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Integrated pest management approaches against *Drosophila suzukii*

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Strategie di difesa integrata contro *Drosophila suzukii*

Riassunto. La biologia di Drosophila suzukii impone, per una efficace difesa della coltura, la combinazione di tutti i mezzi di contenimento: agronomici-colturali (gestione chioma, cotico erboso, bordure, raccolta), fisici (reti anti-insetto), biotecnologici (cattura massale, *lure & kill*), biologici (impiego di parassitoidi) e chimici. Nel presente lavoro vengono trattate le possibilità di contenimento di *D. suzukii* da mettere in atto su ciliegio al fine di rendere economicamente conveniente e sostenibile la convivenza tra pianta ospite e fitofago.

Parole chiave: *Spotted Wing Drosophila* (SWD), ciliegio, mezzi di contenimento agronomico-colturali, difesa ecosostenibile.

Introduction

Drosophila suzukii (Matsumura, 1931) (Diptera: Drosophilidae) - Spotted Wing Drosophila (SWD) (fig. 1) is a highly polyphagous invasive pest, native to Asia, which causes significant damage to a wide variety of berry and stone fruit crops (Rota-Stabelli *et al*., 2013). Unlike other *Drosophila* species, which lay eggs in overripe or decaying fruits, *D. suzukii* lays eggs, not only in ripe and ripening fruits, but also in unripe fruits which have not yet been harvested due to the presence of a serrated oviscapt that allows the female to slice the fruit skin to insert the ovipositor and deposit eggs into fruit (Lee *et al.,* 2011; Walsh *et al., 2*011). Among the characteristics that make this insect an important pest for fruit crops, the polyphagy is the most important (Lee *et al*., 2015; Kenis *et al.,* 2016). In fact, this pest can lay eggs on a wide range of cultivated, ornamental and wild fruits, starting from the first spring ripening species up to the last autumn ones, with a demographic growth difficult to contain. Other characteristics are the rapid growth cycle, the high fertility and the ability to develop at temperatures ranging from 11°C (Tonina *et al*., 2016) to 28-30°C (Kinjo *et al*., 2014), when relative humidity is higher than 70% (Tochen *et al*., 2016).

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D. suzukii as a pest for cherry

Among the host range of *D. suzukii*, cherry is reported as the most susceptible fruit (Lee *et al*., 2011; Ioriatti *et al*., 2015) because it ripes in a period without other hosts, and for its chemical-physical characteristics that are suitable for the larval development (Bellamy *et al*., 2013).

D. suzukii infests cherries fruit close to harvest period (fig. 2), damaging the epicarp of healthy fruits and laying eggs in the mesocarp. The larvae cause damages through their feeding activity (Stacconi *et al*., 2013). The ovipositor injuries can also constitute an entry point for bacterial and fungal diseases or other pests (Walsh *et al*., 2011). Severe cherry infestations were reported for the first time in Japan in 1916 (Kanzawa, 1935); recently, on the Japanese peninsula damages ranging from 26 to 100% were quantified, depending on the environmental conditions (Sasaki e Sato, 1995). In the United States, *D. suzukii* caused 26% damage to cherry production for the first time in 2009 (Beers *et al*., 2011). In Italy, in the two years following the first discovery in 2009 (Cini *et al*., 2012), *D. suzukii* caused damage up to

Fig. 1 - Adult (female) of *Drosophila suzukii* with egg (Photo UniPD with Hirox Digital Microscope RH-2000, Simitecno S.r.l.).

Fig. 1 - Adulto (femmina) di Drosophila suzukii *con uovo (Foto UniPD con Hirox Digital Microscope RH-2000, Simitecno S.r.l.).*

Fig. 2 - Cherries infested close to harvest by *Drosophila suzukii* (Photo Tonina).
Fig. 2 - Ciliegie infestate da Drosophila suzukii *in prossimità della raccolta (Foto Tonina).*

90% in late cherry varieties and in orchards located in the hilly areas, with annual losses estimated at 3-5 € million per year (Grassi *et al*., 2011; De Ros *et al*., 2013; Ioriatti *et al*., 2015).

