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Mini Review

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

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Abstract

Due to increase 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 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

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scientifically known as *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae) is a native to America. WAA are holocyclic, heteroecious aphid species which needs *Ulmus American* 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 swe*et al*yssum, *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 swe*et al*yssum (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).

H. calcarata is a specialist predator and attacks the aphid colonies present in the roots. According to Gresham *et al*. (2013), the appearance of the *H.calcurata* in apple field is from late April to mid Octobers. The density of *H.calcurata* is highest during mid June as well as during mid September-early October. *H.calcurata* is present in the later growth stage of aphids while *E.americanus* 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 swe*et al*yssum 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 swe*et al*yssum 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 swe*et al*yssum 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 swe*et al*yssum, 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 potentialities of biological control of WAA in apple production.

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