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AN OVERVIEW OF THE AVAILABLE MEASURES FOR THE CONTROL OF *DROSOPHILA SUZUKII* (DIPTERA, DROSOPHILIDAE)

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ABSTRACT

The spotted wing drosophila (SWD), *Drosophila suzukii* Matsumura (Diptera: Drosophilidae), is considered a significant invasive polyphagus pest of soft-skinned fruit, including raspberries, strawberries, blackberries, figs, blueberries and cherries. Apart from ripening fruits, *D. suzukii* females lay eggs in numerous wild fruits as well. In the Republic of Serbia, it was detected for the first time during October and November 2014, where it endangers the production of raspberries, one of the most important fruits for the country. Considering a high reproductive rate and short generation time, easy and fast-spreading due to global trade, and a suitable climate with the presence of host plants year-round contribute towards making this pest a serious threat to the reduction of quality and yield of growing fruit. Current control efforts rely mostly on the use of chemical insecticides. In addition to insecticides, sanitary measures and mechanical control are used to control this pest, which is an indispensable and important stage in safe fruit growing. This article provides an overview of the impact of *D. suzukii* on fruit production and establishes available measures and strategies for its control in the Republic of Serbia.

Keywords: *Drosophila suzukii*, *chemical control, mechanical control, monitoring, traps*.

INTRODUCTION

Drosophila suzukii Matsumura (Diptera: Drosophilidae), spotted wing drosophila (SWD), is a polyphagous invasive pest that affects fruit production of stone and, especially berry fruits. Unlike most other Drosophila flies, which lay eggs in fallen, or rotting fruit, owning to the fact that, they can not penetrate the skin of the fruit, in contrast, the SWD females lay eggs in ripening, intact fruits. SWD is widely distributed in regions from Japan to Pakistan, with temperate climates. Due to the global fresh fruit trade, combined with the cryptic nature of the larvae in fruit, it has gradually spread to other parts of the world (Walsh, 2011). *Drosophila suzukii* has spread to Europe, Asia, Africa, America and Oceania. In North America, the first record of SWD was in 2008 in California. Its distribution in the USA has since

increased significantly (Burrack et al., 2012). The first record in Europe was in Spain during 2007. It then quickly spread to other parts of Europe and soon after, it was reported in other European countries including France, Austria, Germany, Belgium, etc. (Cini et al., 2012). Presence in the region was first recorded in Croatia in 2011 on the traps placed in raspberries, peaches, and grapevine (Milek et al., 2011). In Bosnia and Herzegovina SWD was first found in 2013, in several sites in Herzegovina (Ostojić et al., 2014). On the territory of Serbia (Figure 1), the SWD was first registered in 2014 in four sites (Rasinski, Mačvanski, Raški, and Pčinjski) as well as in Zemun (Belgrade) in sampled raspberries, blackberries, figs and grapes (Toševski et al., 2014). During 2016, in the region of Kraljevo, Užice, Čačak, and Novi Sad first flies were registered and captured in traps. During September of the same year, in 29 regions of Serbia, the presence of flies in traps on various types of fruit was determined at 90 localities (Budić and Janković, 2016). Since 2011, *D. suzukii* is listed on the European and Mediterranean Plant Protection Organization (EPPO) A2 list of quarantine pests.

Figure 1. Distribution of *D. suzukii* on the territory of Serbia in 2014 (Toševski et al., 2014)

Biology and Ecology of *Drosophila suzuki*

In addition to larvae, which cause direct damage by feeding on the fruit pulp, the females also cause damage when laying eggs giving the fact that an oviposition scar is a suitable place for the attack of other pathogens and insects which cause additional damage to the fruit and increase economic loss due to reduced quality (Walsh, 2011). The larvae develop and feed inside the fruit, which increases the sugar content, followed by fruit changing color and softening which reduced the market value. The SWD is a polyphagous pest with a broad host range that can infest many fruit crops, over 80 from 19 different families. It can also infest wild

and ornamental plants, including Honeysuckle (*Lonicera spp*.), wild Brambles (*Rubus spp.*), Mulberry (*Morus rubra*), Elderberry (*Sambucus spp.*), and others (Kenis et al., 2016). It most often infests thin-skinned fruits such as blackberries, raspberries, blueberries, strawberries, figs, cherries, and various types of grapes. It also attacks fruits with harder skin including peaches, plums and apricots but previously damaged. Differences in sensitivity between different fruits, but also the varieties themselves, are influenced by various factors such as soluble sugar content, pH, thickens of the skin and fruit penetration force for puncturing the skin (Rajinder and Stelinski, 2017; Shrader et al., 2018; Walton et al., 2019). The most economic impact was recorded on raspberries, blackberries, strawberries and cherries, where during strong attack loss of yield percentage can go to 80%, even 100%. High reproductive capacity and short generation time, with the possibility of developing up to 13 generations per year contributes to its rapid spread (Tochen et al., 2014). Adults mostly occur in the first half of April, or even earlier (unpublished data), during March. They are most numerous in the period May-June and September-October.

