Chapter 12
Management of *Drosophila suzukii* in Berry Crops

Oscar E. Liburd and Elena M. Rhodes

Abstract There has been significant progress in the development of management tools for *Drosophila suzukii* Matsumura populations. Initially, conventional growers relied almost exclusively on conventional insecticides, primarily synthetic pyrethroids, organophosphates, spinosyns, and neonicotinoids, for control of *D. suzukii*. Although these pesticides provided effective control, there has been an increase in secondary pest outbreaks due to the destruction of natural enemies that regulate these secondary pests. Recently, much emphasis has been placed in finding effective biorational pesticides as alternatives to these conventional pesticides. Organic growers had been limited to spinosad as the only effective organic option, which raised concerns over resistance development. Recently, other organic pesticides including azadirachtin + pyrethrins, *Chromobacterium subtsugae*, and sabadilla alkaloids have demonstrated some level of activity against *D. suzukii* and can be used in an organic rotation program. Cultural control tactics such as increasing harvest frequency, field sanitation, mulches, irrigation techniques, and exclusion netting have provided different levels of control for *D. suzukii* populations. The potential to use attract-and-kill techniques is currently being researched and has shown some efficacy. Finally, biological control for *D. suzukii* management has been studied intensively, and much information is available on predators, parasitoids, and pathogens that attack *D. suzukii*.

Keywords Spotted Wing Drosophila · Integrated Pest Management · Insecticide Rotation · Biological Insecticides · Cultural Control

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O. E. Liburd (✉) · E. M. Rhodes
University of Florida, Gainesville, FL, USA
e-mail: oeliburd@ufl.edu

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12.1 Introduction

Spotted wing drosophila (SWD), *Drosophila suzukii* Matsumura, is an invasive pest seriously impacting the production of blackberries, blueberries, cherries, grapes, raspberries, strawberries, and other thin-skinned fruits around the world (Bellamy et al. 2013). *Drosophila suzukii* is an economic threat to fruit industries throughout North America (Hauser 2011; Walsh et al. 2011), Europe (Calabria et al. 2012), and South America (Deprá et al. 2014). Females possess a heavily sclerotized, serrated ovipositor that allows them to oviposit in ripening and ripe fruit (Hauser 2011). Male has a single spot on each of the wings. The spot location in *D. suzukii* differs from other indigenous European *Drosophila* species with black spots including *D. biarmipes* (Malloch) (Gompel et al. 2005) and *D. subpulchrella* (Takamori et al. 2006). *Drosophila suzukii* larvae develop inside the fruit and the presence of a single larva in a shipment of berries can cause that shipment to be rejected.

Current management practices for SWD in all impacted crops rely heavily on applications of insecticides (Bruck et al. 2011; Haviland and Beers 2012; Timmeren and Isaacs 2013). As this approach is not sustainable and can result in issues such as resistance development and secondary pest outbreaks, research into alternative tactics is ongoing. Tactics that have shown some efficacy include border sprays, attract-and-kill technologies, alternative oviposition sites in the form of a food-grade gum, various cultural control tactics, and biological control. An integrated pest management (IPM) strategy to manage SWD on different crops in growing regions throughout the world can be developed by incorporating various combinations of these tactics that will be discussed as appropriate for a given crop and region.

12.2 Insecticides

12.2.1 Conventional

Pesticidal tactics have been the primary tools used to manage high populations of *D. suzukii* on conventional farms since its arrival in the Americas in 2008 (Bruck et al. 2011; Timmeren and Isaacs 2013; Diepenbrock et al. 2016; Iglesias and Liburd 2017a). Pesticides from various classes including organophosphates, pyrethroids, spinosyns, ryanoids, and neonicotinoids have been effective but concerns about resistance development (Timmeren et al. 2019), maximum residue limits (MRLs) levels (Haviland and Beers 2012), and the negative effects on non-target organisms (Sarkar et al. 2020) have caused researchers to investigate other options for management. Different types of insecticide rotational programs have been investigated for management of *D. suzukii*. Several factors are considered when developing insecticide rotational programs including insecticide class, pre-harvest interval (PHI), and MRL levels.

Pesticides with short PHIs ranging from a few hours up to 24 h after application are usually in high demand by fruit growers who experience problems with *D. suzukii*. Once the fruit has reached maturity and ready to be harvested, growers want to be able to apply a pesticide (if needed) and harvest immediately without having to worry about pesticide residues on fruit. The MRL is the highest level of a pesticide residue that is allowed on a fruit. This level varies according to the country where the fruit is exported to (Haviland and Beers 2012). Therefore, depending on the target export market, growers take MRL into consideration when developing their insecticide rotational programs (Table 12.1).

