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Parasitization by *Aphelinus mali* on *Eriosoma lanigerum*: an IPM and Organic comparison

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Abstract
The woolly apple aphid (WAA), *Eriosoma lanigerum* (Hausmann), is a pest of apple orchards infesting both stems and roots of host trees (Baker, 1915). Heavy infestations of WAA can cause yield and growth reduction of apple trees, as this aphid weakens the plant by both feeding on roots and inducing root and shoot galls that damage the xylem and interrupt water transportation (Klimstra & Rock, 1985), and even death of young trees (Brown & Schmitt, 1990; Brown et al. 1994). The pest status of WAA is fluctuating over the years depending on biotic and abiotic factors (Lordan et al. 2015; Angeli, 2015).

The control of the woolly apple aphid by the solitary, host-specific parasitoid *Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae) is cited as one of the most successful examples of classical biological control of insect pests (Mueller et al. 1992; Goossens et al. 2011). De Bach (1964) reported *A. mali* as a successful biological control agent in at least 40 countries and among these also Italy.

The susceptibility of some apple varieties and dwarfing rootstocks, the simplification of the agroecosystems and the management programs of primary pests and diseases are reported as potentially responsible for disrupting the biological control of WAA (Angeli & Simoni, 2006; Baldessari et al. 2007; Beers, 2010; 2014; Angeli, 2015). Some recently introduced agronomic techniques, such as single row exclusion netting, are also negatively involved, reducing the possibility of colonization of the plant's foliage by predators and parasitoids.
E. lanigerum becomes active starting from 267 degree-days above the temperature threshold of 5.2°C (Asante et al. 1991), which generally corresponds to the crop stage of green bud (BBCH 56), whereas *A. mali*, whose lowest developmental threshold is 8.3°C, needs 255 degree-days to begin its activity (Asante & Danthanarayana, 1992). Consequently, the developmental time of *A. mali* is generally delayed throughout the year compared to its aphid host.

A two-year field experiment (2017-18) was conducted in some organic and IPM orchards (*Golden Delicious* and *Fuji* varieties) located in plain (180 m) and hilly areas (500-700 m) of Trentino-South Tyrol Region (north-eastern Italy) to determine the efficacy of a biological control of WAA populations by means of *Aphelinus mali*. The evolution of plant colonization by WAA, the flight of the parasitoid *A. mali* and the percentage of parasitization of WAA colonies were monitored in the selected orchards. A particular attention was paid at evaluating the susceptibility of *A. mali* to the common pesticides used in the two crop management systems and in relation to varieties and altitude of cultivation.

Our results suggest that during summer the parasitoid *A. mali* has certainly an impact on WAA, but insights on the single interactions do not indicate a sufficient biocontrol in the period May-half June, both in IPM and in organic management, in plain and in hilly areas, and also considering the different apple varieties.

It was confirmed (Goossens et al. 2011) that the insufficient contribution of the early parasitation by *A. mali* to avoid woolly apple aphid damage is linked to a later emergence

from diapause and a slower reproduction compared to its host. A delay of parasitoid development in hilly areas has been observed.

Noteworthy, observing the first peak of flight of *A. mali* in the post-flowering period (6^{th}-20^{th} June), although limited in size, is essential for an exponential flight increase and the consequent culmination of the parasitization ratio in summer, generally at the end of July. This constitutes a valuable complement in the integrated control strategy of *E. lanigerum*.

The monitoring of the number of black mummies parasitized and of the *A. mali* adults' flight in the four orchards along the season allowed also to evaluate the development of endoparasitic stages, which covers the same period in the studied orchards, delayed of about one week on the hills. This phase, in which *A. mali* larvae reside inside their host, is strategic to position treatments with compounds with a risk of toxicity on *A. mali* adults, such as some insecticides, to obtain a better selectivity. Outbreaks of *E. lanigerum* have often occurred as a result of pesticide applications which decimated biological control agents (McLeod, 1954; Penam & Chapman, 1980). In presence of high infestations of woolly apple aphid, the chemical control of *D. plantaginea* with spirotetramat (+ oil) or other aphicides, which remains necessary in IPM, shows a favorable side-effect on WAA in order to anticipate the high migration waves and the subsequent colonization of growing shoots.

In this two-year work, there were no differences in the parasite-host relationships in the two crop management systems, IPM and organic, even though a higher presence of WAA was observed in organic orchards. The climatic conditions seem to play a key role in regulating the ability of *A. mali* to control aphid infestations. Investigations are still going on, especially to set up the optimal management of parasitoids through simple practices, such as mowing at alternate rows.

Key words: monitoring, *Aphelinus mali* Haldeman, parasitoids, *Eriosoma lanigerum* Hausmann, wolly apple aphid, IPM, organic.

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