Figure 2: Female (left) and male (right) (Bošković, 2020)

SWD adults are small, 2-4 mm long with characteristic red eyes (Figure 2). Females are usually larger than males. They are mostly confused with *D. melanogaster*, but the SWD adults are larger than the fruit fly. Males have one dark spot on the edge of the both wings, while females do not. Another important male feature is the presence of one row of black combs on the first and also one row on the second tarsal segment. Femalse don't have these these two rows of combs. The females main feature is large serrated ovipositor, which ables them to penetrate the fruit skin is saw-like with serration that are pretty darker then the rest of the ovipositor. The female lay eggs generally from April to November (Mitsui et al., 2010). During their lifetime, female can lay up to 300 eggs. In the same fruit different females can lay eggs (Hauser, 2009; Rajinder and Stelinski, 2017).

The eggs are oval, milky white with two aeropiles at one end (Figure 3). It takes 2 to 72 hours for the larvae to hatch from the egg. Larvae are cylindrical, milky-white with black mouthparts (Figure 3). The complete development take place inside the fruit. Larvae go through three instars before pupation process. It takes from 3-13 days for larvae to mature, depending on the temprature. The larvae are the most harmful because they feed inside the fruit, which leads to its decay. Pupation can take place inside the fruit, or on its surface as well as in the soil. The pupal stage lasts from 4 to 5 days. Pupas are brown (Figure 3), spindle-shaped, with two small finger-like projections at the end (EPPO, 2013; Van Timmeren et al., 2017; Rajinder and Stelinski, 2017).

Figure 3. Eggs (left), larvae (center) and pupa (right) (Bošković, 2022)

SWD favors a moderate climate but it can, as well, survive in a colder environment. The life cycle, from egg to adult, ranges from about 9-10 days at higher temperatures (24-26 °C) (Kanzawa, 1939). SWD overwinter in the stage of adults in the leaf litter that ensures protection from cold conditions. Flies get mobile above 5 °C, and if the average temperature is above 10 °C they start to become active (Hamby et al., 2013; Tochen et al., 2014). The only reliable stage for identification is adult, where the identification of males is even possible just by observation if the dark spots on the wings are visible, while for the identification of females it is necessary to observe them under a certain magnification (Walsh et al., 2011). The dark spots on wings, as well as two sets of black tarsal combs for males and serrated ovipositor for females, make the identification of *D. suzukii* easy, especially on the European continent because no other species of Drosophila, present in Europe have similar morphological features.

Monitoring of Drosophila suzuki

Prosperous agricultural production and prevention of damage caused by this pest require the utilization of fly traps which can be used for mass traping and monitoring. In this way, data collected through traping enables the monitoring of population dynamics and thus ensures timely and effective control of this pest.

Due to the high reproductive rate, short generation time, and fast spreading, the early warning system is of exceptional importance, especially in those regions where its presence has not yet been established. By trapping, it is not possible to

determine the precise population density of *D. suzukii*, due to the fact that traping is affected by various factors such as climate conditions like temperature and precipitation, environmental factors in the site where traps are placed (presence of fruit, is the overwintering habitat nearby, whether are traps installed correctly, is the baitsfresh and properly stored) (Clymans et al., 2019). Sampling by trapping allows only approximate values assessment of population density.