12.2.2 Organic

The most effective organic insecticide against SWD is Entrust®, the organic formulation of spinosad (Fanning et al. 2018). Concerns over potential resistance development, which is already emerging in the Watsonville area of California (Gress and Zalom 2019), have produced research into both alternatives and compounds that can be used in rotation with Entrust®. Though used in some rotation programs, Pyganic (pyrethrins) has minimal impacts on SWD numbers and infestation (Timmeren and Isaacs 2013). Other organic insecticides that have shown some efficacy against SWD include *Chromobacterium subtsugae*, sabadilla alkaloids, and azadirachtin + pyrethrins (Fanning et al. 2018; Iglesias and Liburd 2017a). *Chromobacterium subtsugae* is a soil bacterium that acts as a repellent and antifeedant. Sabadilla alkaloids are made from sabadilla lily seeds and have a similar mode of action to pyrethroids. These products work best in rotation with spinosad.

12.2.3 Adjuvants and Phagostimulants

Two options for enhancing the efficacy of pesticides are the addition of adjuvants and phagostimulants. Adjuvants are added to pesticides to improve spray coverage (spreaders), allow more of a pesticide to adhere to the target crop (stickers), etc.

Table 12.1 Insecticide rotational program for *Drosophila suzukii* in southern highbush blueberries in North Central Florida

Program	Spray 1	Spray 2	Spray 3	Spray 4
1	Spinetoram	Malathion	Zeta-cypermethrin	Zeta-cypermethrin
2	Spinetoram	Phosmet	Malathion	Malathion
3	Fenpropathrin	Spinetoram	Malathion	Malathion
4	Malathion	Spinetoram	Zeta-cypermethrin + Bifenthrin	Zeta-cypermethrin + Bifenthrin
5	Spinetoram	Cyantraniliprole	Cyantraniliprole	Spinetoram
6[a]	Spinosad	Spinosad	Pyrethrins	Pyrethrins

aPesticides are labeled for organic use

(Foy 1996). The adjuvants poly-1-p-menthene, alcohol ethoxylate (Fig. 12.1), and polyether-polymethylsiloxane-copolymer did not improve the efficacy of azadirachtin, azadirachtin + pyrethrins, *Burkholderia* spp., *Chromobacterium subtsugae*, pyrethrins, sabadilla alkaloids, spinosad, or two hydrogen peroxide-based crop sanitizers against SWD even though both poly-1-p-menthene and alcohol ethoxylate caused some SWD mortality on their own (Roubos et al. 2019a).

Phagostimulants are food-based products added to insecticides to increase the target pest's exposure to the pesticide because the phagostimulants are attractive, both keeping the target pest in contact with the insecticide for longer and triggering an increase in feeding behaviors. Sucrose and yeasts have been examined as phagostimulants to improve SWD control by both conventional and organic insecticides. At 1.2 g/L, sucrose increased the efficacy of spinetoram, cyantraniliprole, and acetamiprid (Cowles et al. 2015). In laboratory studies, fermented strawberry juice, the yeast *Hanseniaspora uvarum*, and a combination of the two increased the efficacy of Spinosad, cyantraniliprole, and lambda-cyhalothrin against SWD (Noble et al. 2019). Unfortunately, neither the addition of sucrose nor the yeast *Saccharomyces cerevisiae* increased the efficacy of azadirachtin, azadirachtin + pyrethrins, *Burkholderia* spp., *Chromobacterium subtsugae*, pyrethrins, sabadilla alkaloids, or two hydrogen peroxide-based crop sanitizers against SWD (Roubos et al. 2019b).

Another line of research is focused on erythritol, a sucrose substitute that cannot be digested or converted to a digestible carbohydrate (Choi et al. 2017) that is toxic to SWD and other flies because it accumulates in the body causing an imbalance in osmotic pressure (Tang et al. 2017). Erythritol and some of its less expensive derivatives cause 80–100% mortality in all SWD life stages in laboratory experiments and reduced fruit infestation in a blueberry field by up to 93% (Sampson et al. 2019). The presence of sucrose sources and wounded berries reduces the efficacy of erythritol, however (Choi et al. 2019). The addition of erythritol increased the efficacy of

