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Effect of a sour cherry orchard on the population dynamics of Spotted Wing Drosophila in an adjacent elderberry plantation

Egy meggyültetvény hatása a pettyesszárnyú muslica populációdinamikájára szomszédos bodza ültetvényben

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ABSTRACT

The Spotted Wing Drosophila (*Drosophila suzukii* Matsumura, 1931 - SWD) became a crucial pest of soft-skinned fruits in less than a decade in different continents, including Europe. The larvae of the polyphagous pest can develop within the fruits of several food plants, including wild and cultivated elderberry. Due to their high mobility, the imagoes can shift between the orchards following the different ripening periods of fruits. Our study aimed to test this phenomenon in neighbouring sour cherry and elderberry plantations. The swarming phenology of SWD and related drosophilid populations was monitored by trapping the SWD imagoes using bottle traps with apple cider vinegar as a lure. At the same time, fruit infestation rates were determined by rearing the flies from the collected fruits. Our results have shown that SWD imagoes emerged in great numbers from the remnants of the early ripening sour cherry fruits and colonised the neighbouring elderberry plantation from its adjacent side. According to our results, early-ripening fruits are essential sources for the infestation of neighbouring late fruit orchards; thus, eliminating their fruit residues may lower the infestation rate of adjacent plantations.

Keywords: Spotted Wing Drosophila, mixed production, elderberry, sour cherry, infestation rate

KIVONAT

A pettyesszárnyú muslica (*Drosophila suzukii* Matsumura, 1931) kevesebb, mint egy évtized alatt a puha héjú gyümölcsök jelentős kártevőjévé vált több kontinensen, így Európában is. A polifág kártevő lárvája képes számos tápnövény termésében kifejlődni, többek között vadon termő és termesztett bodzában. Nagy mozgékonyságuknak köszönhetően, az imágók képesek váltani a különböző időben érő gyümölcsök ültetvényei között. Kutatásunk célja e jelenség vizsgálta volt, egymással szomszédos meggy és termesztett bodza ültetvényekben. A pettyesszárnyú muslica és vele rokon Drosophilidae fajok rajzásfenológiáját vizsgáltuk, az imágók almaecetes csapdázásával. Ezzel párhuzamosan, az imágók termésekből való kinevelésével, meghatároztuk a károsított gyümölcsök arányát. Eredményeink szerint, a kártevő imágói nagy számban fejlődtek ki a korán érő meggy betakarítását követően az ültetvényben hátrahagyott termésekből, így kolonizálva a szomszédos bodza ültetvényt. Vizsgálataink alapján, a korai érésű gyümölcsök jelentős forrásai a szomszédos, későn érő gyümölcsű ültetvények kártételének. A gyümölcsmaradványok ültetvényből való eltávolítása csökkenti a szomszédos ültetvények kártételi nyomását.

Kulcsszavak: pettyesszárnyú muslica, vegyes ültetvény, bodza, meggy, kártételi ráta