Monitoring and trapping of *D. suzukii* adults in orchards and vineyards can be done using different traps. As a bait, a mixture of yeast, sugar, and water can be used; fruit purees, different types of vinegar, wine, a mixture of ethanol, acetic acid and phenyl ethanol. At the beginning of its distribution on the European continent, there were no specialized traps for catching them, but in the last few years, these kinds of traps can also be found on the European market (Walsh et al., 2011). The traps should be placed no later than one month before the fruit ripening begins, although some individual flies are caught already in March or even in November, i.e. when the temperature is above 10℃ for several days. One of the traps used for mass trapping and monitoring of the SWD is Drosal Pro. Both females and males are caught in this trap, as well as other species of Drosophila sp., while other non-target insects are caught only sporadically. They are very simple to use and can be used repeatedly in all types of orchards. The most commonly used bait is based on a mixture of apple and wine vinegar, which is poured into plastic bottles, representing an improvised trap (Lee et al., 2011). The advantage is the simplicity of application, low price, and easy availability. These traps can be easily made at home from ordinary water bottles (Figure 4). The main disadvantage is reflected in their reduced selectivity because many other non-target or beneficial organisms can be caught as well. This problem can be overcome by reducing the hole size on the bottles, which at the same time affects the reduction of the evaporation of the bait, due to which the bait remains fresh and attractive for a longer period of time. Trap design is very simple. About 6 small holes are made on the upper third of the one-liter plastic water bottles, the smaller the holes, the greater the selectivity. The easiest way to make the holes is by piercing them with a red-hot nail, making sure that the diameter is no more than 5 mm. On the top part of the bottle, cut a larger opening (4x3 cm) through which the smell of the bait can spread. It is necessary to cover the opening with a fine mash in order to prevent other insects from trapping inside. In orchards, the traps are placed along the plot's edges (5-10 m apart one from another) in shaded parts of the crown. The height of traps should be at the same level as fruits (e.g. for raspberries at the height of 30-120 cm; for cherries at a height of 1-2 m) (PIS Vojvodina, 2018). The lure of SWD traps can be increased by alternating taping black and red tape in the lower half of the bottle. The SWD is attracted to the contrast between dark and light colors, such as black/green and red because they mimic the contrast between the leaf surface and the fruit (Basoalto et al., 2013). Intervals of monitoring and replacement of traps should be done at least once a week (Walsh, et al., 2011; EPPO, 2013; Tran et al., 2020).

Figure 4. Improvised traps for trapping SWD (Bošković, 2020)

As the season progresses and different fruits ripe, the same bottles can be switched from one to another crop. A mixture of apple and red wine or wine vinegar in a ratio of 1:1 (150 ml:150 ml) can be used as bait. A few drops of soap liquid should be added with the aim of reducing surface tension (eg dish detergent) in order to ensure submersion of the flies. A mixture of ethanol and acetic acid can also be used as bait, but in field conditions, they proved to be less effective than a mixture of wine and apple cider vinegar (Landolt et al., 2012).

At the beginning of the season, females are looking for a place to feed, which means that fermentation smells from the trap are more attractive to them in that particular time. For oviposition, females are searching for the smell of ripe fruit, which explains the lower number of female flies in traps before harvest compared to the beginning or end of the season, even though the number of females present in the orchard is just as high (Clymans, et al., 2019). In addition to the smell of the fruit, the SWD is also attracted to beta-cyclocitral from the leaves (Max Planck Society, 2015). Visual stimuli, such as the intensity of colors and their contrast also affect this fly, which explains the recommendation for control not to be before the coloration of the fruit begins (Walton et al., 2019). Females prefer fruits with a higher pH value, while high acidity repels them. They are also attracted by the high sugar content because larvae develop much faster in such fruit (Wang et al., 2019).

Preventive measures for the control of *Drosophila suzuki*

It is very important to know the pest biology, i.e. the way it overwinters, the preference in choosing fruit for oviposition, spatial and temporal distribution (when and where they were first recorded; when the first adults were observed; the number of flies captured in the traps; the degree of last year's attack, climate conditions, etc.) in order to assess the impact on the yield and to manage right the control plan given the above stated, in a timely manner (Cini et al., 2012; Tonnang et al., 2017). It would be optimal to implement all available preventive measures (mechanical and agrotechnical measures) before applying chemical control, in

order to reduce economic losses and pesticide application. Keeping hygiene, in and around the crop, are very important preventive measures when fighting against this pest, which also includes weed control in these areas. Special tendance should be aimed at the control of wild elderberry (*Sambucus nigra* L.), blackberries (*Rubus fruticosus* L.), strawberries (*Fragaria vesca* L.), and black nightshade (*Solanum nigrum* L.). Hygiene within the orchard refers to the removal of rotten, overripe, and infected fruit that can be a food source or a potential breeding site. Such fruits must be destroyed by burying, solarizing, chemical treatment, or physically by placing them in plastic bags that need to be left in the sun for a few days since larvae are very sensitive to high temperatures. Also, attention should be paid to maintaining the hygiene of all agricultural machinery, tools, and other equipment used during the year. Covering the orchard with insect nets with a diameter of 0.98 mm also gives excellent results. Tillage is recommended in order to kill overwintering forms. Preference should be given to varieties with a harder skin of the fruit and traps should be set for regular mass hunting.

