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Original scientific paper

Current integrated pest management tactics for the spotted wing Drosophila and their practical implementation in Switzerland

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SUMMARY

Drosophila suzukii (Matsumura, 1931) (Diptera: Drosophilidae), the spotted wing Drosophila (SWD) is a concern for small fruit and stone fruit growers. This invasive pest lays eggs in healthy fruits with a serrated ovipositor, resulting in considerable economic losses, mainly in berry crops. In Europe, it was first recorded in Switzerland in 2011, causing considerable damage in all small fruit crops, especially in later-developing crops (autumn raspberries, blackberries, blueberries and elderberries). The pest was found in all regions of the country, from low altitudes to the timberline. The range of host plants is very broad, not only affecting crops, but also wild fruits. Switzerland has implemented a strategy at the national level by combining an effective monitoring system with hygiene measures and mass trapping. Insecticide applications, usually based on spinosyns, are only considered as a last resort. In addition to this already operative strategy, innovative alternatives are considered, in particular the use of repellents or masking substances.

Keywords: *Drosophila suzukii*; Monitoring; Mass trapping; Lime treatment

INTRODUCTION

The spotted wing Drosophila (SWD), *Drosophila suzukii* (Matsumura, 1931) (Diptera: Drosophilidae), has spread rapidly from Asia throughout Europe, North America (Calabria et al., 2012; Cini et al., 2012) and South America (Deprá et al., 2014). In 2008 this fly arrived simultaneously in Europe (Italy, Spain) (Cini et al., 2014) and North America (Lee et al., 2011). The colonization has been largely facilitated by human activities, particularly the movement of infested fruits, climatic conditions similar to the fly's native range (Wiman et al., 2014) and the absence of natural factors regulating SWD populations effectively. *D. suzukii* lays its eggs inside ripening fruits. This highly polyphagous pest is known to develop in many economically important fruit crops, e.g. blackberries, blueberries, cherries, peaches, raspberries, strawberries, grapes, bayberries and kiwis (Grassi et al., 2012). In addition, more than 50 wild host plants have been determined in Europe and the USA, providing the pest with large reservoir of alternative hosts throughout the seasons (Kenis et al., 2016; Lee et al., 2015)

Damage is mainly caused by larval feeding, resulting in the degradation of fruits. The wound is an entry door for secondary infections by fungi, bacteria (Bolda et al., 2010; Hauser et al., 2009; Walton et al, 2010) and other *Drosophila* species (Baroffio & Fischer, 2011; Kehrli et al., 2012; Walsh et al., 2011). Significant crop losses can result from *D. suzukii* invasion. In the U.S., they were estimated at $ 500 million for three economically important states in terms of fruit production in 2008 (Bolda et al., 2010). For the same year, crop losses ranging from 30 to 40 % have been observed on blueberry, blackberry and raspberry in Italy, and up to 80% on strawberry in France (Lee et al., 2011). Economical consequences caused by the SWD are not limited to crop losses: increasing production costs and potential market losses might be expected, as well as additional time, money and workforce in order to correctly apply control methods against *D. suzukii* (Cini et al., 2012). Beside the harvest reduction due to the pest, there is also a concern over rejection by retailers of damaged fruits with larvae inside or with too many chemical residues (Lee et al., 2011). Therefore, the detection and monitoring of *D. suzukii* is important for taking pest management decisions.

Monitoring programs with application of traps began in all the concerned countries (Beers et al., 2011; Dreves, 2011). Switzerland launched its first survey in 2011 and then continued over the following years (Baroffio et al., 2015). The aim of this survey was to complete the information about the current distribution of the pest, to study the attractiveness of potential host plants (Kenis et al., 2016) and to initiate a sustainable control strategy. Different trap types and attractants for *D. suzukii* were compared (Baroffio et al., 2014; Lee et al., 2013).