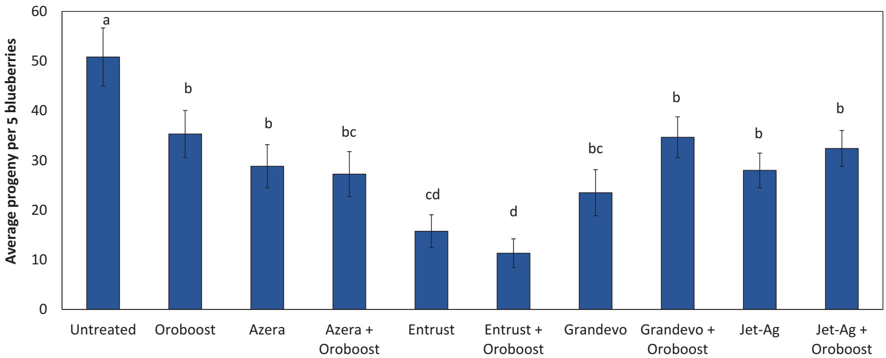

Fig. 12.1 Mean spotted wing Drosophila emerged per five blueberries in a semi-field bioassay treated with various organic insecticides with and without alcohol ethoxylate (Oroboost) in Florida. Azera is azadirachtin + pyrethrins, Entrust is spinosad, Grandevo is *C. subtsugae*, and Jet-Ag is a peroxide-based sanitizer

C. subtsugae and spinosad in laboratory trials (Gullickson et al. 2019). More field trials are needed before erythritol or its derivatives can be recommended as an effective control tactic alone or in combination with insecticides.

12.2.4 Border Sprays

It is well documented that SWD have many wild host plants (Lee et al. 2015; Little et al. 2017; Thistlewood et al. 2019), and numerous studies have shown that wild hosts near crop fields increase SWD numbers in the adjacent crops (Klick et al. 2016; Ballman and Drummond 2017; Santoiemma et al. 2018, 2019; WeiBinger et al. 2019). Border sprays, which are insecticide applications applied only to the border of a crop field, can successfully manage pests migrating into crop fields from outside including another fruit fly pest, the apple maggot, *Rhagoletis pomonella* (Trimble and Vickers 2000). Iglesias and Liburd (2017b) found that border sprays reduced numbers of SWD in organic blackberries in Florida (Fig. 12.2), and the sprays did not adversely impact natural enemy populations.

12.3 Behavioral-Based Tactics

12.3.1 Attract-and-Kill

One alternative to applying insecticides to entire fields is the attract-and-kill technique. An attractant, such as a food bait or pheromone, draws large numbers of a pest insect to a specific area where the pests encounter a killing agent, which is often an insecticide. Bait stations, liquid gels that partially solidify once applied (Vargas

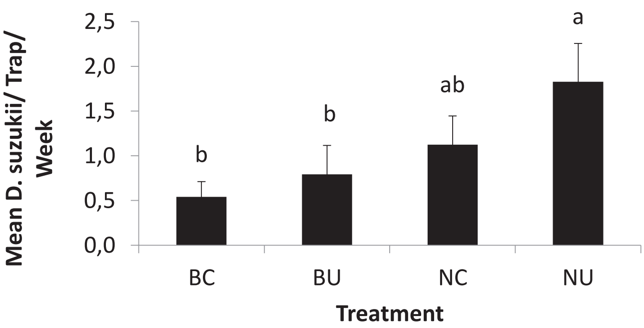

Fig. 12.2 Mean SWD per trap per week in plots treated with boarder sprays and cultivated (BC), treated with a border sprays only (BU), cultivated only (NC), and untreated (NU). Means with the same letter are not significantly different at $P \leq 0.05$. (Reprinted with permission from Iglesias and Liburd (2017b))

et al. 2008), and insecticide-treated spheres (Rice et al. 2017) are common ways of deploying attract-and-kill tactics. Both the insecticide-treated spheres and liquid gels have shown efficacy in SWD management.

Insecticide-treated spheres are used in the management of Tephritid fruit fly pests including the apple maggot, *Rhagoletis pomonella* Walsh (Wright et al. 2012; Morrison et al. 2016), and the blueberry maggot, *R. mendax* Curran (Liburd et al. 2003). The spheres are both colored and baited with sucrose to attract files. The spheres are impregnated with an insecticide that kills flies that land on the spheres and try to feed on them. Rice et al. (2017) developed and tested an insecticide-treated sphere for SWD management. The plastic spheres were painted red and included a cap made of wax, sucrose, and an insecticide. Both dinotefuran- and spinosad-treated spheres reduced SWD infestation of raspberries in the field. Reduction was increased by combining the treated spheres with insecticide applications.

