Use of Predators for the Biological control of *Eriosoma lanigerum* (wooly apple aphids) on apple

Jyotsna Nepal¹ and Bikal Ghimire²

¹Wageningen University and Research, Wageningen, Netherlands
²University of Padova, Italy

**Abstract**

Due to increased demand of organic products, biological control methods have gained interest all over the world. *Eriosoma lanigerum*, commonly known as Wooly apple aphid, is a serious pest of apple. The negative impacts of pesticides on environment and human life make Biological control an important model in the control of the Wooly apple aphid. Some of the biological control agents that have been used in the control of this pest are predators, parasitoids, nectar of flowers etc. The role of the parasitoid *Aphelinus mali* in the biological control of wooly aphid has been studied by many researchers and found that use of parasitoids *Aphelinus mali* is not effective when they attack WAA solely in apple orchards. However, efficiency of use of *Aphelinus mali* in control of WAA is higher when these parasitoids are used along with natural predators (Gontijo, 2011). In recent days, there has been increasing use of predators for the control of aphids. This review focuses on some of the mostly used predators like syrphids, lacewings, earwigs etc. and their role in WAA management. This review focuses on the feeding habits of predators used as biocontrol agents against WAA as well as the occurrence time of these predators before their integration in management practices. Also, this review provides insight into the integration of predators along with other natural enemies for productive control of WAA. This review can be a source of information for producers, as well as researchers who are focusing on organic production of apples and integrated wooly aphid management.

**Keywords**: predators; biological control; aphids; WAA

**Introduction**

Biological control means all strategies that involve the application of natural enemies like pathogens, predators, and parasitoids for the control of pest population in fields (Huffaker, 2012). Biological methods play important role in management of pests without having negative impact on environment and food quality. Chemical control has significant negative effect in the environment and human health. Hence, the need of non chemical control of pests is being realized nowadays. So, the introduction of potential natural enemies and predators as a biological control agent to reduce pests in apple orchards is also increasing (Suckling et al., 1999; Lefebvre et al., 2017).

Biological control measures have become increasingly important in the control of the Wooly Apple Aphid (WAA) on Apple (Gontijo et al., 2011). Wooly Apple Aphids...
scientifically known as *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae) is a native to America. WAA are holocyclic, heteroeous aphid species which needs *Ulmus Americana* L., American elm tree as the winter host and apple trees as the summer host. In the absence of *Ulmus Americana*, this aphid can use apple trees as a host throughout the year (Gontijo et al., 2012). The wax and honey produced by the aphids have serious impact on quality of fruit and post harvest activities as this makes the fruit picking difficult and these can cause problem in respiration too (Mueller et al., 1988; Quarrell et al., 2017; Gontijo et al., 2015). WAA infestation can lead to poor health and vigor of the tree and ultimately reduces the crop production (Quarrell et al., 2017).

WAA can be controlled using different biological methods. However, due to disruption in biological control because of the use of insecticide, the aphids outbreaks are on rise since 2000s (Gontijo et al., 2012). In most of the countries nowadays, there is restriction in the use of pesticides like endosulfans and diazinons which are very effective in control of WAA. As a result, there is increasing trend of using predators and parasitoids in control of this aphid. (Bush et al., 2011). Some of the common predators of the WAA are Earwigs, spiders, syrphids and bugs (Gontijo et al., 2012). Though there are many predators known, till now, the study of their contribution in the control of aphid has not been done as efficiently as of parasitoids (Bergh and Stallings, 2016).

The objective of this review is to find out the different predators of WAA and their roles in WAA suppression. This review also provides idea for the integration of predators as a biological control in the sustainable WAA management in fields. For this review, the words “predator”, “biological control” and “aphids” are searched in scopus.nl website and the articles from 2009 to 2017 are included. The first part of the main body is about different biological controls that are used in the control of WAA in apple. The next section deals with the role of different predators in controlling WAA population in apple orchards. The third section analyzes the effectiveness of predators for the integration in pest management practices of WAA. This review can act as a source of information for the researchers who are focused on biological control compared to the chemical control. Also, this review can act as a guideline for apple producers who want to use biological methods for WAA control.

