Spotted Wing Drosophila Controls: A Systematic Review

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Summary

Spotted Wing Drosophila (*Drosophila suzukii)* has spread thoughout the world and the continental USA very rapidly. Models predict its widespread distribution in temperate and subtropical climate zones. A number of monitoring devices, lures and catch areas have been studied with mixed success but no protocol has been proven the best. The cup color, number of entries in the cup and the type of lure seems to affect the actual estimate of the population at any one time. Positioning traps around the cultivated field near a pile of rotten fruit seems to attract more flies than positioning the traps in the middle of the field. A sugar-yeast/vinegar combination seems to work effectively but other lures work as well. Alternate attractants maybe needed during the different seasons.

Management consists of various approaches that work best in combination:

1. Monitor your fields and adjacent fields, especially spots with wild fruit, for the presence of SWD. Do not use trapping as a method of control since it has been shown it is not effective
2. Implement preventive management strategies including exclusion netting, pruning and weed mat mulches prior to detecting SWD in traps or when berries are ripening or ripe.
3. Once identified, start a chemical (or alternative for organic growers) control, rotating pesticides and continue monitoring, including fruit checks. Thorough spray coverage in the early morning or evening, is paramount because a few survivors will allow for SWD population to escalate again.
4. Controls other than chemical controls are limited in scope and are still being investigated. A recent publication for organic berries recommends some strategies.
5. Harvest fields thoroughly to insure as little fruit left as possible. Dispose of fruit on the floor or left in the bushes. Field sanitation is paramount since SWD can emerge from piles of old fruit and from compost piles. Not only discard fruit but bag it or decompose it thoroughly to insure it is not used by SWD. Clear plastic bags are preferred since the SWD will be killed faster.
6. Store fruit below 40F to insure eggs and larvae do not develop.

Introduction

Drosophila suzukii is an invasive species of Drosophila that has become a major pest of fruits such as blueberries and cherries and stone fruits. *D. suzukii* are native to Asia where it is endemic; however, the relatively fast rate of the global spread of SWD is of special concern causing adverse economic effects (Asplen et al, 2015). It was first observed in the United States (USA) in Hawaii in 1980 without the reporting of causing economic damage (CABI, 2017). *D. suzukii* was first reported in mainland USA in a raspberry field in Santa Cruz County, California in 2008. In 2009 it had spread to more than 20 counties in California, Oregon, Washington, Florida, and in British Columbia, Canada. In 2010, *D. suzukii* was detected in the USA in Michigan, Mississippi, North Carolina, South Carolina, Utah, and Wisconsin. The spread of *D. suzukii* has continued in the USA, as well as Canada, Europe, Argentina and Brazil in South

America (CABI, 2017) and Mexico (Lee et al, 2011). Models indicate their presence in known affected areas already, mainly in temperate and subtropical areas in the continents of Asia, Europe and North and South America. Models predict further invasions of the African and Australian continents due to the environmental suitability of these areas for this species (dos Santos et al, 2017).

As with many other Drosophilia species, *D. suzukii* is a Spotted Wing Drosophila (SWD), males have a dark spot on each wing. However, unlike many insects that infest overripe and rotting fruit, the *D. suzukii* can infest unripe fruit. *D. suzukii* females are especially damaging because they have a saw-like serrated ovipositor that enables them to break into hard-skinned ripening fruit and lay eggs inside the fruit, which causes extensive damage from larvae feeding within the fruits (Rota-Stabelli, Blaxter, & Anfora, 2013). Although, Kinjo et al (2013) demonstrated using 12 blueberry cultivars that fruit firmness had a significant effect on *D. suzukii* infestation. In their experiments, the firmest cultivar, Delite, contained the fewest eggs compared to softer-skinned blueberries such as Herbert and Darrow. The study concluded that female *D. suzukii* will oviposit more eggs in softer blueberry fruits than in firmer fruits (Kinjo et al, 2013).

Captivity observations reported the lifespan of *D. suzukii* as 10 to 24 days (Walsh et al, 2011). Development of *D. suzukii* from egg to adult took 8 days at 25°C/77°F and from 21 to 25 days at 15°C/59°F (Lee et al, 2011). Adult *D. suzukii* are described as small flies only 2 to 3 mm in size with red eyes and pale brown or yellowish-brown thorax and abdomen (Walsh et al, 2011). Males attract females for mating by fanning their wings and tapping their legs. Female *D. suzukii* are fecund and can lay hundreds of eggs over a lifetime (Lee et al, 2011). Walsh et al (2011) reported that females lay 1 to 3 eggs per oviposition site and average 380 eggs in a lifetime. The translucent, milky-white, glossy eggs develop and hatch inside the ripening fruit. The milky characteristic diminishes and larvae become visible. The larval development occurs inside the fruit where the larvae feed on the host fruit until it exits to pupate. Fruit damage can be extensive as multiple clutches of larvae are possible on the same fruit because many females may visit the same fruit for oviposition. Additionally, the damaged fruit creates opportunities for other pests and fungal and bacterial pathogens to invade the fruit (Walsh et al, 2011).