INTRODUCTION

The Spotted Wing Drosophila – SWD (*Drosophila suzukii* Matsumura, 1931) is an invasive alien vinegar fly derived from East Asia and introduced into Europe in 2008. It is the eighth species in a row from the genus *Drosophila* unintentionally introduced to the continent, and it became the most noxious among them (Poyet et al., 2015). Unlike native drosophilids, the females have serrated ovipositors, enabling them to oviposit into intact ripe fruits. The larvae develop inside the fruits, spreading microbes, especially yeasts, and causing soft rot. In Europe, high infestation rates are found in several fruit species (Orsted et al., 2021). SWD became a key pest of cherries in Toscana, Italy's leading cherry production area (Gargani et al., 2013). Two years after its appearance, the annual loss in late cherry varieties reached 90%, with a cost of 3–5 million EUR in the mountainous orchards of Italy (Shawer et al., 2018). In the western states of the USA, damages reached 80% annual loss in the cherry, strawberry and blueberry production (Klick et al., 2016). In Japan, the damage was between 26–100% in sweet cherries in 1995, depending on the localities. *Drosophila suzukii* is a polyphagous pest; the females may oviposit into the ripening fruits of more than 145 plant species (Orsted et al., 2021). Thin-skinned berries and several stone fruits are mainly susceptible to infestation. Cranberry, blueberry, strawberry and cherries are among the common hosts of the species (Asplen et al., 2015). Wild host plants are also available for SWD, e.g. *Rubus fructisosus* Linné, *Cornus* spp., *Eleagnus* spp., *Sambucus* spp. (Cini et al., 2012). These plants are common in the field margins and can act as sheltered places and help the population establishment (Santoiemma et al., 2019). For instance, spill-over of SWD between non-crop and crop areas is evidenced by Tonina et al. (2018). In the study of Bühlmann and Gossner (2022), in *Sambucus nigra* Linné, the SWD infestation rate reached 83%. In the work of Kenis et al. (2016), Frangula alnus Miller, and *Sambucus nigra* Linné were the two plants from field margins from which the SWD imagoes emerged in the highest numbers. Mixed-crop systems have significant advantages for SWD population increase because the resources are available longer due to the different ripening periods and the proximity of the various crops (Harris et al., 2014). The cultivated elderberry (*Sambucus nigra* Linné) is an essential crop in its habitat range and North America. The wild elderberries are common in forest edges, hedges and field margins (Ulmer et al., 2022). Elderberries are well-known food plants of SWD. In a former study, the average infestation rate was 0.11 specimen/berry, with a 0.33–1.00 abundance rate of the infested corymbs. The infestation rate was not correlated with the precipitation but positively correlated with the latitude (Ulmer et al., 2022). During fruit ripening, the oviposition rate increased as the fruit sap's pH level increased and the fruit skin penetration force decreased (Krutzler et al., 2022). The colour preference increased from green to red and black elderberry berries, and the colour of the berries significantly affected the number of emerging imagoes (Ulmer et al., 2022).

The climatic factors can highly affect the phenology of SWD. The most severe damage occurs when fruit ripening coincides with the SWD's peak population size (Kiss et al., 2016). Due to the continental climate of Hungary, the overwintering population of SWD is small, and the population starts to grow only in the middle or at the end of summer. In the work of Orsted et al. (2021), testing different environmental predictors, the temperature extremities seemed critical to the abundance of SWD. The activity of SWD imagoes was strongly dependent on the temperature. When the air temperature reached 34 °C, the catches remained relatively low. When the temperature dropped below 30 °C, the number of catches started to increase, and below 18 °C, decreasing captures were observed again (Nikolic et al., 2022). Other studies investigated deciduous forest habitats, revealing that the daily maximum temperatures significantly impacted the monthly SWD trap captures (Harris et al., 2014). The SWD used the margins more frequently where alternative food plants were present. The captures were significantly lower in the margins where suitable food plants were absent. In sweet cherry orchards, the traps near the forest edges caught significantly more SWD than those far from the forest (Hennig and Mazzi, 2018). On average, the SWDs were captured one week earlier when the forest represented more than 10% of the landscape (Pelton et al., 2016). SWD was first found in Hungary in 2012 (Kiss et al., 2013). Substantial damages have been reported since 2016 in blackberry and autumn raspberry but not in cherry or sour cherry. Hungarian growers have complained about economic losses in elderberry; however, these cases have not been documented. Our study aimed to evaluate the population dynamics of SWD in the cultivated elderberry for the first time in Hungary and to explore the sources of the pest in a multiple-fruit orchard system.

MATERIALS AND METHODS

The experimental orchards belonged to an intensive fruit production farm (sour cherry, sweet cherry, elderberry and apple). The farm lies in Tolna county (Hungary). The area of the experimental elderberry (Haschberg variety) orchard was 57000 m^2, with sour cherry ("cigánymeggy" C7, 59 types) orchards in the neighbourhood and a hedge margin consisting of wild elderberry bushes and arable fields on the other side (Figure 1). Conventionally permitted pesticides were used in both orchards in the experimental years.

