Natural enemies of the woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae): a review of the world literature

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Summary

Literature information was used to compile a summary of natural enemies (parasitoids, predators and a fungal disease) reported attacking the woolly apple aphid, *Eriosoma lanigerum* (Hausmann) under field conditions. Five species of hymenopterous endoparasitoids and two species of Acarina (ectoparasites) were reported to attack *E. lanigerum*. Altogether, 73 species of predatory insects belonging to five orders and seven families (i.e. Coccinellidae, Chrysopidae, Hemerobiidae, Forficulidae, Lygaeidae, Syrphidae, and Cecidomyiidae) have been reported to feed on this aphid species. *Verticillum lecanii* (Zimm.) ViËgas was the only fungal pathogen reported to infect this aphid. Although *Aphelinus mali* (Haldeman) has been widely acclaimed as the most important natural enemy of this aphid species, a review of literature, however, revealed a number of other natural enemies which should be considered in biological control or integrated pest management programs of *E. lanigerum*.

Introduction

The woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae) is one of the economically important and most widely distributed pests of apple, *Malus domestica* (Borkh.) and other species of *Malus*, *Cotoneaster*, *Crataegus*, *Sorbus* and *Pyracantha* (Eastop 1966, Hill 1983). A native of North America (Baker 1915), it now occurs throughout the apple-growing countries of the world (Eastop 1966). Both the nymphs and adults cause damage to apple by feeding on the roots and stems, particularly the tender places on the trunk and branches, new lateral growth and areas with damage caused by mechanical injury (Asante 1995a). Its damage to apple is much more serious in the United States where root infestation is prevalent (Marcovitch 1934, Brown 1986). Infestation of the aphid on apple roots and shoots has been shown to reduce survival of nursery trees and to weaken mature apple trees, leading to the loss of vitality and poor quantitative and qualitative yields (Sherbakoff and McClintock 1935, Klimstra and Rock 1985).

In view of its economic importance, a considerable amount of work has been conducted on its biology, ecology, population dynamics and control by the use of insecticides, resistant apple varieties and natural enemies in all the countries in which it occurs (Baker 1915, Staniland 1924, Hatton *et al.* 1937, Bodenheimer 1947, Evenhuis 1958, Brown and Schmitt 1994, Asante 1995a). Despite the extensive work on its natural enemies world wide for over a century, there has been no attempt to collate the literature. Hence, the information on the natural enemies of *E. lanigerum* remains scattered and obscured which precludes the selection and use of suitable biological control agents in regions where *Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae), the most important parasitoid of this aphid species (DeBach 1964) has proved to be ineffective.

This paper presents a worldwide review of the natural enemies of *E. lanigerum*. It provides information on natural enemies which could be manipulated for the biological control or integrated pest management of this aphid species in different geographic regions.

Materials and methods

Information on the natural enemies of *E. lanigerum* was obtained using abstracts in the Review of Applied Entomology (from 1913 to 1994), Biological Abstracts and original journal articles. The search was made in the Dixonís Library, University of New England, Armidale, New South Wales, Australia. Original articles which were not available in this library were obtained from other libraries in either Australia or overseas through inter-library loans. Furthermore, on-line and CD-ROM services were used to search for other information which could not be obtained from the journal abstracts.

Results

The literature reports that *E. lanigerum* is attacked by five species of hymenopterous endoparasitoids, two species of Acarina (ectoparasites), 73 species of predatory insects and a fungal pathogen. Other species found to be associated with this aphid pest are hyperparasitoids.

Parasitoids

The most important parasitoid of *E. lanigerum* is the Chalcid wasp, *Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae) (Tillyard 1921, Lundie 1924, Bodenheimer 1947, Evenhuis 1958, DeBach 1964). Very scanty information is available for other parasitoids of this aphid. DeSantis (1939) reported the occurrence of *Neoanisotylus* sp. in *E. lanigerum* in Argentina. In the United Kingdom, Rosenberg (1934) and Stary (1976) reported the occurrence of *Proan simulans* Prov. and *Areoproan lepelleyi* Wat., respectively as parasitoids of *E. lanigerum*. Childers and Rock (1981) recorded *Balaustium putmani* Smiley (Acarina) whereas Marchal (1929) reported *Allothrombium fuliginosum* Herm. as ectoparasites of this aphid in the United States and France, respectively. Gurney (1926) observed that *Aphelinus niger* Girult parasitize *E. lanigerum* in New South Wales and Queensland before the introduction of *A. mali*.