D. suzukii occur in a wide variety of environments; however, the invasion into northern climates has been unexpected. Shearer et al (2016) investigated how *D. suzukii* adapted to harsh climates and can overwinter in northern regions. As summer progressed to winter, a trend was observed of higher proportions of insects with the winter morph phenotype, which is characterized by longer wings and darker pigmentation compared to the summer morph. The winter morph was associated with increased survival at 1°C. Demonstrating gene expression differences and physiological mechanisms, Shearer et al (2016) provided the first molecular evidence of a reproductive diapause in *D. suzukii*.

Controlling for *D. suzukii* infestation is critical for growers economically. Crop losses of 20-40% have been reported in California, Oregon, and Washington (CABI, 2017). The primary method for controlling SWD in the USA is the application of insecticides (Asplen et al, 2015), which has several disadvantages. Other methods include cultural and biological controls. Overall a global effort for an integrated pest management system that provides effective strategies for controlling SWD is needed.

Method

The research question for the systematic review was: What are effective methods for controlling *Drosophila suzukii* infestation in blueberries. A literature search was conducted using 3 databases with combinations of the following keywords: *Drosophila suzukii*, spotted wing drosophila, management, control, survey, trap, attractant, chemical, biological, cultural, predator, post-harvest. Study inclusion [experimental design with a control, published in English language, etc., and exclusion criteria for systematic review. Google scholar was found to contain the most comprehensive list of peer-reviewed articles. Further search in Google for extension and other relevant sites was conducted. The search spanned from the 2000s until September 2018, with an emphasis on the past 5 years.

Results

Evaluating Controls: Chemical Control

A large number of articles conducted experiments for chemical control of SWD or specifically, *D. suzukii,* in berries. Other general summary information about chemical control……

Any chemical management has to include rotating modes of action to prevent resistance. However, little pesticide resistance has been shown from studies during the past years (Isaacs et al, 2015). All insecticide applications reviews reported greater adult acute mortality. Older SWD male were significantly more susceptible than females when using the most effective insecticide, malathion, after 30 successive applications (Smirle et al, 2017). The selection for polygenic resistance to malathion using repeated exposure to sublethal concentrations with both the original and an additional blueberry-collected population of laboratory-reared SWD determined no significant difference in susceptibility after 30 generations. Most applications, whether singly or combined, did not have much residual effect after one to two days. Some could last three to four days, but seldom one week. Geographic location (Southeastern vs Midwest vs Northwest US) with different climatic conditions and management practices will affect the pest management program used.

Bruck et al (2011) conducted insecticide field applications in berry crops in the USA west coastal region. Insecticide products that were known or suspected of having activity against SWD and were registered for use on small fruits in Oregon, Washington, or California were used in field spraying applications in 2009-2010 on strawberry, blueberry, and red raspberry. Three classes of pesticides (pyrethoids, organophosphates, and spinosyns) were effective for 5 to 14 days of residual control. Neonicotinoids were not effective and currently not recommended for managing *D. suzukii.* After one day field exposure of *D. suzukii* to blueberries in Washington, malathion caused the greatest levels of adult mortality followed by spinetoram, bifenthrin, zeta-cypermethrin, and imidacloprid. Results of the thiamethoxam and acetamiprid applications were not significantly different compared with the untreated control. Only malathion and spinetoram had a significantly greater mortality of *D. suzukii* than the control after 7 days (Bruck et al, 2011). Programs had no residual effects at seven days after treatment. Within programs, organophosphates (phosmet and malathion) and pyrethroids (zeta-cypermethrin and fenpropathrin) were the most effective.

