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Comparison of Commercial Lures and Food Baits for Early Detection of Fruit Infestation Risk by *Drosophila suzukii* (Diptera: Drosophilidae)

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Abstract

Drosophila suzukii (Matsumura; Diptera: Drosophilidae) is one of the most serious invasive pests of berries and cherries worldwide. Several adult monitoring systems are available to time foliar application of insecticides with the expectation of detecting the presence of *D. suzukii* before they infest susceptible crops. We tested this by comparing four different trapping systems based on two homemade baits, apple cider vinegar (ACV) or fermenting dough, and two fermentation volatile-based commercial lures, Scentry and Trécé. Traps baited with dough or Scentry captured more *D. suzukii* than traps baited with ACV or Trécé in blueberries and traps baited with Trécé in raspberries. In blueberries, traps baited with Scentry, Trécé and dough provided 11–21 d of warning prior to first detection of fruit infestation. However, these traps were not as effective in summer floricane raspberries. The Scentry lure baited traps detected *D. suzukii* on the same week as the first detection of fruit infestation and other trapping systems detected the fly 4 to 11 d after the first detection, suggesting the need for an improved *D. suzukii* detection system in raspberries. Both synthetic lures (Scentry and Trécé) were significantly more selective for *D. suzukii* than dough bait, although the selectivity of all four tested lures/baits were relatively low at <20%. Our results suggest that in locations where *D. suzukii* adults are not trapped in late winter and spring, adult monitoring of *D. suzukii* using a sensitive trapping system may provide early warning of pending infestation risk thereby potentially reducing unnecessary insecticide applications.

Key words: early detection, spotted wing drosophila, monitoring, infestation risk, chemical lure

Drosophila suzukii (Matsumura; Diptera: Drosophilidae), spotted wing drosophila (SWD), is a serious pest of cherries and berries worldwide. It is native to Asia, but after being first recorded in United States and Europe both in 2008, *D. suzukii* spread rapidly and is now considered widespread in the United States and Europe (Asplen et al. 2015). Unlike most other drosophilids, *D. suzukii* females can oviposit on fresh fruits using a specialized serrated ovipositor, making them a serious threat to soft-skinned fruit crop production. Consumer tolerance for fresh or frozen fruit infested by *D. suzukii* is very low.

The combination of high-value fruit crops and low tolerance of infestation has encouraged some growers to initiate chemical control for *D. suzukii* as ripe fruit becomes available. In more northern latitudes, however, it is possible that adult *D. suzukii* are absent or inactive in late winter and spring (Dalton et al. 2011, Hampton et al. 2014, Pelton et al. 2016, Hamby et al. 2016), hence susceptible fruit crops that mature early to mid-season (e.g., June-bearing strawberries) may escape infestation. Also, crops that ripen in mid-season, such as early-maturing blueberries, summer floricane raspberries, and cherries, may fully or partially escape infestation as well depending on site and year (Hampton et al. 2014). Thus, for susceptible crops in more northern latitudes, the ability to reliably monitor *D. suzukii* can be an essential part of an integrated management program. An effective monitoring system would allow growers to confidently delay initiation of chemical control until *D. suzukii* were present and trapped in target crops. For a monitoring system to be reliable the attractants and traps must detect even a small incipient *D. suzukii* population. If undetected and not properly controlled, newly laid eggs can lead to larval development inside fruit where they are much less vulnerable to currently available nonsystemic pesticides registered for *D. suzukii*.

Several commercial lures and homemade baits based on fermentation products and odors typical of a food source (Cha et al. 2012, 2014; Landolt et al. 2012) are available for *D. suzukii* monitoring.

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Whether these food odors are useful in detecting *D. suzukii* before they infest fruit has not been thoroughly evaluated. Apple cider vinegar (ACV) was the initial recommended bait for monitoring *D. suzukii*, although its ineffectiveness was recognized quickly. More recently several versions of different fermentation baits such as yeast-sugar solution (Iglesias et al. 2014), wine and vinegar mixture (Landolt et al. 2012), and whole wheat fermenting dough (Cowles 2013) have been shown to be more effective at detecting *D. suzukii* than ACV but not very selective in terms of nontarget insects. In a study of several different lures in different regions of the United States conducted in 2013, Burrack et al (2015) found that lures based on fermentation products, other than ACV, detected adult SWD prior to first detection of infestation in blueberries and caneberries. However, relatively few fruit were collected to assess infestation (30 to 90 per block per week), with resultant low power to detect even significant infestation in the field. In addition, when this study was conducted, there were no commercial lures available, although they did include a numbered synthetic lure under development by Trécé that has since been commercialized.