The company ISCA Technologies Inc. has developed attract-and-kill tools for a variety of pests using their SPLAT gel matrix as a carrier. They have developed a prototype product for SWD management called HOOK SWD. The attractant components are the gel's red color and a food-based lure that is proprietary (Fig. 12.3). The insecticide typically employed in the product is spinosad. However, a variation of the product without insecticide is now available so that other insecticides can be mixed with it. Research is ongoing into which insecticides will be effective in combination with the SPLAT gel matrix. Klick et al. (2019) found that weekly

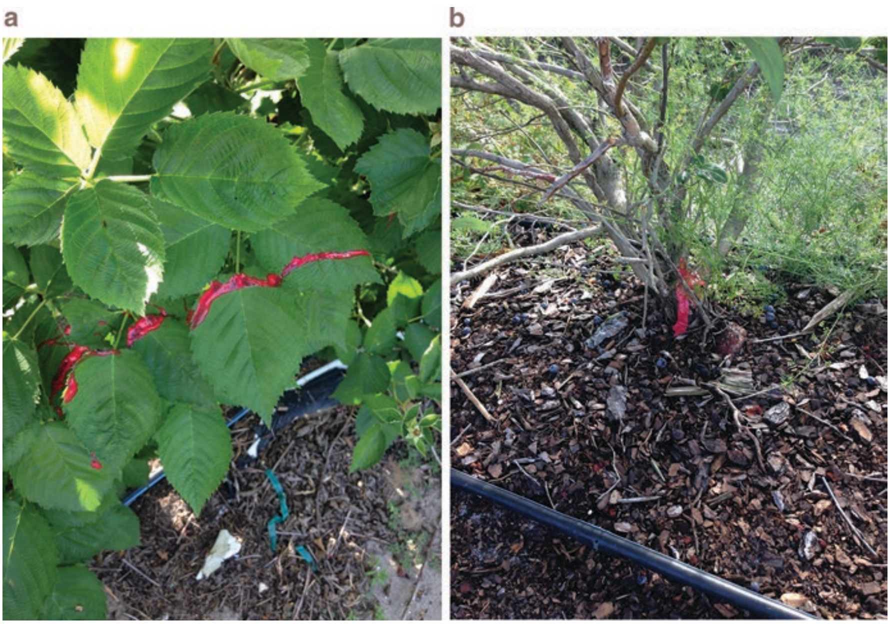

Fig. 12.3 HOOK SWD applications to (**a**) the lower leaves of a blackberry plant and (**b**) the stem of a blueberry bush. (Photo Credit: E. M. Rhodes, University of Florida)

applications of HOOK SWD in combination with a single application of spinetoram effectively reduced SWD infestation in highbush blueberries in New Jersey and red raspberry in California. Research on HOOK SWD is ongoing.

12.3.2 Alternate Oviposition Sites

Another behavioral-based tactic being developed for SWD management is a food-grade gum (Tait et al. 2018). The gum matrix has been developed as a solid formulation with a gel-like consistency and a liquid formulation with a cream-like consistency that can be applied with standard spray equipment. The matrix is entirely food-based and water-soluble. It attracts SWD females with its red color and a six-component synthetic blend of compounds like those found on the surface of fruit containing SWD eggs (Tait et al. 2020). Female SWD oviposit in the gum, where larvae are unable to complete development, instead of in fruit (Tait et al. 2018). Tait et al. (2018) found a mean reduction in fruit infestation of 48.3% in laboratory studies with blackberry, blueberry, cherry, raspberry, and strawberry fruits. In a highbush blueberry field in Oregon, both the solid and liquid matrixes caused a mean reduction in fruit infestation of 51.2%. These preliminary data indicate that the gum will likely be used in combination with other IPM tactics. Research on the food-based gum is ongoing, and it is not commercially available yet.

12.4 Cultural Control Tactics

12.4.1 Frequent Harvests

Harvesting fruit at more frequent intervals can reduce SWD infestations. For example, Leach et al. (2018) found that a 2-day harvest interval was ideal in Michigan raspberries as it reduced SWD infestation and increased fruit harvested per unit effort compared to the standard 3-day harvest interval. Organic blueberry growers in Florida utilize frequent harvests and report that it reduces SWD infestation (E. M. Rhodes, personal observation). Research is needed on optimized harvest intervals for other fruit crops in other areas.

12.4.2 Field Sanitation

Field sanitation is an important cultural control tactic for SWD management. Overripe and rotting fruit left in the field can serve as both oviposition sites and food sources for SWD females (Bal et al. 2017; Cai et al. 2019). Cai et al. (2019) found that SWD females mainly use rotting fruit as a food source and prefer to oviposit in ripe fruit when available. For these reasons, removing overripe and rotting fruit from the field can reduce SWD numbers. Leach et al. (2018) caused 99% mortality in waste berries by sealing the berries in plastic bags for 32 h. Fruit in clear plastic bags reached the highest temperatures.