With the presence of multiple generations of *D. suzukii* in a growing season, the insects can develop a biological/genetic resistance to the chemicals. Growers should rotate chemicals from different modes of action to prevent or delay resistance to insecticides. For organic growers, spinosad is the most effective organic insecticide and *D. suzukii* resistance to this would be disastrous (Bruck et al, 2011). Because of this, Bruck et al (2011) recommended that organic small-fruit growers follow spinosad label restrictions and rotate with pyrethrin applications. In organic red raspberries, high-rate pyrethrin applications reduced infestation but more frequent applications were required to achieve *D. suzukii* control. A single application of spinosad and two applications of pyrethrin had significantly lower levels of infestation (Bruck et al, 2011).

Van Timmeren and Isaacs (2013) conducted field trials with highbush blueberry in Allegan and Ottawa Counties in southwest Michigan in 2011-2012 using conventional, organic, or minimally managed practices to control for SWD. Spray applications included several chemicals, such as acetamiprid, bifenthrin, carbaryl, imidacloprid, zeta-cypermethrin, fenpropathrin, and phosmet for control of *D. suzukii*. Organic fields received organic insecticides and the minimally managed fields were regularly mowed and pruned but not sprayed. Fresh chemical residues of organophosphate, pyrethroid, and spinosyn insecticides had strong initial control on D. suzukii. The organic pyrethrum insecticide was not effective but the neonicotinoid insecticide, acetamiprid, had control activity lasting 5 days. It was noted that rainfall after application reduced the effect of all insecticides (Van Timmeren & Isaacs, 2013).

Diepenbrock et al (2016) examined the acute and residual efficacy of rotational treatment programs designed to meet the needs of commercial blueberry growers in the southeastern United States. Within programs, organophosphates (phosmet and malathion) and pyrethroids (zeta-cypermethrin and fenpropathrin) were the most effective. Season-long rotational chemical treatment programs can be designed to minimize crop damage, meet exportation requirements and manage for resistance. SWD pressure was high throughout the study period, peaking in the first week of August. All treatments significantly reduced SWD infestation in all evaluations, compared with the untreated check, except Mustang Maxx and Veratran + Entrust in the 7-Aug harvest (Table 1). The twice per week application interval of Veratran did not improve its performance over once per week. The study also did not show a rate response in the Harvanta treatments. The Cormoron treatment, a premix of novaluron and acetamiprid, performed equal or marginally better than a full rate of each of the actives separately.

The timing of applying insecticides can influence treatment effectiveness. Sprayings should be conducted after fruit coloring occurs during ripening, when flies are most active such as early morning or late evening when temperatures are 65-70 degrees F. Flies are least active at higher temperatures of 86 F. from
https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20883/em9026.pdf

Chemical odor deterrents have also been used to assist in reducing SWD infestation. Olfactory behavior in *D. suzukii* is related to fruit infestation. The composition of volatile compounds emitted during the ripening process of fruits changes depending on the maturation stage of the fruit. Fruits have higher respiration rates and emit higher levels of CO_2 during ripening and have decreased levels of CO_2 emission with increased rates of yeast-derived volatiles as fruits over-ripen (Pham & Ray, 2015). Whereas most Drosophila prefer to feed and lay eggs on over-ripe and fermenting fruits fallen from plants, *D. suzukii* prefer fruit that is ripening. Pham and Ray (2015) noted that much is known about attractive olfactory odorant pathways in Drosophila species; however, little is known about avoidance pathways in Drosophila. Pham and Ray (2015) identified insect repellents for *D. suzukii* that reduced blueberry fruit damage during ripening. At 10% concentrations, *D. suzukii* avoided traps containing DEET-substitute compounds of butyl anthranilate, methyl N,N-dimethylanthranilate, and ethyl anthranilate. In butyl anthranilate-treated blueberries, *D. suzukii* significantly reduced oviposition, 95% of the unhatched eggs were in the control berries (Pham & Ray, 2015). Wallingford et al (2015) investigated aversive odors and potential *D. suzukii* oviposition deterrents and concluded that geosmin and octanol were effective deterrents. Additionally, fewer adult *D. suzukii* were reared from red raspberry fruit associated with octanol odors. Benzaldehyde did not provide a significantly effective deterrent (Wallingford et al, 2015). Overall, insect repellents appear to be useful in reducing damage to ripening fruit.

Advantages and disadvantages of chemical control

There are benefits (advantages) and limitations (disadvantages) for using chemical control of pests. Advantages of chemical pest control are initial short-term effectiveness, it can be cost effective and time effective compared to other methods, and chemicals are readily available and easy to use. Disadvantages of using chemicals include rain wash off of chemicals, chemical residue limits for fruits, limited organic options, harm is usually done to natural pest predators, repeated exposure to insecticides creates insect resistance to the chemicals, secondary effects of pesticide use on human health and the environment, sustainability, and it can become costly with repeated sprayings. The cost of insecticides vary. Chemical companies may carry the cost of developing and testing new products over to the grower.