A four-component synthetic chemical lure composed of acetic acid, ethanol, acetoin, and methionol has been developed from a mixture of wine and vinegar (Cha et al. 2012, 2014), and was shown to be more attractive and selective than ACV or the original material of wine plus vinegar mixture (Cha et al. 2013, 2015, 2017; Shearer et al. 2015). This chemical lure is now commercially available from two companies (i.e., Scentry and Trécé) formulated using proprietary dispensing technologies and trap designs.

In a preliminary early-detection study conducted in 2014 for blueberries and floricane raspberries in New York, we compared three types of baits/lures for their ability to detect *D. suzukii*; ACV, fermenting dough, and a Trécé lure formulation. Trap catch was temporally juxtaposed to fruit infestation estimated from 400 fruit per block per weekly sample period. The results suggested that both fermenting dough bait and Trécé lure captured *D. suzukii* earlier than fruit infestation in blueberry sites (Supplementary Table S1) and were more attractive than ACV (Supplementary Fig. S1), although traps in raspberries were less effective at detecting flies prior to fining infesting fruit (Supplementary Table S2). Fermenting dough appeared more attractive and more effective for early detection than the Trécé lure tested. Considering the advantages of using synthetic lures over fermentation baits, including grower's preference to use a commercial system, for *D. suzukii* monitoring programs (Cha et al. 2013, 2015), we subsequently tested different versions or formulations of synthetic lures to determine a synthetic lure that is at least as sensitive and efficient as the fermenting dough bait.

Here we report on experiments that compared two new commercially available *D. suzukii* trapping systems (i.e., Scentry and Trécé) and two fermentation bait-based trapping systems (i.e., ACV and fermenting dough) to test whether they captured *D. suzukii* before detection of *D. suzukii* infested fruit in blueberry and raspberry crops in New York. To properly quantify early detection, we started *D. suzukii* trapping early enough in the growing season (i.e., mid-June, 2015) that no adult *D. suzukii* were present and no ripe target crop fruit was available in the field. To quantify fruit infestation, we collected fruits weekly as soon as ripe fruits were available in each experimental site.

Materials and Methods

Commercial Chemical Lure Trapping Systems

D. suzukii trapping systems (i.e., chemical lures and traps) from Scentry (Scentry Biologicals, Inc., Billings, MT) and Trécé (Trécé Inc., Adair, OK) were tested. Lures used in both trapping systems were comprised of four fermentation volatiles (acetic acid, ethanol, acetoin and methionol) isolated from a mixture of wine and vinegar (Cha et al. 2012, 2014, 2017). However, they were formulated in different concentrations and ratios, and dispensed from different proprietary dispensers.

The Scentry *D. suzukii* trapping system is comprised of a Scentry lure and Scentry trap. The Scentry lure combined the four lure components in a gel matrix contained in a plastic bag (7.5 cm × 7.5 cm). The Scentry trap consisted of a clear plastic jar (15 cm-height × 9 cm-diameter) furnished with a white screw cap on top and was encircled by a solid red label (7 cm wide). Three black entry plugs (3 cm diameter) furnished with nine entry holes (0.3 cm diameter) each were situated (9 cm height at center) on three sides of the trap. The lure was hung inside the trap under the lid using a metal S-hook that served the dual purpose as the hanger for the trap.

The Trécé *D. suzukii* trapping system is comprised of a Trécé lure and Trécé trap. The Trécé lure had four components individually compartmentalized in plastic releasers. Three components were compartmentalized on one plastic tab (9 cm × 3.5 cm) and the fourth component was a stand-alone tab (3.5 cm × 3 cm). The Trécé trap consisted of a clear plastic jar (15 cm height × 9 cm diameter) with a white screw cap on top. Two holes (5.5 cm diameter) furnished with red plastic mesh (0.2 cm^2 openings) were located on opposite sides of the trap (9.5 cm height at center) for odor release and fly entrance. The lure hung inside the trap under the lid using a customized plastic clip.