In 2021, the traps were set in the sour cherry in the 3rd row, on the 4th, 7th, 10th, 13th and 16th trees, and in the 3rd, 5th, 12th, 14th, 20th and 22nd rows of the elderberry from the sour cherry parcel, on the 4th, 7th, 10th, 13th and 16th bushes. Five traps were set to every row, and the first trapping period started on 22 June 2021. The last traps were collected on 29 September 2021. In 2022, the traps were placed in the sour cherry into the 3rd and 8th rows, onto the 4th, 7th, 10th, 13th and 16th trees, in elderberry into the 5th, 10th, 15th and 22nd rows, onto the 4th, 7th, 10th, 13th, and 16th bushes and the first trapping period started on 28 June 2022. The last traps were collected on 15 September 2022. The traps were made from 0.5 litre PET bottles with 16 (4×4) holes (2 mm diameter) drilled into the neck of every bottle (Figure 2). Apple cider vinegar (5% acid content) was used as bait and kill. The traps were placed 1.5 meters above the ground inside the canopy. Five traps were also set outside the orchard, into the hedged margin, and hung to the wild elderberry bushes.

The traps were changed by fourteen-day-long trapping periods. The collected traps with sealed holes were transported into the laboratory.

Figure 1. Location of the experimental orchards in 2021 and 2022

Figure 2. The apple cider vinegar trap

Determination of the fruit infestation rates

In both years, sour cherry and elderberry fruits were collected from the orchards. The collections were synchronised to the trapping periods, and the starting and finishing dates depended on the fruits' ripening and harvesting times. Ten sour cherry fruits were collected from each tree where the traps were hung. In the case of the elderberry, one corymb (diameter ~10 cm) was gathered from each of the bushes where traps were placed. The berries were put in a dense mesh bag, and all the arthropod predators were discarded from the bags at the spot before transportation to the laboratory. The collected fruits were placed in cylindrical glass jars (145 mm in diameter, 180 mm in height) on cotton underlay and covered with paper towels. The pots were kept at LD: 14:10, T = 22 °C, RH = 60%. After 14 days, the emerging flies were collected and identified.

Collecting meteorological data

Climatic parameters (T [°C], RH [%]) were measured and recorded with a Dostmann TFA Klimalogg Pro data logger. The frequency of measurements was set to one hour for the duration of the study. The logger was placed in the elderberry bush into the 10th row within a PET bottle with several holes to ensure continuous airflow.

Evaluation of the bottle trap contents

The bottle trap content was poured into large Petri dishes. *Drosophila suzukii* imagoes and all other specimens from the family Drosophilidae were counted under a stereo microscope (Olympus SZ61).

Statistical analysis

The trap results of the two years were treated separately. Statistica v.14 software (TIBCO Software Inc. (2020) Data Science Workbench, version 14.) was used for statistical analyses. The effect of the trap distance from the cherry orchard and the trapping periods on the SWD catches and SWD proportions in the cultivated elderberry plantation were tested using the GLM (General Linear Model). The rows represented the trap distance. In 2021, the 3rd and 5th rows, 12th and 14th, 20th and 22nd rows were treated as three coupled values.

RESULTS

Trap catches of drosophilids

In 2021, 5825 SWD and 2987 other drosophilids were caught, respectively. In 2022, the total capture of SWD was 6812, and the capture of other drosophilids was 1183 (Table 1).