When using chemical control, confirm SWD are in the fields before spraying by using traps or checking fruit for presence of SWD. Sprays must be applied when adults are present and before they lay eggs. Sprays will not control larvae in the fruit. Caprille et al (2011) reported the insecticide spinosad is effective and has less negative effects on the environment than other insecticides. Malathion also controls SWD but is toxic to bees and other natural enemies of some pests and should be applied with care to the target plants while avoiding chemical drift and runoff (Caprille et al, 2011).

For organic growers, few NOP effective chemicals are available. Entrust (spinosad) is the only effective ORI allowed in organic crops but this needs to be rotated. The other ORI have fair to poor effectiveness. Thus, it is imperative that organic growers conduct integrated pest management practices: monitor and track, sanitize fields, prune and mulch well and keep dry, do exclusion netting if possible, harvest frequently and thoroughly, and apply insecticides effectively.

Properly selected chemicals are effective in eliminating most of the pests; however, there will be some pests with slight genetic variations that allow for chemical resistance. Succeeding generations of the resistant pests can develop total resistance to the chemical. Additionally, vast chemical spaying can kill the pests and the pests' natural enemies creating resurgence and a disruption in the natural control of pests. New chemicals are continuously being developed and tested, which can increase the cost to the grower.

Evaluating Controls: Cultural Control

Sanitation of the crop is another important component of a successful integrated pest management program. Over two growing seasons, harvest schedules for the effect on infestation by D. suzukii were compared. Results showed that fruit harvested every 1 or 2 days had significantly fewer D. suzukii larvae than a 3-day harvest schedule. Furthermore, it was found that yield per unit effort was highest on a 2-day schedule. In terms of sanitation, it was found that bagging infested waste berries killed 99% of larvae after 32 h, with higher fruit temperatures in clear bags than white or black bags. In combination, these methods can reduce the effects of this invasive pest on raspberry production. This study will provide guidance to growers on culturally based IPM tactics to decrease reliance on chemical management (Staconni et al, 2018)

Evaluating Controls: Biological Control

Chouinard et al (2016) presented crop protection strategies that embrace "exclusion, sterilization and disruption" instead of pesticide sprays and killing agents. ….sterile insect technique (SIT) and mating disruption http://ac.els-cdn.com/S0304423816301200/1-s2.0-S0304423816301200-main.pdf?_tid=2ca4316e-7c89-11e7-9b78-00000aab0f6c&acdnat=1502231606_c47587c783ffed88506869cca5cdea14

The sterile insect technique (SIT) involves mass-producing a pest species in an artificial environment, exposing them to ionizing radiation causing sterility, and releasing them into the wild to reproduce. Sterile males mating with wild females results in female sterility (not able to produce viable eggs), which can lead to population eradication. For success, the mass-produced insects must be able to compete with their wild counterparts for mating (Lance & McInnis, 2005). http://www-naweb.iaea.org/NaFa/ipc/public/Sterile_Insect_Technique_book.pdf. SIT is a costly method.

Natural predators (spider or predaceous bug), parasitoids (wasp), pathogens (fungi, bacterial, virus). Grow plants nearby that attract beneficial insects, coreopsis, coneflower, sunflower, goldenrodm(Gabarra et al 2014). Predators of SWD larvae in the field- ants, spiders, rove beetles. Predators of SWD pupae - ants, spiders. Parasitoids Also refer to https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20883/em9026.pdf for biological control.

Avoiding plants that serve as wild hosts to SWD is important in controlling SWD. Wild hosts of SWD near crop fields can influence the spread of SWD tremendously by ovipositing on early season wild fruit and later causing SWD infestation to nearby crops. Common wild hosts for SWD include honeysuckle (*Lonicera* spp.), brambles such as wild raspberries and blackberries (*Rubus* spp.), mulberry (*Morus rubra*), pin cherry (*Prunus pensylvanica*), elderberry (*Sambucus* spp.), dogwood (*Cornus* spp.), pokeweed (*Phytolacca Americana*), buckthorn (*Rhamnus cathartica*), yew (*Taxus* spp.), and purple flowering raspberry (*Rubus odoratus*) (Ripley, 2015).