Most invaded countries have established an integrated pest management (IPM) strategy in order to control *D. suzukii* (Asplen et al., 2015). Combinations of different control measures have been applied against SWD, including chemical, physical and biological control, as well as cultural control (Haye et al., 2016). Treatments with insecticides or alternatives (lime) are applied and evaluated. Alternatives to chemical insecticides, such as lime treatments, were tested in experimental fields and in farm trials. Cultural management tactics, such as the use of nets or traps for mass trapping, provide a good alternative in some crops. To date, sanitation is the most important method to fight SWD. Although costly and time consuming, other control measures can only be effective when the crop is "clean" and SWD reservoirs are reduced as much as possible. In berry crops, mass trapping combined with sanitation can be an efficient strategy. However, the choice of an attractant is critical and control may only work if the traps are at least as attractive as the fruits or used prior to the start of fruit ripening. SWD control in fruit orchards will be particularly challenging because a high number of wild host plants in nearby woodlands, unmanaged private gardens or abandoned orchards provide an enormous refugium for SWD requiring an area wide control approach. The SWD will never disappear and we have to learn to live with it and to prevent exponential population growth over the season. Swiss strategy combines an effective monitoring system and an integrated pest management. Insecticidal applications, usually based on spinosyns, are considered only as a last resort. In addition to this already operating strategy, innovative alternatives have been envisaged, in particular the use of repulsive or masking substances. This article deals mainly with the survey of SWD in Switzerland and the efficacy of treatments based on lime hydroxide in protection of berry crops.

MATERIALS AND METHODS

Materials

Two trials will be discussed: the Swiss monitoring between 2012 and 2016 and the effect of lime application in semi-field conditions. The material used is described in Table 1.

Table 1. Description of different materials used for the experiments

Material	Description
Traps	*Profatec trap*: Translucent reusable plastic cup (100 ml capacity) with a red or white lid and 12 holes on the upper side of the cup (3 mm diameter) and a hook. (www.profatec.ch). *Riga trap*: Translucent ready-to-use plastic cup already filled with the attractant from the company Riga (100 ml capacity). The cup is covered with a white aluminum foil which will be pierced with 8 holes (3 mm diameter). Each trap is hung on a metal hook at a structure in the crop (www.becherfalle.ch).
Lure	Biological attractant composed of fruit- and wine vinegar, red wine and sugar from the company RIGA AG (www.becherfalle.ch). The attractant is identical for both traps.
Fruits	Fruits were sampled from the Swiss agricultural research centre Agroscope in Conthey (Canton of Valais, Switzerland). Blueberry bushes of the variety 'Liberty' were produced soilless in black-round plant pots (45 l). Strawberries of the variety 'Joly' were cultivated in the soilless, tunnel system since 2015.
Lime	Product Nekapur 2 - Ca (OH) 2, manufactured by the company KFN (www.kfn.ch), was used at a rate of 1.8 kg / 1000 l of water / ha
Plants	Semi-field trial with lime: Blueberry plants (14) in 45 l pots (cv. Liberty) in 14 single cages: 1.5 x 1.5 x 3 m with a mesh size 300 x 200 µm.
SWD	Individuals were obtained from a laboratory colony (Agroscope in Changins, Canton of Vaud, Switzerland) established of strains from France (Chabert, Lyon) and locally collected wild insects. The insects were kept in a climate chamber at 23°C, 70% r.h. and with a 16:8 (light: dark) photoperiod. Ten adults were released per week per plant (5 males and 5 females).

Methods

Monitoring was conducted all over the country. The network consisted of an average of 200 traps with a variation in numbers throughout the season, distributed according to the importance of fruit growing areas (between 2 and 15 traps/canton). The traps were checked on a weekly basis over the whole year (Baroffio et al., 2013; Baroffio et al., 2015). In 2012, different traps were used for the monitoring and some of them were self-made. Later, Riga and Profatec traps were preferred as they have proved to be more efficient. Records of population development, including crops affected, progression and location of spread, were published in an open access website (www.drosophilasuzukii.agroscope.ch). In this research, we used the monthly average numbers of adults per 100 traps, transformed into log scale, to demonstrate the seasonal tendency of evolution of SWD in Switzerland.