Table 1. Mean catches of drosophilids in the bottle traps in 2021 and 2022

Trap setting date	Period code	SWD in cherry	Drosophilidae in cherry	SWD in elderberry	Drosophilidae in elderberry	SWD in field margin	Drosophilidae in field margin
22 June 2021	June2	0.0	7.6	0.1	2.8	0.0	13.2
08 July 2021	July1	0.2	5.2	0.0	5.5	0.0	18.2
21 July 2021	July2	9.0	4.4	0.3	3.0	0.2	11.6
04 August 2021	August1	15.8	10.4	3.0	3.7	4.8	5.4
17 August 2021	August2	41.4	12.8	9.7	4.2	9.2	6.4
01 September 2021	September1	70.2	25.0	28.4	10.7	26.0	14.0
15 September 2021	September2	136.4	50.4	87.4	33.0	78.6	35.2
28 June 2022	July1	5.9	4.8	0.4	1.3	0.0	5.2
14 July 2022	July2	22.1	5.0	2.4	1.2	1.0	1.0
28 July 2022	August1	40.8	13.8	5.6	1.9	2.2	3.6
09 August 2022	August2	13.3	2.7	3.5	1.3	3.6	2.8
23 August 2022	August3	27.3	2.4	0.9	1.7	1.4	1.4
02 September 2022	September1	146.8	35.8	43.1	14.4	21.6	7.0

Results of 2021

In the sour cherry plantation, the traps collected 1365 SWD and 579 other drosophilids. The first SWD, only one male, appeared in the first half of July. Later on, the captures of SWD increased, and most specimens were collected in the last two weeks of September. The bulk of the SWD catches occurred in the autumn, with 25.7% occurring in the first two weeks and 49.9% in the last two weeks of September.

In the field margin on the other side of the elderberry plantation with wild elderberry bushes, 594 SWDs were found with 520 other drosophilids during the trapping season. The first SWD was collected in the second half of July, with one female and 58 other drosophilids. After this period, the number of catches increased. By the end of September – the last trapping period – the number of collected SWDs reached 393. The bulk of the catches occurred in the autumn. 21.9% of the catches occurred in the first two weeks and 66.2% in the last two weeks of September.

In the elderberry plantation, the first two SWD catches occurred in the first trapping periods; however, the catches remained low until August.

Results of 2022

The first SWD catches occurred in the sour cherry in July1 (the start of the trapping period), with 59 specimens and 48 other drosophilids. The catches increased from that date, with a slight drop in mid-August. The total SWD catches were 2562. Most of the catches occurred in September (57.3%). The number of other drosophilids caught was 658. The trapping trend followed the pattern of the SWD, but the numbers remained low. By the end of the season, the proportion of SWD increased.

In the field margin, there was no catch at the beginning of the season (July1). The first SWDs were captured in July2. The numbers remained low; only 149 SWD were captured during the season. Most of them were caught in September (72.5%). The number of other drosophilids was also low but higher than SWD in the first three trapping periods. The traps caught 105 drosophilids in total.

In the elderberry, the total SWD catches were 1114. The season started with seven specimens in the first trapping period. Then, the catches began to increase. A drop was also experienced in the catches at the end of August. This drop can be seen everywhere; even though the elderberry orchard was watered, the cherry and the field margin were not. The bulk of the SWD catches occurred in September; 77.4% of the SWDs were caught then.

The number of the other drosophilids was also low during the experiment in the elderberry orchard, and the proportion of the SWD in the traps increased from July2 until the end of the experiment. The highest catches occurred in September, with 287 other drosophilids, 66.3% of the total catches.

The joint effect of the distance from the cherry orchard and the trapping period on the catches of SWD

Results of 2021

The sampling period and the distance from the sour cherry plantation significantly affected the SWD catches in the elderberry plantation (effect of period: df = 6 F = 159.0, $P < 0.001$; effect of rows, df = 2, F = 5.1, $P = 0.007$; interaction: df = 12, F = 2.2, $P = 0.015$). The catch numbers increased with the progress of the season. More catches occurred in the rows near the sour cherry plantation, especially in the early population growth phase, in the second part of August (Figure 3).