Both Scentry and Trécé traps had a 210 ml of 0.1% soapy water (unscented Seventh Generation soap; www.seventhgeneration.com, United States) as trap drowning solution. The trap drowning solution was replaced weekly and the lures were replaced every 4 wk. The traps were deployed in the fruiting zone of the respective crop (0.5–1 m from ground).

Homemade Fermentation-Bait Trapping Systems

Two homemade trapping systems were tested consisting of a red cup trap and a fermentation bait, either ACV or fermenting dough. The homemade ACV trapping system was 150 ml ACV (with 0.1% unscented soap) as the bait and trap drowning solution in a red cup trap constructed from a red cup (473 ml; Dart Container Corp., Mason, MI) and clear lid (Lee et al. 2013). We further modified the red cup trap by adding black electrical tape (2 cm wide) that is 2.5 cm from top lip of the cup with 40 entry holes (0.32 cm diameter) within the tape zone based on Basoalto et al (2013).

The homemade fermenting dough trapping system used a fermenting dough as the bait in the red cup trap described above. The dough bait consisted of whole-wheat flour (17.25 g), sugar (2 g), dry active bread yeast (0.325 g), ACV (1 ml), and water (25 ml) and placed in a screened specimen cup (130 ml) (Burrack et al. 2015). Trap drowning solution was 75 ml ACV with 0.1% soap. The specimen cup with the dough bait was placed floating in the drowning solution and the trap was covered with a clear plastic lid (Dart Container Corp.).

For both homemade trapping systems, the baits and trap drowning solutions were replaced weekly. The traps were deployed in the fruiting zone of the respective crop (0.5–1 m from ground).

Field Trapping Experiments

Experiments were conducted at four blueberry sites (B1: lat 42.505947N, long 76.708686W; B2: lat 42.793664N, long 76.999764W; B3: lat 42.7069N, long 77.05159W; B4: lat 42.668289N, long 76.42722W) and four summer raspberry sites

(R1: lat 43.165103N, long 77.338497W; R2: lat 43.251447N, long 77.200656W; R3: lat 42.48945N, long 76.72938W; R4: lat 42.74978N, long 77.06786W) in west-central New York to determine the relationship between adult capture and timing of first detection of infested fruit and to compare trap catch performance throughout the growing season in 2015. The four trapping systems compared were: 1) ACV trap: red cup trap baited with ACV, 2) Dough trap: red cup trap baited with fermenting dough, 3) Scentry trap: Scentry SWD trap baited with Scentry lure, and 4) Trécé trap: Trécé SWD Pherocon trap baited with Trécé lure. Each blueberry and raspberry site was considered as a block. Two replicates of each trap were deployed at each site with both replicates placed along the edge of the field within the crop. Traps were separated by at least 3 m. Traps were monitored weekly for 10 wk from 14 June 2015 to 22 August 2015 with traps re-randomized within rows every week. In addition to male and female *D. suzukii*, we enumerated other nontarget drosophilids and noted the presence of flies, beetles, and other nontarget insects.

Fruit Infestation

D. suzukii fruit infestation was measured by collecting blueberry and raspberry fruit from the field and holding collected fruit in the lab (22 ± 2°C) until flies emerged and could be identified. Weekly fruit collections began at the time of first ripe fruit at a site for both blueberry and raspberry. The first ripe fruits were collected on the week of 28 June 2015 from blueberries and on the week of 21 June 2015 from raspberries. At each site, we collected 20 ripe fruits from each of 20 locations (i.e., total 400 raspberries or blueberries/site/week) and put each 20 fruit sample in a rearing container (0.5-liter plastic deli cups with mesh fabric bottoms nested in 1-liter plastic deli cups and covered with mesh fabric to allow ventilation; Wallingford et al. 2016). Rearing containers were monitored daily for fly emergence up to 3 wk. Emerged flies were identified as *D. suzukii* (Hauser 2011).

Statistical Analyses

A randomized complete block design with repeated measures was used with block as a random factor and trap system and week as fixed factors using repeated statement (week) with compound symmetry variance structure in SAS Proc Mixed (version 9.4). A separate analysis was conducted for blueberry and raspberry sites. The contents of the two traps per treatment per site were summed for analysis. *F*-tests were based on the REML estimation and the Kenward–Roger approximation to compute the denominator degrees of freedom for the test of fixed effects. Treatment means were compared using the Tukey-Kramer test ($\alpha = 0.05$) in SAS Proc Mixed. Trap catch data were square-root transformed to improve normality and homoscedasticity (Zar 1984).