Origin and introduction of A. mali into other apple-growing countries

The most significant advance in the biological control of *E. lanigerum* was made in the early 1920s when *A. mali*, an endoparasitoid, was introduced from its native home, North America, into many countries in an attempt to control it (DeBach 1964). This parasitoid was originally known to occur in areas of the eastern United States and Canada (MacPhee *et al.* 1976). It was initially introduced into Europe in the early part of 1920 and has since then been released in 51 other countries; becoming established in 42 (van Lenteren 1990). It was introduced from North America into France in 1920 and 1921 (Marchal 1929), South Africa in 1920 (Georgala 1953) and Uruguay early in 1921 and 1922. From France, it reached Austria in 1926 (Werneck 1931) and batches were sent to Argentina, England, Italy, Chile and Spain from Uruguay (Trujillo 1922, Nonell 1932). From Italy, it was imported into Malta and Gozo during 1933ñ34 (Borg 1936). This parasitoid was introduced into Holland in 1925 (van Poeteren 1925) and Mexico in 1953 (Coronado 1955). From Ontario, Canada, *A. mali* was introduced into the Okanagan valley, British Columbia, in 1929 (Venables 1931). It reached Transcancasia from the Crimea in 1932 (Stephanov 1935) and Korea from Japan in 1934 (Nakayama 1936). Cisílik and Kawecki (1935) reported that *A. mali* appeared in Poland without having been artificially introduced.

Similarly, Kovacevic (1937) reported its discovery in Yugoslavia in 1930. The parasitoid was introduced into New Zealand in 1921 (Tillyard 1921) and from there it was brought to Tasmania, Australia, in 1922 (Nicholls 1932, Wilson 1960). In Australia, *A. mali* reached the Stanthorpe district of Queensland in 1923 (Jarvis 1926), New South Wales and Victoria in 1924ñ25 (Gurney 1926, Pescott 1935).

The effectiveness of A. mali as a biological control agent

The effectiveness of *A. mali* as a biological control agent for *E. lanigerum* has been reported worldwide such as New Zealand (Tillyard 1924), Australia (Nicholls 1932, Evans 1938, Sproul 1981), South Africa (Lundie 1939), India (Rahman and Khan 1941), The Netherlands (Evenhuis 1958), Japan (Hukusima 1960), Russia (Boldyreva 1970) and Iraq (El-Haidari and Aziz 1978).

The introduction of this parasitoid has been cited in the literature as the first acknowledged case of successful biological control program of an aphid species (van Lenteren 1990) and of a tree fruit pest (MacPhee *et al.* 1976). In western Australia, its introduction has resulted in one of the Stateís most outstanding successes in biological control (Sproul 1981). It has, however, been found to be ineffective under cool climatic conditions (Massee 1943, Miller 1947, Rawat *et al.* 1989, van Lenteren 1990, Asante and Danthanarayana 1992). On the other hand, in warm dry regions, *A. mali* occasionally fails to establish itself (Talhouk 1941).

Various authors have reported that its rate of multiplication is slower than that of its aphid host (Bodenheimer 1947, Evenhuis 1958, Balevski and Vasev 1962, Kuang *et al.* 1989). Temperature has been found to have a differential effect on *A. mali* and *E. lanigerum* (Ehrenhardt 1940, Bodenheimer 1947, Bonnemaison 1965, Kuang *et al.* 1989, Asante and Danthanarayana 1992). Whilst the lower temperature threshold for development of *E. lanigerum* was estimated at 4.2∞C (Bodenheimer 1947, Bonnemaison 1965) and 5.2∞C (Asante *et al.* 1991), that of *A. mali* was estimated at 8.6∞C in Palestine by Bodenheimer (1947), 8.2∞C in France by Bonnemaison (1965) and 8.3∞C in Australia by Asante and Danthanarayana (1992).