12.4.3 Netting and Tunnels

Barriers physically prevent a pest from accessing a crop. Leach et al. (2016) found that exclusion netting reduced SWD infestation in red raspberries as well as insecticide applications to unnetted raspberries. Combining the two tactics reduced SWD infestation even further. Using exclusion cages in high tunnels also reduced SWD infestation though populations eventually increased (Leach et al. 2016). Plastic-covered high tunnels reduced SWD infestation to 2% compared with 35% in netted tunnels, 60% in insecticide-treated open plots, and 81% in open, untreated control plots (Rogers et al. 2016). Rogers et al. (2016) showed that the plastic covering caused the microclimate to become unfavorable for SWD reproduction and development. Barriers are most useful in cooler growing conditions. The biggest drawback is the cost (Rogers et al. 2016).

12.4.4 Irrigation

Using drip irrigation may reduce the population of SWD in fruit crops (Rendon and Walton 2019). Emergence of adult SWD from pupae was reduced in drip irrigated plots in blueberries because humidity was lower than in sprinkler irrigated blueberries, which caused pupae to desiccate. Research into the effects of irrigation on SWD in other fruit crops is ongoing.

12.4.5 Mulches

Rendon and Walton (2019) found higher temperatures and lower humidity above sawdust mulch compared with below the mulch, which caused fewer SWD above the mulch to survive. Rendon et al. (2020) found that SWD larvae can burrow through sawdust mulch to pupate underneath but not through weedmat (Fig. 12.4). The presence of mulch resulted in higher temperatures and lower SWD emergence. This effect was most pronounced at sites with young plants. Therefore, weedmat may reduce SWD numbers by preventing SWD larvae from burrowing into the soil, which can expose them to unfavorable temperatures and predators.

Fig. 12.4 Weedmat in blackberry planting

12.5 Biological Control

An excellent and comprehensive review of current and pending biological control tactics for SWD management has already been published by Lee et al. (2019). The main points will be summarized in this section. Predators observed consuming SWD in the field include earwigs, damsel bugs, spiders, ants, and minute pirate bugs. Sentinel pupal studies have indicated high predation in various crops, although this is likely an overestimation. Native parasitoids have been reared from SWD larvae and pupae in various locations though parasitism rates are generally low. These natural enemies will have a direct role in SWD suppression on organic farms and in wild hosts adjacent to crop areas. Research on classical biological control for SWD has been initiated and the most promising candidate is *Ganapsis brasiliensis* (Ihering), a larval parasitoid that is specific to SWD and closely-related drosophilids.

Several fungi, bacteria, nematodes, and viruses have been found to infect and kill SWD. Commercially available formulations of the fungus *Beauveria bassiana* have shown efficacy against SWD adults (Fig. 12.5) under laboratory conditions. Because fungi need high humidity and can be sensitive to UV degradation, field applications of *B. bassiana* have highly variable levels of success. Similarly, some strains of *Bacillus thuringiensis* bacteria and species of entomopathogenic nematodes have

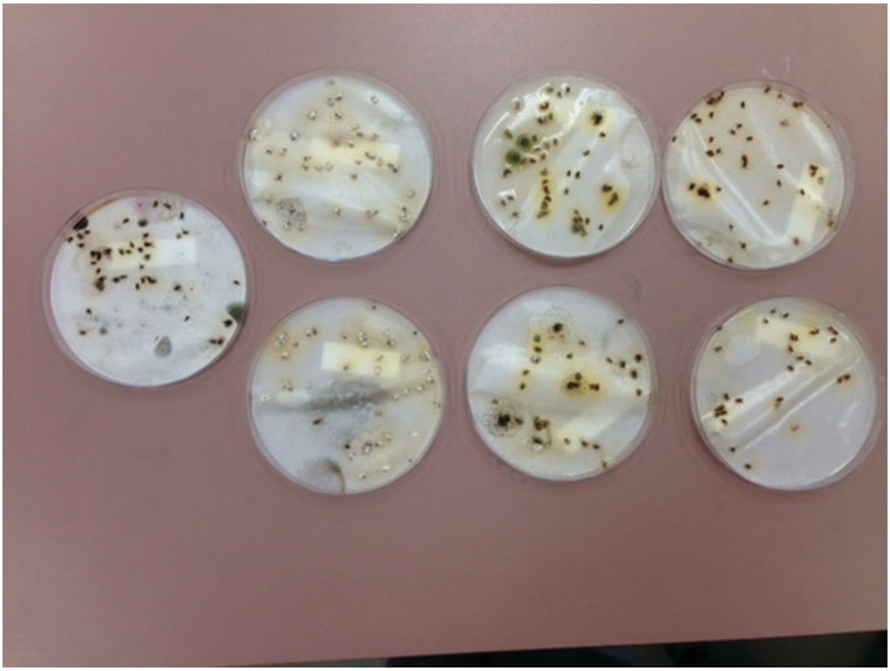

Fig. 12.5 SWD infected with *Beauveria bassiana* after 1 week in an environmental chamber. (Photo Credit: E. M. Rhodes, University of Florida)