Results

Early Detection and Fruit Infestation

At all blueberry and raspberry sites, the first *D. suzukii* adults captured were female, with one raspberry site capturing male and female flies at the same time. Specifically, in blueberries, traps baited with fermenting dough, Scentry lure, and Trécé lure all captured *D. suzukii* adults 1 to 5 wk before the first detection of *D. suzukii* fruit infestation (Table 1). On average, the first females captured by Scentry and Dough traps were 21 d earlier than the first fruit infestation on 29 July 2015. The Trécé trap captured the first *D. suzukii* 11 d ahead of observing infested fruit, but the first fly captures by the ACV trap was 2 d after the first detection of fruit damage (Fig. 1a). On average, the first female *D. suzukii* adults were captured 10.5 d earlier than male *D. suzukii* adults. For male *D. suzukii* flies, first captures by Scentry, Dough, and Trécé traps were 9, 6, and 2 d ahead of the first fruit damage respectively, but 8 d behind for ACV traps.

Compared to blueberry sites, trap catches of adult flies in raspberry usually occurred after infested fruit were detected. Scentry traps first captured adult flies 1 or 2 wk after the detection of *D. suzukii* fruit infestation, with the exception of one site where trap catch first occurred 3 wk ahead of first infestation (Table 1). Dough and Trécé traps also had first adult captures 2–5 and 1–3 wk after the first fruit infestation, respectively. On average, the first trap catches by the Scentry trapping system and first fruit infestation were on the week of 6 July 2015 and the first *D. suzukii* trap captures by ACV, Dough, and Trécé traps were 9, 11, and 4 d after the first fruit infestation, respectively (Fig. 1b). Similar to blueberry sites, the first female *D. suzukii* flies were captured 10.5 d earlier than male *D. suzukii* flies and the first captures of male flies were 7 (Scentry), 7 (Dough), 17 (Trécé), and 17 (ACV) days after the first detection of fruit damage.

Performance of Different Trap Systems Throughout the Season

At blueberry sites, Scentry and Dough traps captured more *D. suzukii* males and females respectively, than ACV and Trécé traps (treatment main effect: $F_{3,9} = 16.81$, $P = 0.0005$ for males, $F_{3,9} = 29.53$, $P < 0.0001$ for females; Table 2). Trap catches among different trap systems in raspberry were similar to those seen in blueberry with the Dough and Scentry systems capturing more flies than the Trécé system (treatment main effect: $F_{3,9} = 6.94$, $P = 0.0102$ for males, $F_{3,9} = 7.80$, $P = 0.0071$ for females; Table 2). However, unlike in blueberries, the ACV system trap catches were not distinguishable from either the Dough and Scentry systems or the Trécé system.

Season long *D. suzukii* trapping results (male and female combined) support a trend of Scentry and Dough traps outperforming ACV and Trécé traps in terms of number of *D. suzukii* captured (Fig. 2). This trend became clearer toward the later season. More specifically, in blueberries, at weeks 8, 9, and 10, Scentry and Dough traps captured significantly more *D. suzukii* than ACV and Trécé traps (except no statistical difference at week 10 between Scentry and ACV and at week 8 between Dough and Trécé traps) (trap by week interaction, $F_{27,108} = 3.72$, $P < 0.0001$ in blueberry; Fig. 2a). In raspberries, at week 9 and 10, Dough trap captured significantly more *D. suzukii* than Trécé traps (trap by week interaction, $F_{27,108} = 2.06$, $P = 0.0049$ in raspberry; Fig. 2b). At both blueberry and raspberry sites, fruit infestation increased at roughly the same rate as the season progressed, though infestations were detected earlier in the raspberry plantings compared to blueberry plantings (Fig. 2). Trap and week main effects were statistically significant at both blueberry and raspberry sites (treatment main effects: $P < 0.007$; week main effects: $P < 0.0001$).