Measuring of the pH value of fruits after lime treatment

One strawberry line was treated with a solution of lime and metallic colloid, while another one did not receive any treatment. The application was performed once in the morning. In total, 18 fruits were selected per modality and those same 36 fruits were used throughout the test. The pH of the 18 fruits per modality was measured in the afternoon during the following three days with the portable pH-meter Seven2GoTM (Mettler Todedo). Before measurement, one drop of demineralised water was applied on each fruit.

Evaluation of the effect of lime treatment on SWD development: 14 blueberry plants were used with 1 plant per cage. Lime at the concentration of 1.8 kg/ha was applied weekly on seven plants in cages with a Stihl© SR430 sprayer. The pH value of the solution was measured with a portable pH-meter Seven2GoTM (Mettler Todedo). One day after each treatment, 10 SWD adults (5 males and 5 females from our breeding) were released into each cage. The trial was conducted over a period of four weeks, between July 22nd and August 22nd 2015. In total, 40 adults were released into each cage during the trial. To measure the efficacy of the treatment, 10 fruits per cage were weekly analyzed for eggs and larvae presence (Dorsaz, 2016).

The results were statistically analyzed with Excel Stat and R package.

RESULTS AND DISCUSSION

Monitoring

Figure 1 shows the development of the SWD population between 2012 and 2016. There was a winter pause in 2012 and 2013 when no catches were recorded during the first months of the year. Since 2014, continuous catches of the insect were recorded. The monitoring shows its repartition in crops and in wild areas all over the country from low to high altitudes (to 1500 m a.s.l) with an increasing population. The highest number of adults was recorded in autumn months of each season (October, 2013 and November, 2012, 2014, 2015 and 2016).

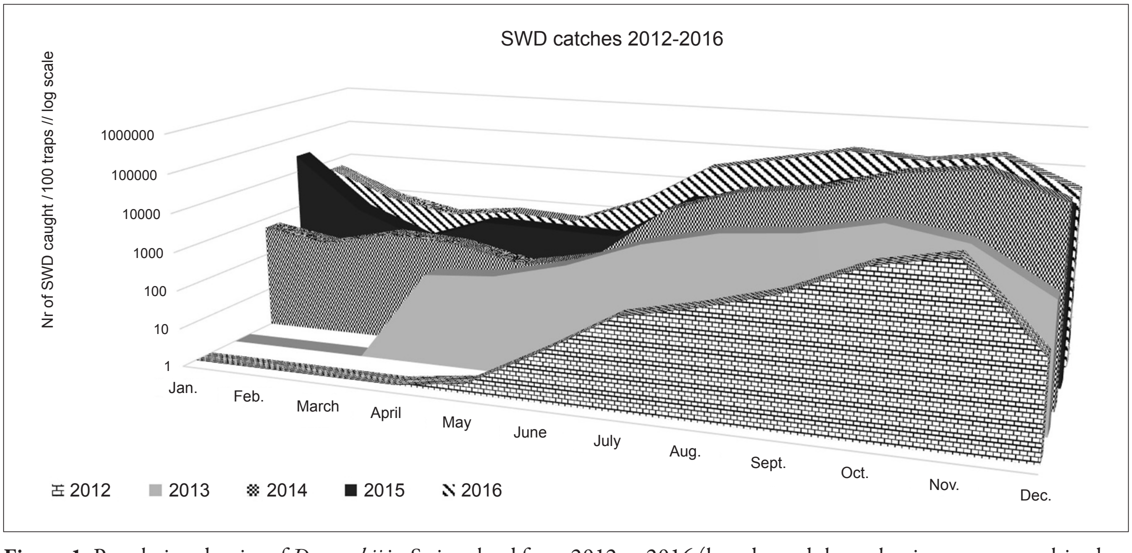

Figure 1. Population density of *D. suzukii* in Switzerland from 2012 to 2016 (based on adult catches in traps, set at altitudes up to 1500 m a.s.l.). The catches are per 100 traps and in a log scale.