been shown to cause SWD mortality in the laboratory. The effects of naturally occurring bacteria and nematodes are unknown. In contrast, viral infections of SWD in the field have been documented, but none have been developed into commercial products at this time.

12.6 Conclusions

There are many chemical options for conventional growers to use to manage SWD infestations. Using these insecticides in rotation will delay the development of resistance. For organic growers, spinosad is still the most effective insecticide available. Other organic insecticides tested so far that could be used in rotation with the organic formulation of spinosad include *Chromobacterium subtsugae*, sabadilla alkaloids, and azadirachtin + pyrethrins. There are many alternative management tactics and cultural control practices that may reduce the number of insecticide applications needed to manage SWD populations. Alternative management tactics under development include border sprays, attract-and-kill technologies, and alternative oviposition sites in the form of a food-grade gum. In terms of cultural control, frequent harvests and field sanitation reduce the amount of SWD oviposition and feeding sites in crop fields. Weed mat mulch prevents SWD larvae from burrowing into the soil to pupate making them easier prey for generalist predators. The use of drip irrigation creates a microclimate unfavorable to SWD development compared with overhead irrigation. Netting and tunnels can provide a physical barrier that prevents SWD from accessing the crop. Progress is being made toward releasing a parasitoid from the native range of SWD that may, in time, reduce SWD populations in natural areas, which will, in turn, reduce pressure on crop fields. All these tactics can be used to develop a robust IPM strategy to manage SWD in a variety of fruit crops whether they are managed conventionally or organically.

References

Bal HK, Adams C, Grieshop M (2017) Evaluation of off-season potential breeding sources for spotted wing drosophila (*Drosophila suzukii* Matsumura) in Michigan. J Econ Entomol 110:2466–2470

Ballman ES, Drummond FA (2017) Infestation of wild fruit by *Drosophila suzukii* surrounding Maine wild blueberry fields. J Agric Urban Entomol 33:61–70

Bellamy DE, Sisterson MS, Walse SS (2013) Quantifying host potentials: indexing postharvest fresh fruits for spotted wing drosophila, Drosophila suzukii. PLoS One 8:e61227

Bruck DJ, Bolda M, Tanigoshi L et al (2011) Laboratory and field comparisons of insecticides to reduce infestation of *Drosophila suzukii* in berry crops. Pest Manag Sci 67:1375–1385

Cai P, Song Y, Yi C et al (2019) Potential host fruits for *Drosophila suzukii*: olfactory and oviposition preferences and suitability for development. Entomol Exp Appl 167:880–890

Calabria G, Máca J, Bächli G, Serra L, Pascual M (2012) First records of the potential pest species *Drosophila suzukii* (Diptera: Drosophilidae) in Europe. J Appl Entomol 36:139–147

Choi M, Tang YSB, Ahn SJ et al (2017) Effect of non-nutritive sugars to decrease survivorship of spotted wing drosophila, *Drosophila suzukii*. J Insect Physiol 99:86–94

Choi M-Y, Lucas H, Sagili R et al (2019) Effect of erythritol on *Drosophila suzukii* (Diptera: Drosophilidae) in the presence of naturally-occurring sugar sources, and on the survival of *Apis mellifera* (Hymenoptera: Apidae). J Econ Entomol 112:981–985

Cowles RS, Rodriguez-Saona C, Holdcraft R et al (2015) Sucrose improves insecticide activity against *Drosophila suzukii* (Diptera: Drosophilidae). J Econ Entomol 108:640–653

Deprá M, Poppe JL, Schmitz HJ et al (2014) The first records of the invasive pest *Drosophila suzukii* in the south American continent. J Pest Sci 87:379–383

Diepenbrock LM, Rosensteel DO, Hardin JA et al (2016) Season-long programs for control of *Drosophila suzukii* in southeastern U.S. blueberries. Crop Protect. 81:76–84