Performance of Different Traps in Terms of Selectivity

In this study, a total of 10,201 and 12,231 *D. suzukii*, 114,374 and 102,014 nontarget drosophilids, 1,699 and 2,789 Diptera, 9,932 and 84,234 Coleoptera, and 9,736 and 9,470 other nontargets, were captured in blueberry and raspberry sites, respectively. In blueberries, the Dough trap captured the greatest number of nontarget drosophilids, which was 1.8-, 10.8-, and 14.1-fold more nontarget drosophilids than Scentry, ACV, and Trécé traps, respectively (treatment main effect: $F_{3,9} = 100.39$, $P < 0.0001$). Still the rates of specificity, calculated as SWD/[SWD + nontarget drosophilids], were all

Table 1. Summary of number of total *Drosophila suzukii* reared out from 400 ripe fruits collected per each site per each week (20 fruits/sample, 20 samples/week/site) and week (and date) of first *D. suzukii* capture by different trapping systems at each site

		Blueberry sites							
		B1		B2		B3		B4	
Week	Date	Reared out	First detect	Reared out	First detect	Reared out	First detect	Reared out	First detect
1	14 June 2015	-		-		-		-	
2	21 June 2015	-	D	-		-		-	
3	28 June 2015	-	S	-		-	D	0	
4	5 July 2015	-		0	D,S	-		0	D,S
5	12 July 2015	0		0	T	-	S	0	T
6	19 July 2015	0	T	32	A	-	T	0	
7	26 July 2015	2		15		0	A	17	A
8	2 August 2015	-		-		57		-	
9	9 August 2015	-	A	-		370		-	
10	16 August 2015	-		-		561		-	

		Raspberry sites							
		R1		R2		R3		R4	
Week	Date	Reared out	First detect	Reared out	First detect	Reared out	First detect	Reared out	First detect
1	14 June 2015	-		-		-	S	-	
2	21 June 2015	1		-		-		-	
3	28 June 2015	0		0		0	A,D,T	0	
4	5 July 2015	0	S	0		45		2	S,T
5	12 July 2015	3	A,T	9		58		9	A,D
6	19 July 2015	2		24	D,S,T	72		75	
7	26 July 2015	153	D	47	A	-		391	
8	2 August 2015	-		-		-		1169	
9	9 August 2015	-		-		-		-	
10	16 August 2015	-		-		-		-	

'-' indicates that fruits were not collected due to unavailability of ripe fruits. A: red cup trap baited with apple cider vinegar, D: red cup trap baited with fermenting dough, S: Sentry trap baited with Scentry lure, T: Trécé trap baited with Trécé lure.

relatively low ranging from 5.5 to 18.9%, although the selectivity of Scentry and Trécé traps were significantly greater than both homemade traps (treatment main effect: $F_{3,9} = 19.17$, $P = 0.0003$; Fig. 3). In raspberries, Dough trap captured the greatest number of nontarget drosophilids, which was 3.1-, 15.3-, and 26.8-fold more nontarget drosophilids than Scentry, ACV, and Trécé traps, respectively (treatment main effect: $F_{3,9} = 18.13$, $P = 0.0004$). Again, the rates of SWD specificity were all relatively low ranging from 4.8 to 13.1% still with the selectivity of Dough trap significantly lower than other three traps tested (treatment main effect: $F_{3,9} = 10.52$, $P = 0.0027$; Fig. 3).

Numbers of nontarget flies were greatest in Dough traps at both blueberries (treatment main effect: $F_{3,9} = 45.76$, $P < 0.0001$) and raspberries (treatment main effect: $F_{3,9} = 1.42$, $P = 0.2995$), although the difference was not statistically significant in raspberries. In both blueberry and raspberry, numbers of nontarget beetles were greatest in traps baited with fermenting dough and lowest in traps baited with Scentry lure (treatment main effect: $F_{3,9} = 20.61$, $P = 0.0002$ in blueberry, $F_{3,9} = 5.39$, $P = 0.0163$ in raspberry; Table 2). In both blueberry and raspberry, numbers of nontarget other insects were greatest in traps baited with fermenting dough and lowest in traps baited with Trécé lure (treatment main effect: $F_{3,9} = 6.92$, $P = 0.0103$ in blueberry, $F_{3,9} = 4.42$, $P = 0.0359$ in raspberry; Table 2). When all nontarget insects were considered, the rates of SWD/[SWD + nontarget insects] were 16.3%, 15.1%, 6.5%, and 4.1% in blueberries and 11.2%, 7.8%, 5.3%, and 2.5% in raspberries for Scentry, Trécé, ACV, and Dough traps respectively.