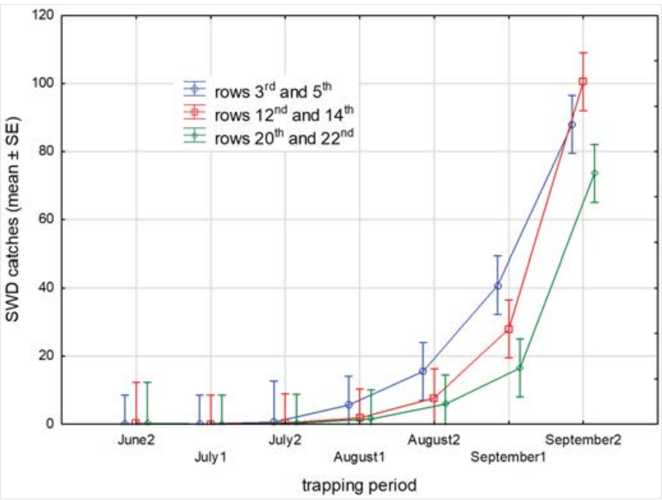

Figure 3. Number of SWD caught by traps in different trapping periods in 2021

Results of 2022

In 2022, the trapping period significantly affected the total SWD catches in the cultivated elderberry within the four selected rows (df = 5, F = 486.3 $P < 0.005$). This was mainly due to the sharply increased catches in the last trapping period in September (Figure 4). This year, the distance significantly impacted the catches (df = 3, F = 2.9, $P = 0.0369$). This could be the effect of the difference in the last trapping period. The period–row interaction also significantly differed (df = 15, F = 2.3, $P = 0.0091$).

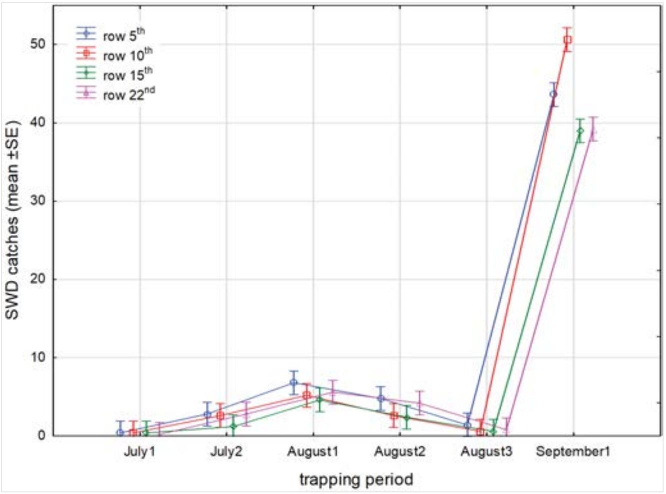

Figure 4. Number of SWD caught by traps in different trapping periods in 2022

The joint effect of the distance from the cherry orchard and the date of trapping on the proportion of SWD in catches of drosophilids

Results of 2021

The trapping period, the rows and their interactions significantly affected the proportion of the *D. suzukii* / Drosophilidae in the traps in 2021 (trapping period: df = 6, F = 115.8, $P < 0.005$, row: df = 2, F = 10.6, $P = 0.0005$, interaction: df = 12, F = 2.5, $P = 0.004$). The SWD was present in the traps, with a relatively small proportion at the beginning of the experiment (Figure 5). When the catches increased (July2), a 30% SWD proportion was detected in the 3–5 rows. In August1, the SWD proportion was above 60%. Significant differences between the 12^{th}–14^{th} and 20^{th}–22^{nd} rows could not be proven. The increase of the SWD proportion was slower than in the 3^{rd}–5^{th} rows.

In July2, the proportion did not reach 20%. In August1, it remained below 30%. The proportions of the three rows were near to each other by September, and by the end of the experiment, it reached 70% in every row.

The difference between the closest cultivated elderberry row (22nd row) and the wild field margin was examined. No significant difference was found between the SWD catches in 2021 (df = 1, F = 0.184, P = 0.669). The month–row interaction had an insignificant effect (df = 6, F = 0.157, P = 0.987). During the summer, no catches occurred in these two rows. The increase in the number of captured flies was similar in the rows. A very slight significant difference between the catches of the other drosophilids was found (df = 1, F = 723, P = 0.0119); more flies were caught at the margin. The more diverse margin can provide different food plants and shelters than the elderberry monoculture. In 2022, no significant differences were found between the two rows in the SWD catches. The month–row interaction showed substantial differences (df = 5, F = 4.64, P = 0.0016). Because the numbers were low, the high values in September can distort the statistical results. However, higher numbers occurred in the plantations compared to the field margin. There were no significant differences between the rows in the case of other drosophilids.