The amount of damage varies among the different areas and it is strongly influenced by the landscape where orchards are located. Generally, infestations are higher at the margins of orchards, near hedgerows and forests, due to high presence of wild host plants that provide food and shelter areas to the insect (Grassi *et al*., 2013; Pelton *et al*., 2016; Santoiemma *et al*., 2018; Tonina *et al*., 2018b). This gradient (fig. 3) must be considered in new orchards design or in insecticide applications (Tonina *et al*., 2018b). Early-ripening cultivars should be preferred at the orchard margin (with less probability of infestation), moreover, the rows should be planted parallel to the source of infestation in order to intercept the individuals coming from the forest on the first rows of plants and then protect the inner part of the orchard. Insecticide applications could be more intense at the margins of the orchard (always respecting the buffer zones indicated on the insecticide label). These considerations suggest the need of management strategy of *D. suzukii* at the agro-ecosystem level and not only to the single orchard. Moreover, *D. suzukii* catches and damages vary broadly depending on weather conditions: years characterized by mild winters and cool and rainy springs are favorable to pest infestation with low mortality in the overwintering period and a strong demographic increase on the first ripening fruits (cherry, *Prunus mahaleb* L., elderberry, blackberry, ...). On the contrary, cold, dry and windy winters followed by hot and dry months harshly limit the development of populations (Sancassani *et al*., 2016).

Integrated management strategies

The integrated pest management (IPM) of *D. suzukii* on cherry is complex because eggs are laid inside the healthy fruit during the ripening close to harvest and the larvae complete their cycle totally

Fig. 3 - Drosophila suzukii infestation trend in Cherry orchard. The color gradation indicates the intensity of *D. suzukii* infestation (darker color means more infested cherries).
Fig. 3 - Andamento delle infestazioni di Drosophila suzukii *all'interno del ceraseto. La gradazione del colore indica l'intensità di attacco da parte di D. suzukii (più è scuro e più le ciliegie sono danneggiate).*

repaired inside the fruit pulp. For this reason, pest management is mainly focused on reducing the adult presence and then protect fruit during ripening.

The biology and the ecology of this pest impose, to obtain an effective crop protection, the integration of several control tools.

The essential prerequisite for a rational IPM strategy against *D. suzukii* is the setup of an adequate monitoring plan inside the cherry orchard and in the surrounding area. Considering that the infestations are not correlated with the number of catches, in addition to the adults monitoring with traps activated with food baits, it is important to control the oviposition on the ripening fruit (Tonina *et al*., 2018a).

Chemical control

An adulticide-ovicide and residual approach is needed because effective control of larvae is not possible. In Europe and the USA broad spectrum insecticides (e.g. OPs, carbamates, pyrethoids, spynosins and diamides) have been shown to be effective (Beers *et al*., 2011; Van Timmeren e Isaacs, 2013; Cuthbertson *et al*., 2014; Profaizer *et al*., 2015; Shawer *et al*., 2018). Prior to SWD invasion, Italian cherry orchards were treated with only two insecticide applications, the first against aphids (Myzus cerasi Sulz.) before flowering and the second against Rhagoletis cerasi, about 20-30 days before harvest. After *D. suzukii* invasion, additional two-three preharvest (close to harvest) insecticide treatments are required (Beers *et al*., 2011; Haviland and Beers, 2012; Shawer *et al*., 2018), but the number of insecticide applications can increase to five-eight depending on pest abundance, crop susceptibility and other environmental factors (Van Timmeren e Isaacs, 2013). The intensive use of insecticides poses serious concerns that residues on fruits will exceed maximum residue limits (MRLs) (Haviland e Beers, 2012), the development of insecticide resistance and negative impacts on the environment beyond beneficials (Asplen *et al*., 2015).

Moreover, rely exclusively on the use of insecticides is not enough to obtain a good and sustainable control of *D. suzukii* since this pest has a fast life cycle, is highly polyphagus and adapted to a wide range of temperatures.

Mass trapping

The aim of mass trapping is to contribute to the containment of the *D. suzukii* damage by reducing the adult population density using numerous traps. However, the effectiveness of this method is limited due to the lack of a highly specific and attractive lure that is able to compete with the ripe fruits in the *D. suzukii* attraction (Ioriatti *et al*., 2015, Tonina *et al*., 2018b). Investigation in North Italy, using Drosotraps® (Biobest) baited with Droskidrink® (Prantil), showed that this method is suitable and cost-effective only for cultivations where the pest pressure is considerably low. This is where orchards are of medium to large size and regular in shape, not surrounded by forest or hedgerow, in a geographically flat area with a hot and dry microclimate (Sancassani *et al*., 2016). To protect orchards, traps should be placed around the perimeter outside the fields (at least 5 m from the fruit trees) (Sancassani *et al*., 2016) (fig. 4). Moreover, insecticides need to be applied to the surface of traps or on nearby fruit to function as an attract-and-kill strategy (Hampton *et al*., 2014).