Discussion

The Dough, Scentry, and Trécé traps on average captured female *D. suzukii* 11 to 21 d earlier than our first record of fruit infestation in blueberries. Thus, the available data indicate that all of these three trapping systems can be used for the efficient early detection of *D. suzukii* for this crop. This pattern was consistent with the results from our preliminary study conducted in 2014, where Dough and Trécé traps captured first *D. suzukii* 19 and 7 d earlier, respectively, than the first blueberry infestation (Supplementary Table S1). However, these trapping systems were not effective as early detection monitoring systems in raspberry sites. In 2015, Scentry trap was the only trapping system that captured *D. suzukii* females on the same week that we detected infested raspberries. The consequences, in terms of infestation risk, of initiating chemical control a week or more after first detection of adult flies have not been investigated. If the rate of increase in infestation is initially slow, as is suggested by data from this study (Fig. 2b), then the risk of delaying treatment 1 wk in raspberries might be minimal, depending on how fruit will be marketed.

All other trapping systems used in raspberries detected *D. suzukii* 4 to 11 d after the first infestation in 2015. This result was also

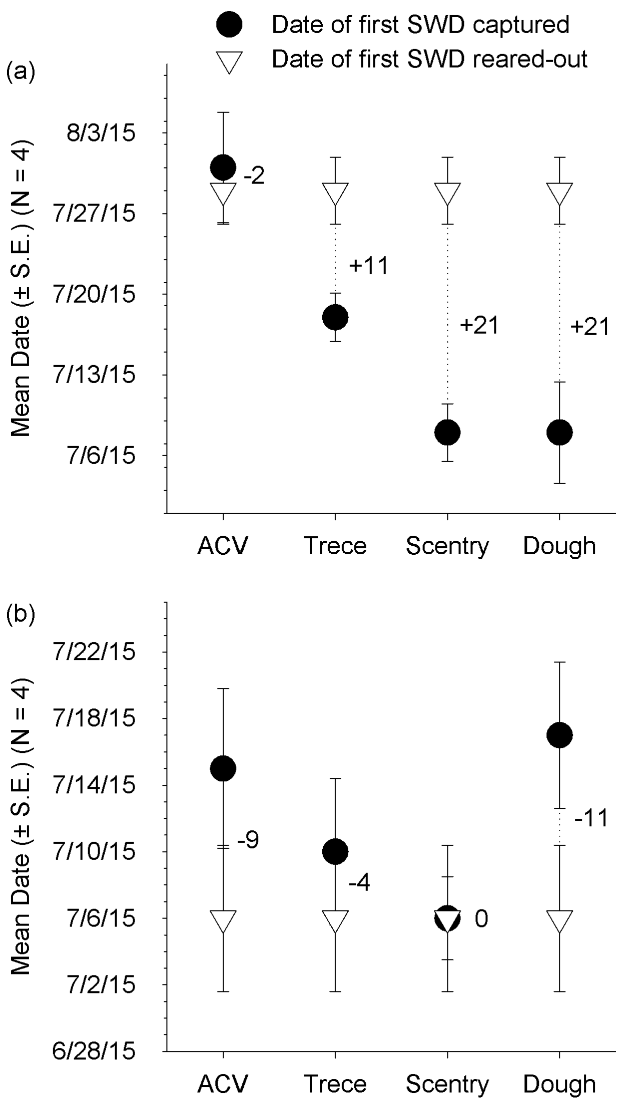

Fig. 1. Summary of mean (± SE) first *Drosophila suzukii* capture date by four different *D. suzukii* trapping systems (ACV, Trécé, Scentry, Dough) in (a) blueberry sites and (b) raspberry sites, and mean first *D. suzukii* reared out date from collected (a) blueberry and (b) raspberry fruits. '+' indicates number of days ahead of first fruit infestation determined by *D. suzukii* rear-out data. '-' indicates number of days behind the first fruit infestation.