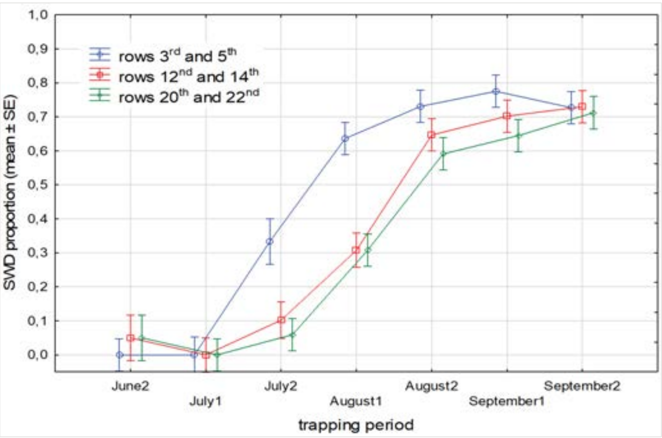

Figure 5. The proportion of SWD in 2021

Results of 2022

The trapping period significantly affected the proportion of SWD (df = 5, F594.3, P < 0.005) in 2022. The rows (distance) did not affect the SWD's ratio (df = 3, F = 0.9 P = 0.445). At the beginning of the field experiment, the SWD's proportion remained low (rows 5th, 10th, and 15th, around 30%, and row 22nd, below 10%) (Figure 6). By the end of July, the proportion of SWD in the mean catches reached 50%, in the case of the 22nd row, above 80%. These high proportions remained until the end of August but began declining later. In the 22nd row, it remained below 30%, but the highest proportion was under 60% (5th row). By the end of the trapping season, the ratios increased again in every row (70–80%), and no significant differences were detected between them. The interaction of the rows and trapping time was insignificant (df = 15, F = 0,8, P = 0.668).

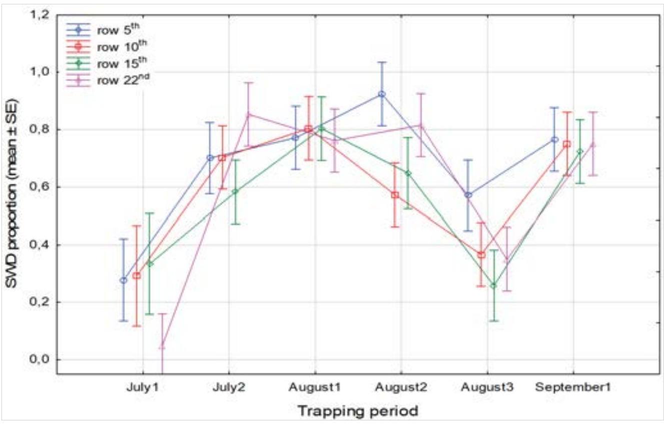

Figure 6. The proportion of SWD in 2022

The effect of the distance from the cherry orchard and the date of trapping on the drosophilid catches

The period significantly affected the mean number of the drosophilid catches other than SWD (df = 6, F = 121.2, P < 0.005), but there were no significant differences between the rows (df = 2, F70.05, P = 0.9552) in 2021. By the end of August, the mean numbers of the other drosophilids remained below 10 in every row. It started to increase with the number of SWDs from September. The mean number of drosophilid catches reached 30–35 in every row.

In 2022, other drosophilids were also captured in low numbers, and the trapping period significantly affected their numbers (df = 5, F = 197.2, P < 0.005). The mean numbers of other drosophilids increased in September, from 1–4/trap to 12–16/trap. The rows and the period–row interaction did not significantly affect the numbers of other drosophilids (row: df = 3, F = 0.08, P = 0.471, interaction: df = 15, F = 1.7, P = 0.0584). No decline could be detected in the drosophilid catches in August, as in the case of SWD in 2022.