According to Kuang *et al.* (1989) the intrinsic rate of increase of *A. mali* was 0.1146 and 0.1628 at 20 and 25.5∞C, respectively, while that of its host, *E. lanigerum* was 0.1390 and 0.2647, respectively. It has been reported that predators and parasitoids of insects, in general, tend to have activity and development thresholds higher than their hosts (Campbell *et al.* 1974, Neuenschwander *et al.* 1975). By developing more slowly than their hosts, some parasitoids ensure the continued availability of a minimum host supply and thus their own survival, but would fail to contribute in any significant way to the control of the host (DeBach 1964). However, the main cause of reduced effectiveness of *A. mali* has been attributed to the frequent use of broad spectrum insecticides against other major apple pests such as the codling moth, *Cydia pomonella* (L.) (Georgala 1953, Bengston 1960, Adlakha and Hameed 1972, Yothers 1974, Hely *et al.* 1982). On the other hand, Holdsworth (1970) stated that in addition to killing *A. mali*, some spray programs used generally in apple pest control, also control *E. lanigerum* so that the natural control disturbance may not become an economic factor.

Hyperparasitoids of A. mali

Evenhuis (1958) recorded three species of hyperparasitoids, *Pachyneuron aphidis* (Bouche), *Asaphes vulgaris* Walk and *Ceraphron* sp. from *E. lanigerum* in The Netherlands. Also, *P. aphidis* has been reported to attack *A. mali* occasionally in Yugoslavia (Kovacevic 1937) and Australia (Asante 1995a). Moreover, the two Pteromalids, *P. aphidis* and *A. vulgaris* have been reported to attack *A. mali* in Crimea (Meier and Telenga 1933) and in Germany (Sprengel 1931).

The following species have been recorded from *E. lanigerum* in New South Wales, Australia; *Ophelosia bifasciata* Girault, *Moranila comperei* (Ashmead), a *Chartocerum* sp. and *Paramyiocnema* nr. *flavithorax* (Girault and Dodd) (Asante 1995a). In all cases, the authors reported that their effect on the parasitoid was insignificant.

Fungal pathogen

The only identified fungal pathogen of *E. lanigerum* is *Verticillium lecanii* (Zimm.) ViËgas. This pathogen has been reported to attack all life stages of *E. lanigerum* in New South Wales, Australia (Asante 1995a). Large numbers of the aphid were found to be killed by the fungus as the aphid population density increased. Its incidence, however, was confined to only a few trees, hence, the overall impact was very low. The mortalities caused by this pathogen during peak aphid populations ranged from 1ñ14% (Asante 1995a).

Predators

Altogether, 73 species of predatory insects belonging to five orders namely, Coleoptera, Diptera, Neuroptera, Dermaptera and Hemiptera have been reported to feed on *E. lanigerum* in many parts of the world (Table 1). The most important family (in terms of numbers of species recorded) was coccinellidae which formed 48% of all the predatory insects. They have been recorded in 13 countries with most species occurring in South Africa, Australia, Germany and the United States of America (Table 2). Syrphidae and Chrysopidae formed 21 and 14%, respectively, whereas the remaining 17% was made up of Cecidomyiidae, Forficulidae and Lygaeidae. Syrphidae and Chrysopidae have been reported in nine and five countries, respectively. Very little quantitative work has been conducted to evaluate the impact of predators on *E. lanigerum* populations in apple orchards. The functional response data obtained in the laboratory for *F. auricularia*, *P. australasiae* and *H. conformis* all fitted well to the type II model of the Holling disc equation (Asante 1995b). These predators were found to consume larger numbers of early than later instars of *E. lanigerum* within the same time period. Many studies have confirmed that *F. auricularia* is an effective predator of *E. lanigerum* (McLeod and Chant 1952, Mueller *et al.* 1988, Asante 1995b). Asante (1995b) reported that an adult *F. auricularia* could consume up to 107 individual nymphs of *E. lanigerum* per day. However, *F. auricularia* has only been recorded in Australia and The Netherlands as a predator of *E. lanigerum*. Also, the seven species of predatory Hemiptera found in the literature have all been recorded in The Netherlands (Table 2).

Conclusion

It has been found from this study that apart from the exotic endoparasitoid, *A. mali*, which has been introduced into all apple-growing regions of the world to control this cosmopolitan apple pest (DeBach 1964), *E. lanigerum* is naturally under predation by the European earwig, lacewing, several coccinellid beetles and syrphid flies in many apple-growing regions (Table 1).