similar in 2014 when we compared ACV, Dough, and Trécé traps (Supplementary Table S2). Burrack et al. (2015) also reported a similar finding that various traps detected first *D. suzukii* adults up to 7 wk earlier than first blueberry infestation but up to 2 wk later than first raspberry infestation in Oregon and Wisconsin, respectively. This may be due to stronger competition between fruits and the evaluated trapping systems in raspberries than in blueberries, as *D. suzukii* appears to prefer odors from raspberry fruit over blueberry fruit (Abraham et al. 2015) and raspberry is a preferred host for oviposition (Lee et al. 2011, Bellamy et al. 2013). It might also be related to the timing when ripe fruit is first present in relation to overall *D. suzukii* population levels. Floricane raspberries had ripe fruit slightly earlier than blueberries in this study (Fig. 2) when overall population levels are very low and therefore the probability of detection would be low. Coupled with differences in host preference, this might be sufficient to explain differences in early detection between blueberries and raspberries.

The ability to detect *D. suzukii* before fruit infestation is an important requirement to develop a successful early detection based integrated pest management programs. For example, in places such as cherry orchards in northwestern United States, where cherry harvest is often complete even before the presence of adult *D. suzukii* is detected, a sensitive attractant or trapping system can ensure the absence of *D. suzukii* in the area and save unnecessary pesticide applications. Similarly, in northern latitudes where adult *D. suzukii* is not captured in traps over much of the winter, susceptible fruit crops that mature in early or mid-season, such as June-bearing strawberries, early maturing blueberry cultivars and summer floricane raspberries, may escape infestation in most years. Thus, in more northern latitudes, having a reliable adult monitoring system can improve decision making. In contrast, in areas where *D. suzukii* populations are active throughout the year, including the spring and early summer, weekly calendar-based pesticide applications may be required (Van Timmeren and Isaacs 2013, Diepenbrock et al. 2016), and adult monitoring for initiation of chemical control may be less useful.

In this study, Scentry and Dough traps were generally more attractive to *D. suzukii* than other attractants tested. However, there are several advantages in using commercial chemical lures rather than food-type fermentation baits. First, chemical lures appear to have more consistent performance than baits. For example, although Dough traps and Scentry traps performed similarly for early detection in blueberries (both captured *D. suzukii* females 21 d earlier than the fruit infestation), Dough traps were 11 d later than the Scentry traps in raspberries. Fermentation baits such as Dough traps are alive and the volatiles coming out from the bait may change over the course of fermentation process. Moreover, different environmental conditions and differences in additional microbes that can be introduced to the bait may affect volatile profiles of the same bait in different places. Thus, it is possible that volatile signals from the bait may be less consistent than those from the chemical lures. Second, chemical lure-based trapping systems are easier to maintain than the food bait-based traps. For example, Scentry and Trécé lures do not need weekly replacement, while fermentation baits require weekly replacement. Third, although it is well documented that the selectivity of a trapping system is greatly influenced by location specific conditions (i.e., crop type and nontarget insect community at the location), our study supports the findings from previous studies that chemical lures are generally more selective for nontargets than food-type baits (Cha et al. 2013, 2015). Nonetheless, none of the tested trapping systems appeared particularly selective for *D. suzukii* and further improvement in the selectivity is desirable.

We compared different commercial chemical lures and homemade fermentation baits using traps suggested by the manufacturer of the commercial lures or suggested by the literature (e.g., red cup traps for ACV and fermenting dough; Lee et al. 2013, Burrack et al. 2015). Since we did not test all possible combinations of attractants and trap designs, it is not possible to determine whether the differences in trap captures are due to attractants or due to trap design. In other words, although it is clear that the Dough bait was more attractive to *D. suzukii* than ACV bait in red cup traps, it is not clear whether Scentry lure and Dough bait is still similarly attractive to *D. suzukii* when they are compared either in red cup traps or in Sentry traps. Since the same attractants in different traps can have different effect on the attractiveness to *D. suzukii* (Cha et al. 2013), further studies may be necessary to determine the best trap design for different attractants. In terms of the effect of trap design on nontarget specificity, relatively few large flies were captured in this study compared to a previous study, where a large number of large flies

