Bioecology and management of *Halyomorpha halys* in fruit orchards in Southern Europe

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Abstract

Halyomorpha halys is an invasive fast-spreading pest of global importance native to East Asia, introduced and successfully established in the United States, Canada, Chile and Europe. In Northern Italy it quickly became a key-pest of fruit orchards and in 2019 estimated losses in fruit production exceeded €350mln. The fast spread and high damage caused by this pest forced growers to increase broad-spectrum insecticide treatments, seriously disrupting previous Integrated Pest Management (IPM) and Organic farming programs. To face H. halys, a task force made of farmers, technicians and researchers of public and private structures was established in Emilia Romagna, the region of first appearance, to investigate the bioecological features and identify appropriate approaches for its monitoring and sustainable management.

Keywords: Brown marmorated stink bug, invasive species, polyphagous crop pest, integrated pest management, biological control

Introduction

Halyomorpha halys Stål, 1855 (Heteroptera, Pentatomidae) is an emerging pest of global importance for many agricultural crops (Haye & Weber, 2017) and also a household nuisance, due to the overwintering aggregations inside man-made structures. Native to east Asia it has successfully invaded and established in the United States, Canada, Chile and is fast spreading all over the European continent and along the Black Sea regions (Inaturalist, 2019). The propensity to aggregate in narrow, hidden microhabitats (e.g. slots of vehicles, packaging materials, suitcases, clothes etc.) exhibited particularly during overwintering, allows these bugs to hitchhike on any type of goods and means of transport, highly facilitating the human assisted spread all over the world.

H. halys caused millions of dollars losses in fruit orchards and horticultural crops in the USA (Leskey & Nielsen, 2018) and is a serious pest of hazelnuts grows in Piedmont and in the countries along the Black Sea (Bosco, Moraglio & Tavella, 2018). Soon after its first detection in Italy in Emilia Romagna, one of the most important regions for fruit production in Europe, it became a key pest of fruit orchards with up to 60% fruit damaged in integrated crop production and over 90% in organic management (Maistrello *et al.*, 2017), eliciting high concern in the whole agriculture sector. Outbreaks of *H. halys* in northern Italy in 2019 caused more than € 356 million damage in pear, peach and nectarine with up to 80-100% yield losses in the orchards (CSO Italy - Centro Servizi Ortofrutticoli, 2019). The fast spread and damage levels caused by this pest forced farmers to increase broad-spectrum insecticide treatments, seriously disrupting the previous Integrated Pest Management (IPM) programs, causing an impressive negative trend reversal with respect to sustainability. Production losses on organic farms are often very high, at the limit of economic convenience. Management of *H. halys* is particularly challenging. Chemical control proved

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to be scarcely effective due to the general robustness, as well as to the high polyphagy combined with high mobility of all instars, that results in continuous movements of the bugs between different host plants (Lee & Leskey, 2015). To face the threat posed by *H. halys*, a task force made of farmers, technicians and researchers of public and private structures was established in Emilia Romagna to study its spread and bio-ecology and to identify effective solutions and appropriate approaches for its monitoring and sustainable management.

Material and Methods

The activities focused on the following topics:

- follow the spread of the pest in Italy and Europe and identify the patterns of the invasion by means of a citizen science survey and genetic analyses of the collected samples;
- obtain insights on *H. halys* biological parameters by means of a life table study;
- field surveys and laboratory studies to evaluate the potential of native antagonists for *H. halys* biocontrol;
- evaluating appropriate monitoring strategies and techniques;
- identify additional stimuli to improve the efficacy of monitoring;
- evaluate efficacy of insecticidal products authorized in Italy;
- evaluate the use of physical barriers for pest exclusion from orchards;
- evaluate behaviour manipulation strategies;
- evaluate the effectiveness of inundative releases with native parasitoids.

Results and Discussion

The citizen science survey indicated that in Italy *H. halys* is fast spreading in centre, southern regions and the main islands (Maistrello *et al.*, 2018), confirming the importance of human-assisted spread. The same study allowed also to elaborate a model of its spatio-temporal dynamics and to guess that 2009 was likely the initial year of the Italian invasion (Maistrello *et al.*, 2018). Genetic analyses of specimens collected in different European sites demonstrate a high diversity of the invading populations, especially in Italy (Cesari *et al.*, 2017) and Greece (Morrison *et al.*, 2017), indicating multiple introductions, still ongoing, from native Asia and other invaded countries.