**Commonly Used Biological control Agents of WAA**

Some of the flowering plants have capacity to attract the natural enemies of certain pests. Natural enemies who are attracted to these flowers take nectars as well as pollen as their alternative food, for e.g. lady beetles are attracted to the pollen of the alfalfa flowers (Landis et al., 2000; Davidson and Evans, 2010). Also, the lifespan and fecundity of some parasitoids increases after taking carbohydrates as a major energy source from the floral resources (Winkler et al., 2006). Similarly, nectar from flowers like *sweet alyssum*, *Lobularia maritima* can attract the natural enemies of WAA. Natural enemies like spiders, syrphids, parasitoid wasps will then attack the WAA species colonizing in apple orchards can control the aphid population near to the *sweet alyssum* (Gontijo et al., 2013).

Among parasitoids, only *Aphelinus mali* is responsible for the control of WAA. *A. mali* species are the specific endoparasite and one of the most important biological control agents of WAA (Shaw and Walker, 1996). *A. mali* species parasitize aphid colonies in the aerial parts and are not present in the roots (Gontijo et al., 2012). *A. mali* numbers are reduced by some of the conventional pesticides like spinosad, carbaryl, organophosphates and neonicotinoids which are used in apple orchards and thus, hamper the controlling of WAA (Rogers et al., 2011). Also, the suppression of WAA is not efficient when it is done solely by *A. mali*. *A. mali* species have very low reproduction rate below 25°C and can attain its maximum density only at the later stage of emergence of the aphid population (Asante and Danthanarayana 1992; Goossens et al., 2011; Mols and Boers 2001; Nicholas et al., 2005; Quarrell et al., 2017). Hence, there is a need of early season predation by predators to control the WAA population before *A. mali* species attain its population size (Lordan et al., 2015). This supports that predator’s role is important in biological control of WAA (Gresham et al., 2013).

**Characteristics and Role of predators in WAA management**

Some of the predators plays major role in controlling the WAA population. The most common predators that are found attacking WAA colonies along with their roles are highlighted in this part of the review. Predators are found attacking the WAA in apple orchards. The difference in occurrence time and feeding habit of different predators in apple orchards may provide regular control of WAA (Gontijo et al., 2012). Most of the predators attacking the WAA belong to syrphids, chrysopids, coccinellids, nabis, spiders and earwigs (Gontijo et al., 2012). In a 3-year survey about natural enemies done in apple orchards of Washington State with record of WAA infestation, it was shown that syrphids are the most abundantly present predators followed by coccinellids and chrysopids (Gontijo et al., 2011). The percentage of syrphids is 62-81% followed by 6-24 percent of coccinellids and chrysopids (Gontijo et al., 2012). In the next few paragraphs, we will discuss about the most common predators preying on the WAA population.

The most common among the syrphids are *Heringia calcarata* and *Eupeodes americanus* (Gresham et al., 2013).
The biological control of Wooly Yssum with predators and prey on WAA. These females lay eggs during mid June as well as during mid September-early October. H.calcarata is present in the later growth stage of aphids while E.americanaus is beneficial in controlling the aphid during the early growth period of the aphid species.

Among the coccinellids, Coccinella transversoguttata and Hippodamia convergens are two major species that can decimate WAA population to large extent (Walker 1985; Aslan and Karaca, 2005; Gontijo et al., 2012). Coccinellids mostly appear in apple colonies during July and August (Gontijo et al., 2012).

Similarly, Chrysopa nigricorni lacewings are abundantly present in apple orchards and feed upon aphids and other arthropods as well. Due to their resistance against insecticides, they are also released for augmentative control of Wooly apple aphid. Lacewings have been found to be attracted to some of the pheromones like nepetalactones which are produced from the Nepeta cataria (Lamiaceae), the catmint that is the non-food crop (Birkett et al., 2003) and also to semiochemicals like iridodial and methyl salicylate. Hence, use of these pheromones and semiochemicals as attractants in apple orchards with WAA infestation will attract lacewings and thus increase the effectiveness of biological control of WAA (Gontijo et al., 2011).