Websites of interest

National

https://swdmanagement.org/
http://spottedwing.org/ (OregonSU)
https://learn.extension.org/events/2965

State

https://www.canr.msu.edu/news/michigan-spotted-wing-drosophila-update-july-31-2018
https://entomology.ces.ncsu.edu/2016/06/preventing-and-managing-spotted-wing-drosophila-infestation/
https://site.caes.uga.edu/blueberry/swd/
https://ag.umass.edu/fruit/resources/spotted-wing-drosophila
https://extension.psu.edu/spotted-wing-drosophila-update
https://www.ars.usda.gov/pacific-west-area/parlier/sjvasc/cpq/docs/spotted-wing-drosophila-development/services/

International

https://horticulture.ahdb.org.uk/swd
https://gd.eppo.int/taxon/DROSSU
https://www.researchgate.net/project/DROPSA-Biological-control-of-Spotted-Wing-Drosophila
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Table 1. Efficacy of rates & timings of insecticides against SWD in Blueberry (Wise et al, 2018)

Treatment/formulation	**Rate /acre**	**Appl. timing**	**(# SWD per lb)**			
			31 Jul	**7 Aug**	**14 Aug**	**21 Aug**
Untreated Check			84.5 a	119.8 a	63.8 a	49.8 a
Cormoran EC	20 fl oz	ACEGI	32.5 bc	35.5 d	20.0 b	9.8 fg
Rimon EC	20 fl oz	ACEGI	36.8 bc	56.0 bcd	18.8 b	10.3 fg
Assail 30SG	5.3 oz	ACEGI	33.0 bc	68.5 bcd	11.8 b	16.0 b–f
Imidan 70WP +	1.33 lb	A	26.8 bc	44.5 bcd	10.3 b	12.0 d–g
TriFol L	0.5 pt/100 gal	A				
Delegate 25WG	6 oz	C				
Lannate LV	3 pt	E				
Exirel 0.83SE	10 fl oz	G				
Grandevo WDG +	3 lb	I				
R-56 P	0.1 3% v: v	I				
Grandevo WDG +	3 lb	A	19.8 bc	48.5 bcd	11.0 b	11.3 efg
R-56 P	0.13 % v: v	A				
Imidan 70WP +	1.33 lb	C				
TriFol L	0.5 pt/100 gal	C				
MustangMaxx 0.8EC	4 fl oz	E				
Delegate 25WG	6 oz	G				
Grandevo WDG +	3 lb	I				
R-56 P	0.13 % v:v	I				
Grandevo WDG +	3 lb	A	27.0 bc	60.5 bcd	15.3 b	8.8 g
R-56 P	0.13 % v:v	A				
Delegate 25WG	6 oz	C				
Imidan 70WP +	1.33 lb	E				
TriFol L	0.5 pt/100 gal	E				
Lannate LV	3 pt	G				
MustangMaxx 0.8EC	4 fl oz	I				
Imidan 70WP +	1.33 lb	ACEGI	15.5 c	49.0 bcd	8.5 b	9.8 fg
TriFol L	0.5 pt/100 gal	ACEGI				
MustangMaxx 0.8EC	4 fl oz	ACEGI	23.8 bc	85.3 ab	13.0 b	20.5 bc
Azera 0.21SC	32 fl oz	ABCDEF	42.8 bc	72.0 bcd	12.5 b	22.0 b
Entrust 2SC	6 fl oz	ABCDEF	40.5 b	61.5 bcd	24.8 b	18.8 bcd
Veratran D WP	15 lb	ABCDEFGHI	30.5 bc	70.3 bcd	25.8 b	11.5 d–g
Veratran D WP	15 lb	ACEGI	42.5 b	35.3 d	12.3 b	10.5 efg
Veratran D WP +	15 lb	ACEGI	39.3 b	79.8 abc	13.3 b	12.8 d–g
Entrust 2SC	6 fl oz	BDFH				
Harvanta 50SL	16.4 fl oz	ACEGI	27.0 bc	43.3 cd	12.3 b	13.3 c–g
Harvanta 50SL	22 fl oz	ACEGI	28.8 bc	52.3 bcd	12.8 b	14.3 b–g

Means followed by the same letter do not significantly differ ($P = 0.05$, Tukey's HSD). ANOVA performed on log-transformed data; data presented are actual counts. A = 18 Jul (First Trap Catch with ripe fruit), B = 21 Jul (A + 3 Days), C = 25 Jul (A + 7 Days), D = 27 Jul (C + 3 Days), E = 1 Aug (C + 7 Days), F = 3 Aug (E + 3 Days), G = 8 Aug (E + 7 Days), H = 10 Aug (G + 3 Days), I = 15 Aug (G + 7 Days).