The biological parameters obtained during a 4 years study (2015-2018) keeping the bugs outdoors, show that the peak of overwintering exits is April-mid May; there are two complete, partially overlapping generations, with the simultaneous presence of the different stages of development; the overwintering generation lays on average 285 eggs/female from mid-May to mid-July for the summer generation; are produced by the overwintering generation and 215 by the summer one (R0 = 24.04 and 5.44 respectively for the two generations) (Costi, Haye & Maistrello, 2017); the average life span is about one year for the overwintering generation and 70-80 days for the summer generation. Considerable variability was observed between the various years in the timing of exit from overwintering, of oviposition and development times and on the fertility and mortality values from egg to adult, attributable to the different climatic conditions. These informations together were of immediate practical utility for the advisors and farmers, aiding in decision-making, and they will also be crucial for the elaboration of forecasting models.

A 3-year field survey have shown that in Emilia Romagna egg parasitization (on fresh sentinel egg masses) was on average 1-3%, only by the generalist parasitoid *Anastatus bifasciatus* (Geoffroy) (Hymenoptera: Eupelmidae), and that egg predation was 2-5% (Costi, Haye & Maistrello, 2018). Based on a survey performed in 2019 on naturally laid *H. halys*

eggmasses collected in the province of Modena, overall egg parasitism was 19% and egg predation 3% (Vaccari et al. personal communication). In a laboratory study the tree ant *Crematogaster scutellaris* (Olivier) (Hymenoptera: Formicidae), did not prey on the eggs but proved to be very effective in predating all juvenile stages (Castracani *et al.*, 2017). Other laboratory studies carried out using native European species of different generalist predators collected in nature have shown that young nymphs can be preyed on by some species of Tettigonidae, Reduvidae and Nabidae (Bulgarini, in prep.). Field monitoring presently relies on traps baited with aggregation pheromones that, if properly positioned, can provide some useful information on *H. halys* presence. However efficiency is not so high and damage is higher on the plants surrounding the installation point. The use of substrate-borne vibrational stimuli might favour the development of innovative multi-modal trapping devices as well as other behavioural manipulation approaches (Mazzoni *et al.*, 2017).

From the trials with insecticides it emerged that none of the chemicals tested in the laboratory showed a satisfying efficacy to kill eggs whereas some effects were recorded on emerging nymphs. The semi-field trials showed a certain persistency with a residual effect at 3-7 days, of chemicals belonging to organophosphates, neonicotinoids and pyrethroids, against nymphs and adults of *H. halys*. In open field trials some chemicals show a certain mortality of *H. halys* in the short period, with nymphs more sensitive than adults to sprays.

Among the innovative strategies based on ethology, the "IPM-CPR (Integrated Pest Management - Crop Perimeter Restructuring)" (Blaauw, Polk & Nielsen, 2015), focused on performing insecticide treatments only in the orchards edges, allowed a reduction of 40-50% of insecticidal inputs compared to standard applications on the whole orchard.

Concerning the low impact solutions, exclusion netting proved to be the most effective strategy to prevent *H. halys* infestation and damage on pear orchards compared to uncovered orchards (Caruso & Vergnani, 2019). This technique allows a consistent reduction of chemical sprays and so far it appears to be the only one solution applicable in organic orchards to control the pest. The inundative field trials performed releasing *A. bifasciatus* in small woods/hedges close to productive IPM orchards gave unsatisfactory results, as the average parasitization did not exceed 9.4% in the release area and no significant differences were detected with the control areas (Maistrello *et al.*, 2020).

A survey on field collected *H. halys* egg masses resulted in the detection of adventive populations of the non-native parasitoids *Trissolcus japonicus* and *T. mitsukuuri* (Scelionidae) in almost all northern Italian regions in 2018 and 2019. The procedure for the modification of the Italian regulation to authorize the use of *T. japonicus*, the most efficient BMSB biocontrol agent in China, is currently ongoing, opening up new perspectives for a more sustainable management of this pest in Italy.

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