Forficula auricularia, the European earwig is an omnivorous predator and prey on WAA. These female earwigs need protein rich diets in their juvenile stage. Hence, these earwigs attack on the aphid population to fulfill their diets. F auricularia females lay eggs during winter season and most of these females die or fly to the other nests for continual of their subspecies (Gingras and Tourneur 2001; Lamb, 1976; Lamb and Wellington, 1975; Wirth et al., 1998). Because of this, there will not be enough earwigs in the place, where they are previously attacking aphids. Thus, this low population of earwigs will not be able to control WAA population once threshold of aphid population is crossed (Moerkens et al., 2009; Quarrell et al., 2017).

The integration of predators with different feeding habits and occurrence time will increase the rate of control of WAA in apple orchards. For e.g. predators like earwigs attack on day time whereas syrphids and ladybeetles are mostly seen attacking on night time. Likewise, some predators like earwigs attack outside the foliage whereas coccinellids beetles mostly under the foliage (Gontijo et al., 2015). This provides continuous suppression of aphid outbreak in apple orchards.

### Integration of Predators with Other Biological Control Methods

Biological control of the pest population will be enhanced when natural enemies of the pests complement with each other (Straub et al., 2008). Likewise, WAA population is suppressed when generalist and specialist natural enemies unite and attack aphid species (Snyder and Ives, 2003). In this section integration of predators with other control agents are discussed.

Integration of flowering plants like sweet alyssum with apple trees helps to attract generalist predators like syrphid and parasitoids like Aphelinus mali. These predators and parasitoids are attracted to the nectar of sweet alyssum which contributes for the food sources. Hence, augmentation of food sources for parasitoids and predators in the apple orchards through the use of flowers like sweet alyssum helps in the significant reduction of aphid’s population (Gontijo, 2011).

Studies have shown that WAA control was enhanced when predators attack WAA complementary with parasitoid A. mali (Wearing et al., 2010). In a cage experiment done with predator’s exclusion, Bergh and Stallings, 2016, presented that the aphid population increased when all natural enemies of WAA were excluded. However, aphid population decreased when the cage was kept fully and partially open. Moreover, the presence of A. mali controlled the growth of aphid population. The aphid population decreased in the experiment when the A. mali was released with the predators. Syrphids which are among the abundantly found predators in the apple orchards are present mostly in the early summer (June) whereas are mostly absent during September and October. The high occurrence of A. mali during the fall can contribute in the suppression of WAA in the fields when the predators are absent (Gontijo et al., 2012). The early season predation of WAA by the predator F. auricularia when followed by parasitoid A. mali gives better control of WAA in apple orchards (Lordan et al., 2015; Quarrells et al., 2017).

### Concluding Remarks

From our review, it is concluded that the integration of predators and natural enemies of wooly aphid is the main demand for its control. The biological control of Wooly Apple Aphid (WAA) has higher efficiency by integration of different predators like syrphids, lacewings, earwigs etc. with parasitoids like Aphelinus mali (Gontijo, 2011). However, for optimizing use of biological control of WAA further researches should additionally focus on WAA interactions with other host plants, interactions with insecticides use, economical analysis of use of biological control etc.

Wooly aphids need Ulmus Americana L., American elm tree, as the winter host to complete its life cycle (Gontijo, 2011). However, if WAA does not find this elm...
tree it spends its whole year in apple. Making WAA unlikely to fly towards this elm tree as winter host may be possible if American elm can be made WAA repellent. When aphid does not fly towards elm tree for winter cycle then it will reside whole year on apple and it will help for the complete eradication of WAA on the same host. So research on the repellent property of this elm tree towards aphids can break a new ground for biological control of aphids which will open door to new science of aphid’s control.

Reduction in insecticides usage is another important aspect of biological control method. Organic apple production with biological control can help in the reduction of use of insecticides; insecticides augment in the outbreak of aphids. So following farming practices that makes use of insecticides as less as possible can promote biological control. However, reduction of insecticides use for supporting biological control of aphids may not help to control other insects and pests found on apple tree. Avoiding of insecticides may cause increase in the population of other insects and pests in apple tress as predator and parasitoids of aphids may not help to control other insects, which cause damage to apple production. Hence, it needs further research regarding which other insects population can be a threat to apple in absence of insecticides and use of biological control agents that are specialized for WAA’s control.