Impact of lime treatment on pH values of strawberries

The pH value of strawberries treated with lime was significantly different from the untreated modality (p-value < 0.0001 at 95% confidence interval). The pH of the treated strawberries was always higher than the pH of the untreated fruits (Figure 2). This could be explained by a modification of the environment surrounding the fruit surface by lime application, resulting in a reduction of fruit attractiveness or repulsive effect on SWD. Calcium hydroxide quickly reacted with aerial $CO_{2,}$ increasing the pH value. After 3 days there was still a significant difference between the pH values of the treated and untreated modalities.

Lime treatment of blueberries in semi-field conditions

Table 2 gives the median value of the counts of *D. suzukii* individuals (eggs and larvae) per date and the related p-values of Kruskal-Wallis tests per date, as well as for the total study period. Over the first three periods, the median individual number of SWD in lime-treated and untreated blueberries was not statistically different. In the fourth period (20.08.2015), with a p-value of 0.034 at a 95% confidence interval, the two modalities were statistically different, with the median individual number being significantly higher in the non-treated modality. Between the modalities, the median individual (eggs and larvae) numbers were substantially higher for the non-treated than for the treated fruits. The median individual number for the treated modality slightly increased by 05.08.2015, and then dramatically dropped, while it remained constantly high for the non-treated modality.

Table 2. Number of SWD eggs and larvae (median) per modality and p-values (Kruskal-Wallis)

Date	Lime	Control	P-value
29.07.2015	7	16	0.272
05.08.2015	8	12	0.275
13.08.2015	2	11	0.063
20.08.2015	0	9	**0.034***
Kruskal-Wallis p-value	0.134	0.968	–