Chemical control of *Drosophila suzuki*

Currently, the control strategy of *D. suzukii* heavily relies on the application of insecticides. Taking into account that the greatest damage appears right before the harvest, chemical control is not recommended due to the high risk of a residues in the fruits. Also, there is a danger for the insect resistance development, as well as, manifestation of pesticide side effects on pollinators and other beneficial organisms (Cini et al., 2012). In Europe, insecticides from the chemical class of pyrethroids, organophosphates, spinosyns, and neonicotinoids are mostly used to control SWD (Shaw et al., 2019). Currently, in the Republic of Serbia, for this purpos, three insecticides are registered (Table 1).

The insecticide based on deltamethrin as an active ingredient, which shows contact and digestive effect, was the first registered. However, the limitation of its application is the prohibition on its use during pollinator flight, as well as the fact that it must be adapted to those regions where resistance to deltamethrin or another pyrethroid has not been recorded. Since 2021, two more active ingredients have been registered. The first, which is based on spinosad, for the used in strawberry, raspberry, blackberry, blueberry and cherries plantations, and the second based on spinetoram for the use in raspberry, blueberry, strawberry, cherries and currant crops (Petrović i Sekulić, 2023). It has already been recorded in the USA and Greece that the SWD can develop resistance to these two insecticides (Van Timmeren et al., 2019; Disi and Sial, 2021).

Table 1. Registered insecticides in Serbia for control of the SWD (Petrović and Sekulić, 2023)

Insecticide	Fruit	Application rate	Application time	Max. number of app.	PHI* (days)
Deltamethrin (EW; 15 g/l a.i./l)	Sour cherry	0,5-0,7 l/ha	At the beginning of fruit ripening	1	7
	Strawberry	0,5-0,7 l/ha		2	3
	Raspberry				14
	Blueberry	0,5 l/ha			7
	Grapevine	0,5-0,7 l/ha			14
Spinosad (SC; 480 a.i. g/l)	Blueberry	0,1-0,2 l/ha	Beginning of ripening or fruit colouration (81-85 BBCH)	2	3
Spinosad (SC; 240 a.i. g/l)	Blueberry	0,1-0,2 l/ha	Beginning of ripening or fruit colouration (81-85 BBCH)	2	3
	Strawberry	0,3 l/ha			1
	Raspberry	0,4 ml/ha			3
	Blackberry				3
	Sweet/sour cherry		Beginning of fruit colouration (59-85 BBCH)	1	7
Spinetoram (SC; 25 a.i. g/kg)	Raspberry	2,4 l/ha	First true leaf, until second harvest: most fruits are colored (11-89 BBCH)	1	7
	Blueberry			1	7
	Currants			1	7
	Strawberry	2 l/ha		1	7
Spinetoram (WG; 250 a.i. g/kg)	Sweet/sour cherry	0,3 kg/ha	At the beginning of larvae hatching	1	7

*PHI – pre-harvest interval

With the aim of reducing the use of chemicals to control this pest, an arsenal of biological control measures is emerging, like the employment of biological control which is based on the use of natural enemies (parasitoids, predators, parasites, pathogens, mycotoxins, antagonists or competitors) (Vuković i Šunjka, 2021; Šunjka and Mechora, 2022). Besides this, an emerging topic in the field of SWD control are bioinsecticides based on essential oils as biologically active agents. These bioinsecticides have the potential to play a significant role in organic and integrated pest management approaches, thereby reducing the need for chemical insecticides (Bošković et al., 2023).

CONCLUSION

Large economic damages and the rapid spread of the invasive pest *D. suzukii* represent a challenge for fruit production in Europe. Effective control of *D. suzukii* in agricultural production requires major efforts at the local and global level. For the successful control of SWD, it is necessary to follow the instructions of the reporting services, as well as to monitor own catch in traps, so that the optimal treatment period can be reached on time. It is necessary to apply all available preventive measures, which include agrotechnical and mechanical, to reduce the spread and infestation, which can significantly reduce the number of harmful organisms. Pay special attention to sanitary measures, which include maintaining the hygiene of fields, non-agricultural areas, tools, machines, crates and other tools that come into contact with fruit. When choosing varieties, give preference to more resistant or tolerant varieties and healthy planting material. Infected or overripe fruits must be destroyed regularly and never be used for composting. Installing insect netting with small openings also provides good protection. Traps should be used for mass hunting and monitoring, and chemical control should be used only under justified conditions.

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