Fruit infestation rates

In 2021, SWD imagoes emerged from each sample for sour cherry. The most significant number was detected from the sample of 4 August, from which 21 SWD and 9 other drosophilid flies were reared. From that time, the number of emerging SWDs decreased. No more cherry fruits could be collected on the last sampling date (15 September 2021). From the elderberry, the SWD – and other drosophilids) emerged only from the previous samples (collected on 15 September 2021) with more than 150 specimens/samples from each, 212 SWD from wild elderberry and 202 and 186 SWDs from the orchard samples, respectively. The increased infestation rate overlapped with the harvesting period of the elderberry. No significant differences were found between the cultivated and wild elderberry and the orchard rows.

In 2022, no imagoes emerged from the wild and cultivated elderberry during the survey. One male and one female SWD were counted from the sour cherry samples collected on 14 July 2022. On 09 August 2022, four females and four males with one other drosophilid were caught. From 23 August 2022, only one SWD female emerged.

DISCUSSION

In both years, the peak of the imago population of SWD occurred in autumn, which is the typical pattern in Hungary since the establishment of the pest. Several surveys revealed the same trend, even in non-crop habitats. Until recently, no damages were reported in the country in early ripening fruits like cherries. A similar phenomenon has been reported in Europe and North America. The highest trap catches were observed during autumn and winter in both crop and non-crop habitats (Buck et al., 2022). In Piedmont (Italy), in vineyards, the trap captures were low in July and increased by August and September (Mazzetto et al., 2020). A similar pattern can also be seen in North Europe under the oceanic climate. In the Netherlands, in 20 blueberry orchards, the SWD populations were low in July, but they established a higher population density by August (Haro-Barchin et al., 2018). However, under the Mediterranean climate, the population phenology is different. In Turkey's Aydin province, SWD can be captured annually with an autumnal population peak (Baspinar et al., 2022). In contrast, in the coastal parts of Greece, the population has two prominent peaks, first in spring and later in autumn, while in the hot summer, the catches are practically missing in cherry orchards (Papanastasiou et al., 2020). Similar dynamics were found in multiple fruit orchard systems in California State, USA, where two prominent capture peaks were present in spring and autumn, with very low abundances in the hot summer and cold winter months (Wang et al., 2016). During the first year of our survey, the temperatures were milder than in the second year. Slightly lower mean temperatures were measured in summer and September, with a drop at the end of August. The highest temperatures were between 32.3 and 37 °C. The mean humidity was around 65–70% but consistently above 60% during the first year, substantially increasing to 78% in the last two weeks of September, where the trap catches and fruit infestations were relatively high. On the contrary, in 2022, the daily maximum temperatures were higher, between 34.5 and 39.3 °C. The hottest period was in the second half of July, with a 48.6% mean RH. The hot and arid climate lasted till the end of August when the temperature dropped, and the mean humidity rose to 90.7%. These climatic conditions can explain the differences in the catches between the two years. The drip irrigation system in the plantation had a relatively moderate effect on the microclimate inside the canopy. These climatic patterns can explain a substantial part of seasonal and yearly variation in the trap catches of SWDs and the infestation rates.

In 2021, the distance from the sour cherry plantation significantly affected the trap catches in the elderberry plantation. The catches of the neighbouring rows were higher than those of the farther rows, and the population increase began earlier. This was remarkable in the first half of September when a tremendous difference was observed. During the last trapping period, there were no differences between the catches of the nearest and middle rows. The catches of the farthest row remained low.

In 2022, the meagre catch results did not allow for statistically significant differences to be demonstrated. This low abundance of SWD is probably due to the hot and arid summer and late spring. However, the peak of catches in September was also surprisingly high this year. In September, the highest numbers were counted in the 10th row and the second highest in the 5th row. No differences were found between the farthest rows (15th and 22nd).