Parasitoids used in the biological control of WAA are attracted towards apple by planting flowers like sweet alsyssum, rich in nectars, in the periphery of apple tree. Plantation of such flowers rich in nectars sources may be economically expensive. Therefore, it requires further research about how economically feasible this practice is as compared to the application of insecticides. Further research can be focused on the economic aspect considering the yields of apple and gross profit with the use of flowers in the biological control of WAA.

Use of predators for the control of WAA requires the release of the predators selectively according to seasons as well as growth stages of the apple trees. The effect of predators during different life stages of WAA should be thoroughly studied before doing further researches. We can see predators and parasitoid integration has successful results in many experiments done with WAA. Gontijo (2015) studied the comparative effect of A. mali solely and by integration with generalist predators like earwigs, syrphids, predatory bugs and spiders to aphid suppression and found integration of predators and parasitoid has higher efficiency in WAA control. These results can be taken as standards for further researches oriented towards other serious pests of apples.

The integration of parasitoid and predators has been shown in many experiments whereas the cost analysis for the use and integration of predators were not found in these experiments. So, researches should also focus on the economical aspects as well if the production of apples has to be done in large scale. As a whole, we can conclude that the predators have considerable role in suppression of WAA when integrated with parasitoids. However, further research based on economic feasibility about apple productions, apple yield and gross profit when parasitoids are integrated with predator is the need for exploring more potentials of biological control of WAA in apple production.

References

Asante SK and Danthanarayana W (1992) Development of Aphelinus mali an endoparasitoid of woolly apple aphid, Eriosoma lanigerum at different temperatures. Entomologia Experimentalis et Applicata 65(1): 31-37. DOI: 10.1111/j.1570-7458.1992.tb01624.x

Aslan B and Karaca I (2005) Fruit tree aphids and their natural enemies in Isparta region, Turkey. Journal of pest science 78(4): 227-229. DOI: 10.1007/s10340-005-0097-2

Bergh JC and Stallings JW (2016) Field evaluations of the contribution of predators and the parasitoid, Aphelinus mali, to biological control of woolly apple aphid, Eriosoma lanigerum, in Virginia, USA. BioControl 61(2): 155-165. DOI: 10.1007/s10340-016-9714-7

Birkett MA and Pickett JA (2003) Aphid sex pheromones: from discovery to commercial production. Phytochemistry 62(5): 651-656. DOI: 10.1016/S0031-9422(02)00568-X

Bush M, Dunley JE, Beers EH, Brunner JF, Walsh DB, Xiao C-1, Elfving D, Davenport J,Smith TJ, Daniels C, et al. (2012) Crop protection guide for tree fruits in Washington. Bull. EB0419, Washington State University Cooperative Extension, Pullman, WA.

Davidson LN and Evans EW (2010) Frass analysis of diets of aphidophagous lady beetles (Coleoptera: Coccinellidae) in Utah alfalfa fields. Environmental entomology 39(2): 576-582. DOI: 10.1603/EN08308

Gingras J and Tourneur JC (2001) Timing of adult mortality, oviposition, and hatching during the underground phase of Forficula auricularia (Dermaptera: Forficulidae). The Canadian Entomologist 133(02): 269-278. DOI: 10.4039/Ent133269-2

Gontijo LM (2011) Integrated biological control of woolly apple aphid in Washington State (Doctoral dissertation, Washington State University).

Gontijo LM, Beers EH and Snyder WE (2015) Complementary suppression of aphids by predators and parasitoids. Biological Control 90: 83-91. DOI: 10.1016/j.biocontrol.2015.06.002

Gontijo LM, Cockfield SD and Beers EH (2012) Natural enemies of woolly apple aphid (Hemiptera: Aphididae) in Washington State. Environmental entomology 41(6): 1364-1371. DOI: 10.1603/EN12085

Goossens D, Bangels E, Belien T, Schoevaerts C and De Maeyer L. (2011) Optimal profit of the parasitization by Aphelinus mali in an IPM complementary strategy for the control of
Erioso maligerum. Communications in agricultural and applied biological sciences 76(3): 457.

Gresham SDM., Charles JG, Sandanayaka MWR, and Bergh JC (2013). Laboratory and field studies supporting the development of Heringia calcarata as a candidate biological control agent for Erioso maligerum in New Zealand. BioControl 58(5): 645-656. DOI: 10.1007/s10526-013-9530-2

Huffaker CB (Ed.) (2012) Theory and practice of biological control. Elsevier.

