (Julien 1992),
- (ii) are known crop pests (Okiwelu *et al.* 1988),
- (iii) are crop pests using amaranths as secondary hosts (Bendixen *et al.* 1981),
- (iv) were found during field surveys for potential biological control agents (Baloch *et al.* 1981; Alex and Heal 1994), and
- (v) are just recorded as being associated with *Amaranthus* spp. in the entomological literature.

The species recorded belong to nine orders, the majority being Coleoptera and Lepidoptera (Table 2). Information is provided on the geographic distribution, the *Amaranthus* species recorded as hosts, the degree of host specificity, the damage to crops, and as far as is indicated, the plant parts attacked.

In selecting potential biological control agents, insect host records have to be considered carefully with regard to specific geographic areas, because the status of *Amaranthus* species may vary considerably. For example, *A. dubius* is a serious weed in Venezuela but is cultivated in West Africa as a green vegetable, and as a garden crop in Indonesia (Spencer and Havranek 1989). Further, most of the species are monoecious, but some dioecious species exist, e.g., *A. palmeri*. The status of the species is very important in deciding if an insect can be introduced from one country to another.

Potential biological control agents

Considering the relatively large number of arthropod species recorded from *Amaranthus* spp., only a small number of them seem to have potential as biological control agents. Some groups were listed just for the sake of completion: the Aphids form a large group of insects, but their rate of polyphagy means they are not useful for biological control. The Hymenoptera, Isoptera and Orthoptera are listed because of the importance of their role in outcrossing between individual plants as well as between those of different species of genus *Amaranthus* (Cane *et al.* 1992) and their impact on seed production and the formation of seed banks (Tevis 1958; Brust 1994).

The species first suggested by Garman in 1892 (in Tisler 1990) is the pigweed flea beetle *Disonycha glabrata* (Fabricius). Vogt and Cordo (1976) found it during their field surveys in South America, suppressing pigweeds in Argentina and Brazil. It is also native to the southern parts of the United States, and was released in North Dakota in 1979 and 1980 (Balsbaugh *et al.* 1981). Although adults and larvae feed heavily on pigweeds, beetle populations developed slowly early in the season and severe damage occurred too late to reduce pigweed competition and prevent seed production. Nevertheless, the use of *D. glabrata* as a control agent of *A. retroflexus* in warmer areas of the USA is still being promoted (Tisler 1990).

Schuester (1987) reports heavy damage on pigweeds by the meloid beetle *Epicauta leopardina* Haag in Paraguay, and considers it as a potential biological control agent. Also in

Table 2. Relative importance of the orders

Order	Number of families	Number of species
Coleoptera	13	65
Diptera	9	29
Heteroptera	6	22
Homoptera	6	37
Hymenoptera	2	6
Isoptera	1	1
Lepidoptera	13	58
Orthoptera	3	14
Thysanoptera	2	9
Total	55	241

the native range of *Amaranthus* spp., *Melanagromyza consueta* Spencer (Diptera) mines the stems of *A. dubius*, the most common *Amaranthus* species of 13 recorded for Venezuela, killing the plant. However, Spencer and Havranek (1989) report that *M. consueta* frequently co-occurs with an unidentified moth. Whether or not it will be as damaging acting on its own needs to be investigated. Provided the host range of *M. consueta* is not too restricted, it would be a potentially interesting species for biological control, especially because of the extended range of altitudes (400-1,600 m) it occupies.

Another potential source of biological control agents for noxious *Amaranthus* spp. is known pests of crop amaranths which could be transferred to areas where these species are not cultivated. An example is the weevil *Conotrachelus seniculus* LeConte, a pest of *A. cruentus* in southern Arizona. It causes severe damage early in the season, a prerequisite for a suitable biological control agent in order to prevent seed production of noxious species (Schori and Fossati 1990).

Some insect species have been used successfully as biological control agents. In Thailand, augmentative releases of the weevil *Hypolixus truncatulus* (Fabricius) have resulted in a satisfactory degree of control of *A. spinosus*, and replaced herbicide use (Napompeth 1982). Another species of this genus is reported by Kolaib *et al.* (1986), namely *H. nubilosus* (Boheman), a stem and root borer native to Egypt. According to the authors, attack rates on *A. caudatus* can locally reach 100%.

It is likely that the list of insects associated with *Amaranthus* spp. is still incomplete, knowing that the most information comes from those countries most interested and which do not lack the financial means to conduct surveys. Additional potential control agents could be discovered by more extended surveys, especially in South and Central America, the native range of *Amaranthus* spp., according to Wapshere (1974), who suggests that the most interesting agents occur in the area of origin of the genus and sub-genus of the weed. The potential transfer of oligophagous species from areas outside the native distribution of the genus *Amaranthus* to other areas should also be considered.

Recent field surveys for insects associated with noxious and cultivated *Amaranthus* spp. in Europe revealed that none of the species found has potential for biological control (Bürki, in prep.). Classical biological control of noxious pigweeds in Europe depends, therefore, on the introduction of phytophagous insects from outside Europe.

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