Insect-proof nets

The use of insect-proof nets has proved effective, reducing or completely replacing the use of insecticides in some instances, and providing high levels of exclusion of *D. suzukii* from the crop. Mesh size should not exceed 1 mm (Grassi *et al*., 2013). The netting needs to be installed after flowering, in the case of cherry to allow pollination, but prior to fruits changing colour and should be kept closed until the end of the harvest (Caruso *et al*., 2017). Different net application methods are available: "single plant", "single row" (fig. 5) or "whole orchard" being the latter the most effective. Indeed, perimeter netting where the farm machinery and fruit pickers can enter and leave through one door guarantees the integrity of the barrier around the orchard. These netting systems can be compromised by workers forgetting to close doors on exiting the orchard or damage to the mesh that is not repaired in a timely fashion (Ghelfi *et al*, 2016; Caruso *et al*., 2017). Although the initial investment is extremely high, it is balanced, on the long term, by the high economic return of fruit and the substantial reduction of potential losses due to *D. suzukii* and adverse weather events (Ghelfi *et al*., 2016).

Agronomic and cultural practices

As already reported, *D. suzukii* prefers fresh and humid microclimates: the vitality of larvae and pupae is lower in hot and dry conditions (Kinjo *et al*., 2014; Tochen *et al*., 2016). Within the canopy, high

Fig. 4 - Cherry orchard with mass trapping tecnique (Photo Tonina).
Fig. 4 - Ceraseto con cattura massale (Foto Tonina).

infestations occur in the inner part, close to the ground or in shady areas (fig. 3). To limit *D. suzukii* damage it is necessary to adopt, inside the cherry-orchard, all those agronomic and cultural practices that are able to reduce the conditions favorable for the pest development. In this view, opening the canopy to increase the airflow and reduce the shading is essential and can be obtained by a proper winter and summer pruning. For the same reason, the rootstock choice and the planting designs should be properly ponderated.

Fig. 5 - Cherry orchard with insect-proof nets (Photo Tonina).
Fig. 5 - Ceraseto con reti anti-insetto monofila (Foto Tonina).

Open canopy also facilitates the penetration of insecticide sprays and allow to uniform the ripening period of fruit in the different parts of the canopy allowing a single and rapid harvest. Row mulching, frequent inter-rows grass mowing, and localized irrigation, which avoids water stagnation, contributes to the humidity reduction inside the orchards (Tonina *et al*., 2017). During the ripening period it is essential to remove the infested fruit or the ripe fruits that fall to the ground or remain on the plants (Lee *et al*., 2011; Shi 2015, Tonina *et al*., 2017) since they represent an important source of new *D. suzukii* individuals (Dreves *et al*., 2009; Walsh *et al*., 2011). The complete collection and destruction must be adopted. For this purpose, fruit could be treated by solarization (inside the closed plastic bags), or disposed in closed containers or buried. The destruction of this important source of *D. suzukii* eggs and larvae is the most important agronomic practice to limit infestations on healthy cherries in late ripening cultivars (Cini *et al*., 2012; Noble *et al*., 2017).

Biological Control

Many generalist natural enemies have demonstrated their capability to attack *D. suzukii* in both European and North American invaded regions: predators, such as some Dermaptera and Hemiptera species, carabid beetles and spiders (Woltz *et al*., 2015; Schmidt *et al*., 2019) and parasitoids (Chabert *et al*., 2012; Rossi-Stacconi *et al*., 2013). Among the latter, several indigenous generalist hymenopterous species associated with the genus Drosophila have been reported able to adapt to *D. suzukii*. The larval parasitoids *Leptopilina heterotoma* e *L. boulardi* (Hymenoptera: Figitidae), under laboratory conditions, successfully parasitized the pest although they could not often develop until the adult instar because of the strong immune response of the host. The pupal parasitoids *Trichopria drosophilae* (Hymenoptera: Diapriidae) e *Pachycrepoideus vindemiae* (Hymenoptera: Pteromalidae) are considered the more effective biocontrol agents since they are less susceptible to the host defence (Chabert *et al*., 2012; Gabarra *et al*., 2015; Rossi Stacconi *et al*., 2015). Augmentative releases of pupal parasitoids alongside conservation of generalist predators might strongly contribute to IPM of *D. suzukii*. Nonetheless, to achieve this result a special attention should be paid to mitigate the possible negative effects related to some current control methods, such as the use of insecticides (Rossi Stacconi *et al*., 2018; Wolf *et al*., 2018).