Fanning PD, Grieshop MJ, Isaacs R (2018) Efficacy of biopesticides on spotted wing drosophila, *Drosophila suzukii* Matsumura in fall red raspberries. J Appl Entomol 142:26–32. https://doi.org/10.1111/jen.12462

Foy CL (1996) Adjuvants—current trends and technology. In: Foy CL, Pritchard DW (eds) Pesticide formulation and adjuvant technology. CRC Press, Boca Raton, pp 323–352

Gompel N, Prud'homme B, Wittkopp PJ et al (2005) Chance caught on the wing: cis-regulatory evolution and the origin of pigment patterns in *Drosophila*. Nature 433:481–487

Gress BE, Zalom FG (2019) Identification and risk assessment of spinosad resistance in a California population of *Drosophila suzukii*. Pest Manag Sci 75:1270–1276

Gullickson MG, Rogers MA, Burkness MC et al (2019) Efficacy of organic and conventional insecticides for *Drosophila suzukii* when combined with erythritol, a non-nutritive feeding stimulant. Crop Protect 125:1–6

Hauser M (2011) A historic account of the invasion of *Drosophila suzukii* (Matsumura) (*Diptera*: *Drosophilidae*) in the continental United States, with remarks on their identification. Pest Manag Sci 67:1352–1357

Haviland DR, Beers EH (2012) Chemical control programs for *Drosophila suzukii* that comply with international limitations on pesticide residues for exported sweet cherries. J Integr Pest Manag 3:F1–F6

Iglesias LE, Liburd OE (2017a) Identification of biorational insecticides for managing spotted wing drosophila in organic blueberry production. Acta Hortic 1180:283–292

Iglesias LE, Liburd OE (2017b) The effect of border sprays and between-row soil tillage on *Drosophila suzukii* in organic blackberry production. J Appl Entomol 141:19–27

Klick JW, Lang Q, Walton VM et al (2016) Distribution and activity of *Drosophila suzukii* in cultivated raspberry and surrounding vegetation. J Appl Entomol 140:37–36

Klick J, Rodriguez-Saona CR, Cumplido JH, Holdcraft RJ, Urrutia WH, de Silva RO, Borges R, Mafra-Neto A and Seagraves MP (2019) Testing a novel attract-and-kill strategy for *Drosophila suzukii* (Diptera: Drosophilidae) management. J Insect Sci 19:3

Leach H, Timmeren SV, Isaacs R (2016) Exclusion netting delays and reduces *Drosophila suzukii* (Diptera: Drosophilidae) infestation in raspberries. J Econ Entomol 109:2151–2158

Leach H, Moses J, Hanson E et al (2018) Rapid harvest schedules and fruit removal as non-chemical approaches for managing spotted wing drosophila. J Pest Sci 91:219–226

Lee JC, Dreves AJ, Cave AM et al (2015) Infestation of wild and ornamental noncrop fruits by *Drosophila suzukii* (Diptera: Drosophilidae). An Entomol Soc Am 108:117–129

Lee JC, Wang X, Daane KM et al (2019) Biological control of spotted-wing drosophila (Diptera: Drosopilidae)—current and pending tactics. J Integr Pest Manag 10(13):1–9

Liburd OE, Finn EM, Pettit KL et al (2003) Response of blueberry maggot fly (Diptera: Tephritidae) to imidacloprid-treated spheres and selected insecticides. Can Entomol 135:427–438

Little CM, Chapman TW, Moreau DL et al (2017) Susceptibility of selected boreal fruits and berries to the invasive pest *Drosophila suzukii* (Diptera: Drosophilidae). Pest Manag Sci 73:160–166

Morrison W, Lee DH, Reissig D et al (2016) Inclusion of specialist and generalist stimuli in attract-and-kill programs: their relative efficacy in apple maggot fly (Diptera: Tephritidae) pest management. Environ Entomol 45:202–203

Noble R, Dobrovin-Pennington A et al (2019) Improved insecticidal control of spotted wing drosophila (*Drosophila suzukii*) using yeast and fermented strawberry juice baits. Crop Protect 125:1–9

Rendon D, Walton VM (2019) Drip and overhead sprinkler irrigation in blueberry as cultural control for *Drosophila suzukii* (Diptera: Drosophilidae) in northwestern United States. J Econ Entomol 112:745–752

Rendon D, Hamby KA, Arsenault-Benoit AL et al (2020) Mulching as a cultural control strategy for *Drosophila suzukii* in blueberry. Pest Manag Sci 76:55–66

Rice KB, Short BD, Leskey TC (2017) Development of an attract-and-kill strategy for *Drosophila suzukii* (Diptera: Drosophilidae): evaluation of attracticidal spheres under laboratory and field conditions. J Econ Entomol 110:535–542