As the datasets were heterogenous, the medians were used to compute the tests

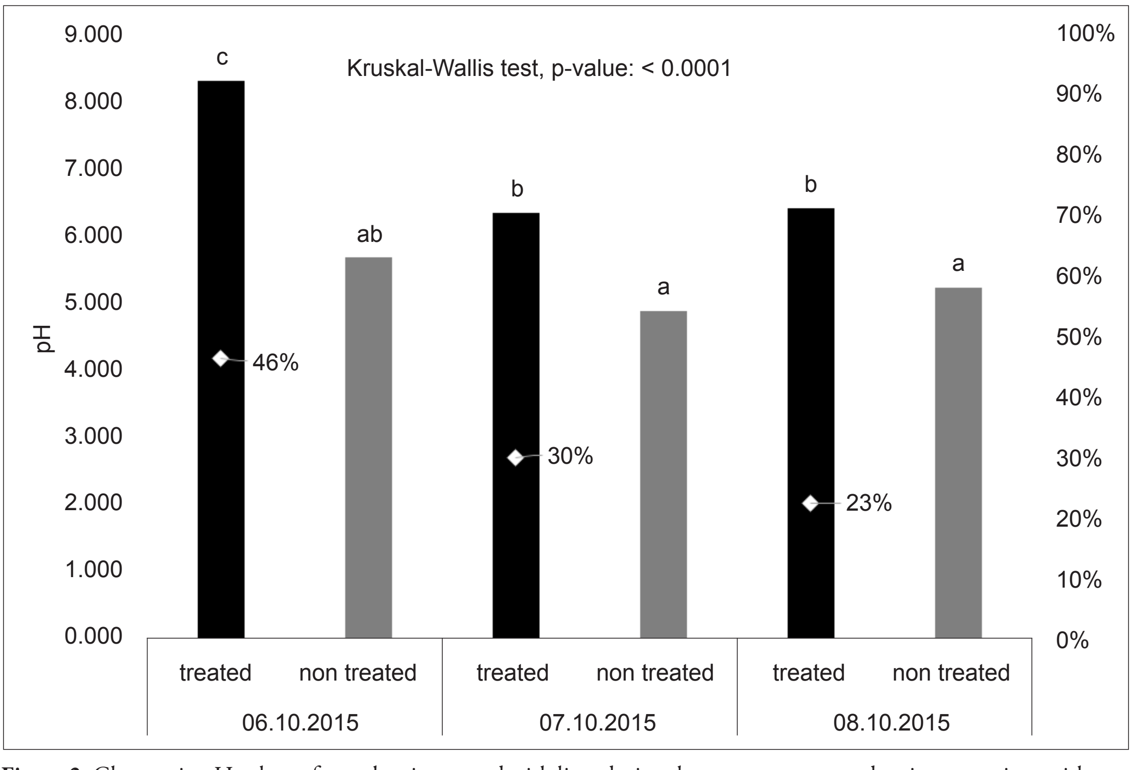

Figure 2. Changes in pH values of strawberries treated with lime during three post-treatment days in comparison with untreated fruits. Relative pH increase percentage of treated strawberries compared to non-treated strawberries are indicated for each post-treatment day.

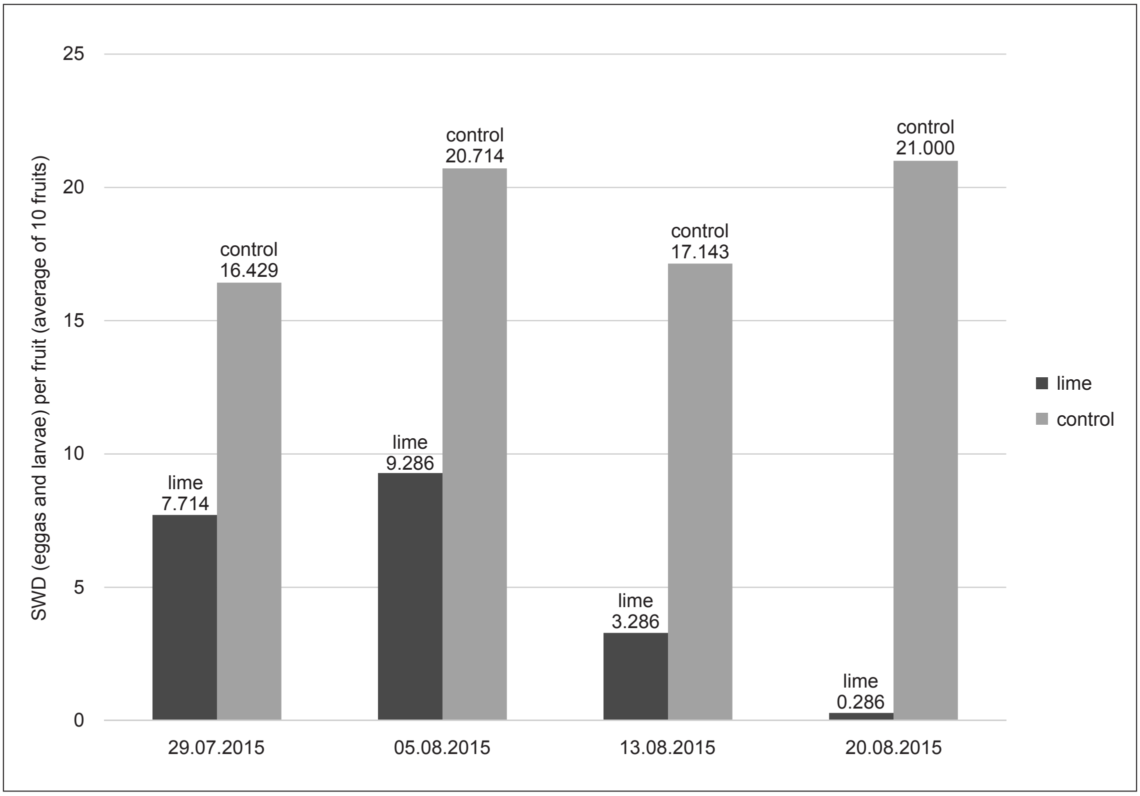

Figure 3. Weekly mean number of *D. suzukii* individuals (eggs and larvae) recorded in blueberry fruits in two modalities of the trial in semi-field conditions (lime-treated and control). Each value represents the mean number of individuals recorded in 10 analyzed fruits