Entomopathogenic fungi commercially available (e.g. Beauveria bassiana, Metarhizium anisopliae e Isaria fumosorosea) have been able to reduce *D. suzukii* populations under lab conditions (Cuthbertson *et al*., 2014; Cuthbertson e Audsley, 2016), whereas entomopathogenic nematodes (Heterorhabditis bacteriophora, Steinernema carpocapsae, S. feltiae, S. kraussei) seem to be efficient if applied on fallen fruits hosting larvae and pupae of the pest (Cuthbertson *et al*., 2014; Woltz *et al*., 2015). Finally, also entomopathogenic bacteria have recently been demonstrated to exert a toxic effect on *D. suzukii* (Shawer *et al*., 2018) However, field experiments are needed to confirm the potential of these biological control agents in limiting the pest.

Conclusions

The biology and ecology of *D. suzukii* impose, for effective crop protection, the integration of all the pest control tools (Van Timmeren and Isaacs 2013; Haye *et al*., 2016, Tochen *et al*., 2016). First of all, it is necessary to adopt all those agronomic and cultural practices aimed at hampering the development of *D. suzukii* such as pruning, mowing, orchard margin management and the abandonment of ripe fruit. From ripening, the use of mass trapping helps to reduce the pest population density; the use of insect-proof nets, that guarantees effective control, must be subjected to a prior economic evaluation. Problems related to pesticide residues and their side-effects on the environment, require careful management of chemical treatments. In fact, insecticide applications must be limited to the periods of higher infestation. Moreover, it is important to plan a rapid and proper collection of all infested fruits.

In the near future, it is desirable that *D. suzukii* infestations can find an effective limitation with other biotechnological and biological tools; many hopes are posed on the adaptation of native parasitoids and on the authorization to release those present in the areas of origin of *D. suzukii*.

The IPM of *D. suzukii* requires a holistic approach that must involve the entire food chain, from the integrated production (fig. 6) to the transport in controlled temperature conditions, to the storage and distribution phases, where short thermal shocks have been observed (0.5°C for 24 hours) can block current infestations and prolong the shelf life of fruits (Saeed *et al*., 2018).

The research for tools to contain the *D. suzukii* populations is extremely challenging due to the high biological performance of the species. The eradication of the pest from areas where it is already present