Lamb RJ (1976) Parental behavior in the Dermaptera with special reference to Forficula auricularia (Dermaptera: Forficulidae). The Canadian Entomologist 108(06): 609-619. DOI: 10.4039/Ent108609-6

Lamb RJ and Wellington WG (1975) Life history and population characteristics of the European Earwig, Forficula Auricularia (Dermaptera: Forficulidae), at Vancouver, British Columbia. The Canadian Entomologist 107(8): 819-824. DOI: 10.4039/Ent107819-8

Landis DA, Watten SD and Gurr GM (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual review of entomology 45(1): 175-201. DOI: 10.1146/annurev.en.45.1.175

Lordan J, Alegre S, Gatius F, Sarasua MJ, Alins G (2015) Woolly apple aphid Erioso lanigerum Hausmann ecology and its relationship with climatic variables and natural enemies in Mediterranean areas. Bull Entomol Res 105: 60–69. DOI: 10.1017/S0007485314000753

Moerkens R, Leirs H, Peusens G, Gobin B (2009) Are populations of European earwigs, Forficula auricularia, density dependent? Entomol Exp Appl 130: 198–206. DOI: 10.1111/j.1570-7458.2008.00808.x

Mols PJM and Boers JM (2001). Comparison of a Canadian and a Dutch strain of the parasitoid Apheinus mali (Hald)(Hym., Aphelinidae) for control of woolly apple aphid Erioso lanigerum (Hausmann)(Hom., Aphididae) in the Netherlands: A simulation approach. Journal of Applied Entomology 125(5): 255-262. DOI: 10.1046/j.1439-0418.2001.00543.x

Mueller TF, Blommers LHM and Mols PJM (1988) Earwig (Forficula auricularia) predation on the woolly apple aphid, Erioso lanigerum. Entomologia experimentalis et applicata 47(2): 145-152. DOI: 10.1111/j.1570-7458.1988.tb01129.x

Quarrell SR, Corkey R and Allen GR (2017). Predictive thresholds for forecasting the compatibility of Forficula auricularia and Apheinus mali as biological control agents against woolly apple aphid in apple orchards. BioControl 62(2): 243-236. DOI: 10.1007/s10526-017-9792-1

Rogers DJ, Sharma N, Stretton DC and Walker JTS (2011) Toxicity of pesticides to Apheinus mali, the parasitoid of woolly apple aphid. New Zealand Plant Protection 64: 235-240.

Shaw PW and Walker JTS (1996) Biological control of woolly apple aphid by Apheinus mali in an integrated fruit production programme in Nelson. In: Proceedings of the New Zealand Plant Protection Conference (pp. 59-63). New Zealand Plant Protection Society Inc.

Snyder WE and Ives AR (2003) Interactions between specialist and generalist natural enemies: parasitoids, predators, and pea aphid biocontrol. Ecology 84(1): 91-107. DOI: 10.1890/0012-9658(2003)084[0091:IBSAGN]2.0.CO;2

Straub CS, Finke DL and Snyder WE (2008) Are the conservation of natural enemy biodiversity and biological control compatible goals? Biological control 45(2): 225-237. DOI: 10.1016/j.biocontrol.2007.05.013

Suckling DM, Walker JTS and Wearing CH (1999). Ecological impact of three pest management systems in New Zealand apple orchards. Agriculture, ecosystems & environment 73(2): 129-140. DOI: 10.1016/S0167-8809(99)00022-5

Walker JTS (1985) The influence of temperature and natural enemies on population development of woolly apple aphid, Erioso maligerum (Hausmann). Washington State University.

Winkler K, Wäckers F, Bukovinszkine-Kiss G and Van Lenteren J (2006) Sugar resources are vital for Diadegma semiclausum fecundity under field conditions. Basic and applied ecology 7(2): 133-140. DOI: 10.1016/j.baec.2005.06.001

Wirth T, Le Guellc R., Vancassel M and Veuille M (1998) Molecular and reproductive characterization of sibling species in the European earwig (Forficula auricularia). Evolution 52(1): 260-265.