Figure 3 and Table 2 show that after several applications conducted on weekly basis, the lime treatment was effective in suppressing *D. suzukii* on blueberries. Lime deposit on the fruit may affect the respiratory filaments of the eggs and cause their suffocation. The larvae living inside the berry are thus less exposed. This observation supports laboratory test results whereby the relationship between emerging adults and the number of eggs laid was lower for treated blueberries than for untreated blueberries (Fischer, 2015). The trial on blueberries in semi-field conditions confirmed that after several applications, the lime treatments reduced infestation rate. The contamination of non-treated blueberries with SWD was significantly higher than for the treated blueberries. However, treatment efficacy of lime has to be tested in open field conditions in order to confirm our results. Ground treatment with lime was authorized in Switzerland in early 2017 (www.blw.admin.ch: homologation en cas de situation d'urgence, lutte contre *Drosophila suzukii*).

CONCLUSIONS

The following conclusions can be drawn from our trials:

- The monitoring survey is a useful tool to observe SWD development during the season and to compare population densities in different years.
- The pH of strawberry fruits treated with lime was significantly higher than the pH of untreated fruits
- Lime can be used to avoid a severe SWD infestation of fruits.

Final considerations

The Swiss IPM strategy relies on sanitation measures as the most important prerequisite to reduction of SWD populations. Sanitation is costly and time consuming for the producer but no other control measure can be effective if the crop is not clean. The survey with an efficient trap (Profatec or Riga) is a good tool. It will allow deciding of the right time to start the control measures, such as mass trapping, application of protective nets or treatment. Mass trapping can be effective only with efficient traps, which must be more attractive to SWD than the fruits themselves. The ready-to-use Riga trap is a good tool in berries and the attractant is one of the best on the market today. Lime treatment might be an interesting alternative to chemical insecticides. The IPM tactics must be implemented from the beginning of the season with the aim to keep the population as low as possible. IPM will only be possible and effective with implementation of a combination of different strategies. Development and optimization of the control program are still needed and further research should be continued in that direction.

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Aktuelni metodi integralnog suzbijanja azijske vinske mušice i njihova primena u praksi u Švajcarskoj

REZIME

Drosophila suzukii (Matsumura, 1931) (Diptera: Drosophilidae), azijska vinska mušica, uzrokuje probleme u gajenju jagodičastog voća i koštunica. Ova invazivna štetna vrsta koristi nazubljenu legalicu za polaganje jaja u zdrave plodove, što dovodi do značajne ekonomske štete, uglavnom u usevima bobičastog voća. U Evropi je najpre zabeležena u Švajcarskoj 2011, gde je pričinila značajnu štetu na jagodičastom voću, naročito u usevima kasnijeg sazrevanja (jesenje maline, kupine, borovnice i bazga). Vrsta je nađena u svim delovima zemlje, od predela na nižim nadmorskim visinama sve do planinskih goleti. Spektar biljaka domaćina je veoma širok i uključuje gajene useve, kao i divlje voćne vrste. Švajcarska je primenila nacionalnu strategiju koja kombinuje efikasan sistem monitoringa sa higijenskim merama i masovnim hvatanjem u klopke. Primena insekticida, obično spinozina, smatra se poslenjim izborom. Pored strategije koja se već primenjuje, razmatraju se i inovativne alternativene metode, posebno korišćenje repelenata ili maskirajućih supstanci.

Ključne reči: *Drosophila suzukii*; Monitoring; Masovno hvatanje u klopke; Krečni tretman