Rogers M, Burkness EC, Hutchison WD (2016) Evaluation of high tunnels for management of *Drosophila suzukii* in fall-bearing red raspberries: potential for reducing insecticide use. J Pest Sci 89:815–821

Roubos CR, Gautam BK, Fanning PD et al (2019a) Evaluation of adjuvants to improve control of spotted-wing drosophila in organic fruit production. J Appl Entomol 143:706–720

Roubos CR, Gautam BK, Fanning PD et al (2019b) Impact of phagostimulants on effectiveness of OMRI-listed insecticides used for control of spotted-wing drosophila (*Drosophila suzukii* Matsumura). J Appl Entomol 143:609–625

Sampson BJ, Easson MW, Stringer SJ et al (2019) Laboratory and field assessments of erythritol derivatives on the survival, reproductive rate, and control of *Drosophila siuzukii* (Diptera: Drosophilidae). J Econ Entomol 112:173–180

Santoiemma G, Mori N, Tonina L et al (2018) Semi-natural habitats boost *Drosophila suzukii* populations and crop damage in sweet cherry. Agric Ecosyst Environ 257:152–158

Santoiemma G, Trivellato F, Caloi V et al (2019) Habitat preference of *Drosophila suzukii* across heterogenous landscapes. J Pest Sci 92:485–494

Sarkar N, Rhodes EM, Spies JM et al (2020) Evaluation of non-target effects of OMRI-listed insecticides for management of *Drosophila suzukii* Matsumura in berry crops. J Appl Entomol 144:12–25. https://doi.org/10.1111/jen.12713

Tait G, Kaiser C, Rossi-Stacconi MV et al (2018) A food-grade gum as a management tool for *Drosophila suzukii*. Bull Insectology 71:295–307

Tait G, Park K, Nieri R et al (2020) Reproductive site selection: evidence of an oviposition cue in a highly adaptive dipteran, *Drosophila suzukii* (Diptera: Drosophilidae). Environ Entomol 49:355–363

Takamori H, Watabe H, Fuyama Y et al (2006) *Drosophila subpulchrella*, a new species of the *Drosophila suzukii* species subgroup from Japan and China (Diptera: Drosophilidae). Entomol Sci 9:121–128

Tang SB, Lee JC, Jung JK, Choi MY (2017) Effect of erythritol formulation on the mortality, fecundity and physiological excretion in *Drosophila suzukii* (Diptera: Drosophilidae). J Insect Physiol 101:178–184

Thistlewood HMA, Rozema B, Acheampong S (2019) Infestation and timing of use of non-crop plants by *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae) in the Okanagan Basin, Canada. Can Entomol 151:34–48

Timmeren SV, Isaacs R (2013) Control of spotted wing drosophila, *Drosophila suzukii*, by specific insecticides and by conventional and organic crop protection programs. Crop Protect 54:126–133

Timmeren SV, Sial AA, Lanka SK, Spaulding NR, Isaacs R (2019) Development of a rapid assessment method for detecting insecticide resistance in spotted wing drosophila (*Drosophila suzukii* Matsumura). Pest Manag Sci 75:1782–1793

Trimble RM, Vickers PM (2000) Evaluation of border spays for managing the codling moth (Tortricidae: Lepidoptera) and the apple maggot (Tephritidae: Diptera) in Ontario apple orchards. J Econ Entomol 93:777–787

Vargas RJ, Stark JD, Hertlein M, Mafra Neto A, Coler R, Piñero JC (2008) Evaluation of SPLAT with spinosad and methyl eugenol or cue-lure for "attract-and-kill" of oriental and melon fruit flies (Diptera: Tephritidae) in Hawaii. J Econ Entomol 101:759–768

Walsh DB, Bolda MP, Goodhue RE, Dreves AJ, Lee J, Bruck DJ, Walton VM, O'Neal S, Zalom FG (2011) *Drosophila suzukii* (Diptera: Drosophilidae): invasive pest of ripening soft fruit expanding its geographic range and damage potential. J Integr Pest Manag 2:1–7

WeiBinger L, Schrieber K, Breuer M, Müller C (2019) Influences of blackberry margins on population dynamics of *Drosophila suzukii* and grape infestation in adjacent vineyards. J Appl Entomol 143:802–812

Wright SE, Leskey TC, Jacome I, Pinero JC, Prokopy RJ (2012) Integration of insecticidal, phagostimulatory, and visual elements of an attract and kill system for apple maggot fly (Diptera: Tephritidae). J Econ Entomol 105:1548–1556