However, it is worth mentioning that the elderberry harvest was carried out on the same day when the last traps were set in the field. Therefore, the high number of SWD imagoes could cause no harm. Due to the dry and decomposed berries, the remaining cherry was not susceptible to the imagoes. Because no emerging flies from the collected fruits were found, it is assumed that late specimens in the elderberry plantation did not necessarily originate in the adjacent orchards. There was also no evidence that these flies came from the field margin. Firstly, the nearer rows had lower catches, and secondly, no emerging imagoes were found in the elderberries collected from the margin during the whole season. Several studies have examined the longer-distance movement of SWD between different crops and forested areas. In Switzerland, near Lake Zug, more flies were captured closer to the forest during fruit ripening in plum, raspberry, and blackberry orchards. The SWD abundance decreased as the distance from the forest increased, but when the fruits were ripe, no significant difference could be found between the trap catches (Cahenzli et al., 2018). The authors suggested a migration from the forest, which was driven by fruit ripening. This should also be the case in the sour cherry-elderberry orchards. The possible ecological background is the metapopulation source-sink model, where the sour cherry is the source. There, the SWD can build a large, viable meta-population, and when the elderberry reaches the susceptible ripening stage, the flies migrate into a new, sink habitat. This situation was investigated in California State, USA, where the SWD movement was observed between different – differently ripening – fruit orchards. The ripening stage of the fruits, the fruit susceptibility and the fruit preference of the SWD together decided which host plant and even non-host plant habitats were source and sink habitats (Wang et al., 2016).

On the contrary, in blueberry farms in the Netherlands, the SWD population inside the orchard may spill over the forest habitat after the fruit harvest. Therefore, the pest can find an alternative host plant to maintain the population and avoid pesticide use within the plantation. This shows a counter-movement. Nevertheless, the authors also mentioned that after pesticide use, the SWD population can re-colonise the orchard from the forest (Haro-Barchin et al., 2018).

The proportion of the SWD in all drosophilids is also a valuable parameter for evaluating the seasonal dynamics of the pest. In 2021, higher values were measured in the 3rd–5th rows. In these cases, the ratio was notably higher than in the other rows, especially at the beginning of the increase at the end of July and the beginning of August. The same phenomenon was found in our further experiments. With a more refined trapping method (weekly, daily collection), the increase in the SWD rate may be visible at lower catch numbers. The monitoring of the proportion can be used as an early warning method for the pest. This would be essential in cases when the timing of insecticide treatments should be exceptionally accurate. The SWD proportion quickly reached 50% and 70% as the season progressed. For this time, the traps were "filled" with SWDs, and the proportion curves showed typical logistical shape.

It should also be noted that catches of drosophilids other than SWD increased in the last part of the experiment, but their numbers in the traps were not constant. Therefore, it does not explain the increase of the SWD proportion alone. However, the other drosophilid samples are indeed composed of several species. The earlier samples may contain different species than the late ones. The mean catches of other drosophilids did not show significant differences between the rows, which suggests that the effect influencing the SWD catches in the different rows (distance) has no influence on other related species. In 2022, the effect was not apparent at lower abundance values, but the SWD proportion started to increase as the catches began to expand and reach 80%. No significant differences were found between the rows that year. The insufficient number of captured adults made conducting a proper statistical analysis challenging. The high temperature and arid weather conditions caused a slight drop in the proportion in August. This effect did not impact the other related drosophilids. The occurrence of heat-tolerant species could be the explanation for this phenomenon. It is unlikely that the insecticide treatments caused the decrease in SWD rates, as contact insecticides would have also killed off other related flies.

CONCLUSION

In summary, in the elderberry plantation, more catches were observed in the rows closer to the sour cherry in the early periods of population increase in mid-summer. This probably reflects the movements of SWDs between cherry (source) and elderberry plantations. Based on these results, the direction of the population from the remnants of sour cherry plantations towards the later ripening fruits in complex plantation systems can be detected. However, it is also true that when the population peaks in autumn, which is typical in Hungary, the SWD presence becomes uniformly high in different habitats practically throughout the country. Based on our studies, even with low SWD catches, if their proportion in apple cider vinegar traps rises compared to other drosophilids, a sudden population increase is expected. The authors hope their results may contribute to future forecasting and controlling of SWD.

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