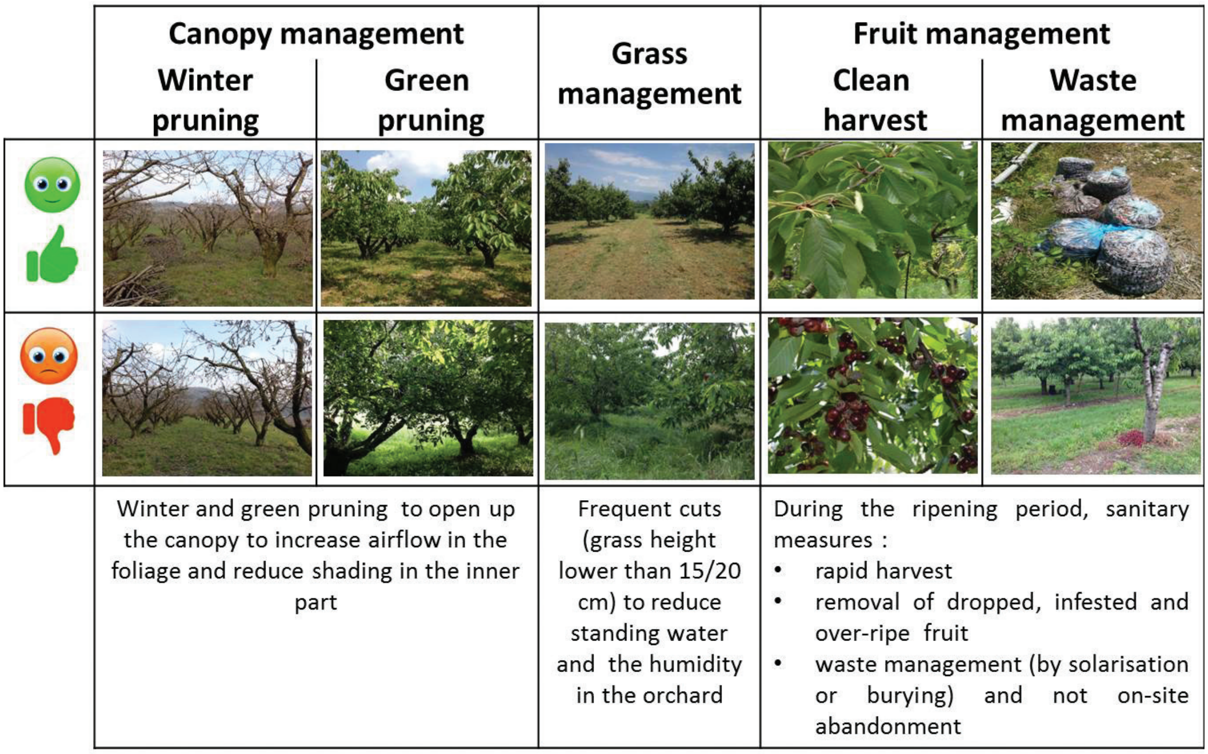

Fig. 6 - Tecniche di produzione integrata per il contenimento di *Drosophila suzukii*
Fig. 6 - Integrated production techniques for Drosophila suzukii control

is impossible (EPPO 2018), therefore it is necessary to integrate all the possible strategies for the continuous suppression of populations to reduce further infestations.

Abstract

The appearance of *Drosophila suzukii* in 2009 has strongly affected the cherry cultivation. Prior to SWD invasion, Italian cherry orchards were treated with only two insecticide applications, the first against aphids (*Myzus cerasi* Sulz.) before flowering and the second against *Rhagoletis cerasi*, about 20-30 days before harvest. After *D. suzukii* invasion, additional two-three pre-harvest (close to harvest) insecticide treatments are required, but the number of insecticide applications can increase to 5-8 depending on pest abundance, crop susceptibility and other environmental factors. The intensive use of insecticides poses serious concerns about the presence of residues on fruits exceeding maximum residue limits (MRLs), the development of resistance, and negative impacts on the environment beyond beneficials. To obtain a good and sustainable control of *D. suzukii* the chemical strategies should be coupled with cultural management the use of nets and parasitoids. To achieve good control of the carpophagus it is essential to monitor, as well as the adults with trap lured with blends of fermentig substances, the oviposition on the ripening fruit, because the percentage of infestation is not related to the number of catches in the food traps. Considering the viability of SWD eggs and larvae is lower under dry, warm conditions, cool humid microhabitats should be avoided by pruning to open up the canopy in order to increase airflow on the trees and reduce shading. In addition, the use of mulches reducing standing water can further contribute to the reduction of humidity in fruit orchards. Precision irrigation should also be incorporated to reduce pooling of water on the ground. Mass trapping, placing numerous traps around the perimeter outside fruit fields, is suitable and cost-effective method only for cultivations where the pest pressure is considerably low, if necessary insecticides could be applied to the surface of the traps to function as an attract-and-kill strategy.
Among the sustainable protection techniques for the control of *D. suzukii*, the use of insect-proof nets has proved effective, reducing or completely replacing the use of insecticides in some instances, and providing high levels of exclusion of *D. suzukii* from the crop.
During the ripening season, sanitary measures such as removal of dropped, infested and over-ripe fruits is suggested. The collection and treatment of infested fruit through sun exposure, disposal in closed containers, crushing, low temperature treatments, bagging and burying, to destroy *D. suzukii* eggs and larvae are

essential IPM procedures to limit the infestation of healthy fruit. The augmentative release of parasitoids and conservation biocontrol of generalist predators, potentially, could contribute to the integrated management of *D. suzukii* populations, especially in natural habitats close to commercial crops, however further work on the effectiveness of native parasitoids and generalist predators in Europe and the USA, in the field, is required. In this paper, the integration of different tools for *D. suzukii* control will be discussed, in order to develop effective, eco-friendly and practical strategies in the management of the pest on cherry.

Key words: Spotted Wing Drosophila, Cherry, Cultural management, Eco-friendly control strategies.

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