In view of the current worldwide concern of the effects of frequent use of broad spectrum insecticides necessary for the control of other key pests, such as environmental pollution, development of pest resistance to insecticides, insecticides residues in food and adverse effects on beneficial organisms (e.g. pollinators, predators and parasitoids), it is imperative to develop ecologically sound and sustainable management strategies for all important crop pests. There has not been, to date, a comprehensive review of the natural enemies of *E. lanigerum* in Australia and elsewhere. The present review, however, suggests that predators and the fungal pathogen, *V. lecanii* may contribute effectively to the management of *E. lanigerum* if they could be conserved and augmented in apple orchards, particularly in areas where *A. mali* has been reported to be ineffective due to climatic reasons. It has been reported by a number of authors that predaceous insects can play an important role in regulating populations of insect herbivores (Hunter and Price 1992). Hall (1980) reported that *V. lecanii* infects aphids; and most attempts to introduce fungi for the biological control of aphids have involved an inundative approach by using a fungus-based preparation as a mycoinsecticide. A commercial product based on conidia of *V. lecanii* was developed in England mainly for use in greenhouses against whiteflies, aphids, thrips and mites (Hall 1981).

Table 1. Predators of *Eriosoma lanigerum* reported from different localities.

Insect species	Reference	Location
(a) Coleoptera: Coccinellidae		
Adalia bipunctata L.	Del Guercio (1925)	Italy
	Marchal (1925)	France
	Speyer (1935)	Germany
	Ravensberg (1981)	The Netherlands
Adomia variegata Gze.	Speyer (1935)	Germany
Alesia sp.	Anon. (1921)	South Africa
Allograpta obliqua Say	Alden (1930)	USA
Chilocorus stigma Say	Michelbacher and Borden (1944)	USA
C. bipustulatus L.	Del Guercio	Italy
	Marchal (1929)	France
	Borg (1929)	Malta
C. rubidus Hope	Hori (1930)	Japan
C. similis Ross.	Hori (1930)	Japan
C. quatuorpustulatus L.	Riveros (1916)	Argentina
Coccinella septempunctata L.	Borg (1929)	Malta
	Marchal (1929)	France
	Hori (1930)	Japan
	Speyer (1935)	Germany
	Singh (1942)	India
	Bodenheimer (1947)	Palestine
C. axiridis Pall.	Toyoshima (1938)	Japan
C. repanda Thunberg	Asante (1995a)	Australia
C. quinquepunctata L.	Speyer (1935)	Germany
Cryptolaemus montrouzieri (Mulsant)	Asante (1995a)	Australia
Cydonia (*Chilomenes*) *lunata* F.	Lundie (1939)	South Africa
Cycloneda sanguinea L.	Clausen (1916)	USA
Diomus notescens (Blackburn)	Asante (1995a)	Australia
Exochomus flavipes Thumb.	Anderson (1915)	East Africa
	Geyer (1947)	South Africa
E. melanocephalus Zoubkoff (*nigromaculatus* Goeze)	Lundie (1939)	South Africa
E. quadripustulatus (L.)	Del Guercio (1925)	Italy
	Borg (1929)	Malta
	Marchal (1929)	France
	Kovacevic (1932)	Yugoslavia
	Speyer (1935)	Germany
	Clausen (1956)	USA
	Evenhuis (1958)	The Netherlands
	Radwan and Lovei (1983)	Hungary
Harmonia dimidiata (L.)	Chakrabarti *et al.* (1988)	India
H. conformis (Boisduval)	Sproul (1981)	Australia
Hippodamia variegata F.	Anderson (1915)	East Africa
H. convergens Guer.	Clausen (1916)	USA
	Tillyard (1926)	New Zealand
Leucopis puncticoris Mg.	Bodenheimer (1947)	Palestine
Oenopia cinctella Muls.	Anon. (1921)	South Africa
Parapriasus australasiae (Boisduval)	Asante (1995a)	Australia
Pharoscymnus (*Midus*) *quadristillatus* Muls.	Lundie (1939)	South Africa
Platynaspis sp.	Lundie (1939)	South Africa
Propylaea 14-*punctata* (L.)	Ravensberg (1981)	The Netherlands
Rhyzobius sp.	Asante (1995a)	Australia
Scymnus bineavatus Muls.	Lundie (1939)	South Africa
S. castroemi Muls.	Lundie (1939)	South Africa
S. hilaris Motsch.	Hori (1930)	Japan
Thea (*Halyzia*) *variegata* F.	Lundie (1939)	South Africa

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Table 1. continued\…

Insect species	Reference	Location
(b) Diptera: Syrphidae		
Cnemoden vitripennis (Meig.)	Evenhuis (1959)	The Netherlands
Episyrphus sp.	Lyon and Tiefenau (1976)	France
Macrosyrphus confrater (Wied.)	Asante (1995a)	Australia
Melangyna viridiceps (Macq.)	Asante (1995a)	Australia
Metasyrphus (*Syrphus*) *confrater* (Wied.)	Zaka-ur-Rab (1972)	India
Pipiza sp.	Lyon and Tiefenau (1976)	France
P. dubia Lundb.	Speyer (1936)	Germany
P. modesta Lw.	Davidson (1916)	USA
P. radicum Walsh & Riley	Davidson (1916)	USA
Syrphus sp.	Lyon and Tiefenau (1976) Fischetti *et al.* (1969)	France Argentina
S. auricollis Mg.	Rosenberg (1934)	UK
S. (*Episyrphus*) *balteatus* De G.	Staniland (1922) Hori (1930) Nakayama *et al.* (1928) Rosenberg (1934) Speyer (1936) Verma and Singh (1985)	UK Japan Korea UK Germany India
S. pusillus Frog.	Jarvis (1922)	Australia
S. ribesii L.	Curran (1920) Marchal (1929) Speyer (1936)	Canada France Germany
S. viridiceps Macq.	Jarvis (1922)	Australia
(c) Diptera: Cecidomyiidae		
Uncinelella sp.	Del Guercio (1919)	Italy
(d) Neuroptera: Chrysopidae (green lacewing)		
Chrysopa corna Stephens	Ravensberg (1981)	The Netherlands
C. formosa Br.	Kalandadze (1927)	Germany
C. perla L.	Kovacevic (1932)	Yugoslavia
C. porterina Navas	Porter (1918)	Chile
C. prasina var. *abdominalis* Brum.	Kalandadze (1927)	Germany
C. septempunctata cognata Mclach.	Nakayama *et al.* (1928) Hori (1930)	Korea Japan
C. tenella Schn.	Withycombe (1924)	UK
C. vulgaris Schneider	Marchal (1929)	France
C. walkeri Mclach.	Marchal (1929)	France
(e) Neuroptera: Hemerobiidae (brown lacewing)		
Drepanepteryx phalaenoides (L.)	Prance (1982)	UK
Hemerobius humulinus L.	Ravensberg (1981)	The Netherlands
H. lutescens Fabr.	Ravensberg (1981)	The Netherlands
Micromus tasmaniae (Walker)	Asante (1995a)	Australia
(f) Dermaptera: Forficulidae (European earwig)		
Forficula auricularia L.	Ravensberg (1981) Asante (1995a)	The Netherlands Australia
(g) Hemiptera: Lygaeidae		
Anthocoris nemorum (L.)	Ravensberg (1981)	The Netherlands
Antractotomus mali (Meyr-Dur)	Ravensberg (1981)	The Netherlands
Blepharidopterus angulatus (F.)	Ravensberg (1981)	The Netherlands
Heterotoma merioptera (Scopoli)	Ravensberg (1981)	The Netherlands
Himacerus apterus (Fabr.)	Ravensberg (1981)	The Netherlands
Phytocoris sp.	Ravensberg (1981)	The Netherlands
Pilophorus sp.	Ravensberg (1981)	The Netherlands

Table 2. Number of predatory species reported to attack *Eriosoma lanigerum* from different localities.

Country	Coleoptera	Diptera	Neuroptera	Dermaptera	Hemiptera
The Netherlands	3	1	3	1	7
Australia	6	3	1	1	–
Germany	5	3	3	–	–
France	4	3	3	–	–
Japan	4	1	1	–	–
USA	5	2	–	–	–
Italy	3	1	–	–	–
India	1	2	–	–	–
Argentina	1	1	–	–	–
South Africa	10	–	–	–	–
Malta	3	–	–	–	–
New Zealand	1	–	–	–	–
Tuscany	1	–	–	–	–

Insect pest management and biological control strategies offer promise to provide options and pathways to alternative solution to insect pest problems rather than reliance on chemical control (Watson *et al.* 1975), therefore, it is hoped that the information provided here on the natural enemies of *E. lanigerum* will be useful for the development of biological control or insect pest management strategies for this cosmopolitan apple aphid in those countries in which it occurs as a serious pest.

Acknowledgments

Financial support provided by the Australian International Development Assistance Bureau (AIDAB) and the University of New England Internal Research Grants Committee is gratefully acknowledged.

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