Table 2. Mean (±SE) numbers of female and male *Drosophila suzukii*, nontarget drosophilid, nontarget fly, nontarget beetle, and other nontarget insects captured in 1) red cup trap baited with apple cider vinegar (ACV), 2) Trécé SWD trap + Trécé SWD lure, 3) Scentry SWD trap and Scentry SWD lure, and 4) red cup trap baited with fermenting dough (Dough) in four blueberry sites and four raspberry sites over the 10-wk trapping period

	Drosophila suzukii		Nontargets			
Treatments	Female	Male	Drosophilids	Fly	Beetle	Other
Blueberry sites						
ACV	6.5 ± 2.9b	3.8 ± 1.8b	120.8 ± 21.1c	4.0 ± 1.0c	27.5 ± 10.3b	16.2 ± 3.4b
Trécé	5.6 ± 1.4b	5.3 ± 2.2b	92.4 ± 14.2c	1.4 ± 0.3c	13.1 ± 4.4b	5.8 ± 0.9b
Scentry	29.5 ± 7.9a	32.8 ± 9.9a	713.5 ± 105.0b	12.8 ± 2.1b	6.6 ± 1.6b	35.8 ± 5.3ab
Dough	32.5 ± 10.5a	20.6 ± 6.3a	1306.4 ± 153.3a	22.7 ± 3.7a	191.6 ± 46.8a	182.8 ± 66.0a
Raspberry sites						
ACV	20.1 ± 10.1ab	22.6 ± 12.3ab	115.4 ± 41.6bc	11.4 ± 6.0ns	424.7 ± 135.0ab	36.1 ± 14.5ab
Trécé	2.7 ± 0.7b	3.4 ± 1.0b	65.9 ± 13.8c	1.7 ± 0.5ns	46.0 ± 14.2b	8.5 ± 1.7b
Scentry	29.3 ± 11.3a	64.8 ± 29.4a	561.6 ± 81.1b	22.0 ± 7.6ns	22.2 ± 6.1b	53.5 ± 15.8ab
Dough	62.6 ± 26.2a	65.4 ± 29.5a	1767.5 ± 296.2a	34.6 ± 12.4ns	1612.9 ± 371.4a	138.7 ± 31.9a

For each insect, within each fruit type, different letters on means indicate significant differences by Tukey–Kramer tests at $P < 0.05$. Statistical tests were based on square-root transformed data. Means from untransformed data are shown.

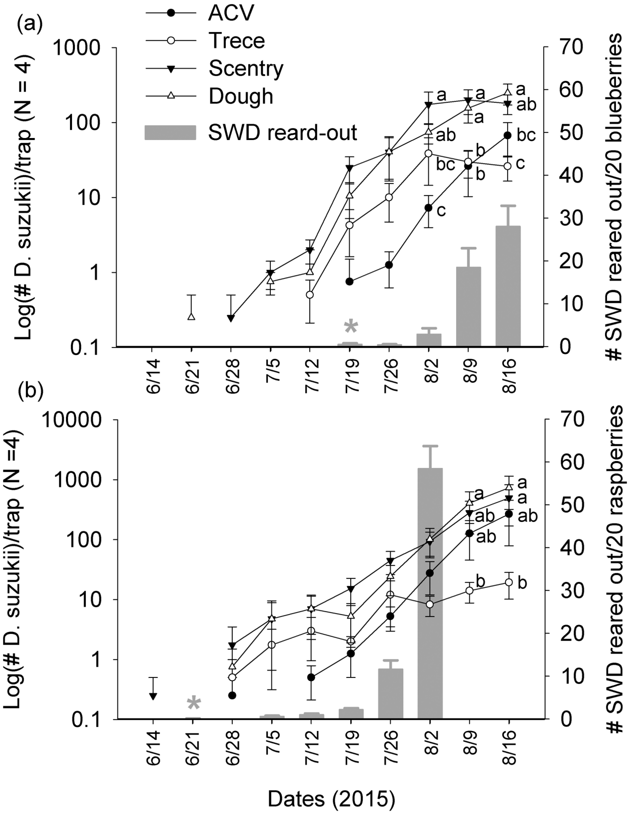

Fig. 2. Mean (± SE) numbers (shown in common log scale) of male + female *Drosophila suzukii* captured (line graphs) by red cup trap baited with apple cider vinegar (ACV), Trécé trap + Trécé lure, Scentry trap and Scentry lure, and red cup trap baited with fermenting dough (Dough) and mean (±SE) numbers of *D. suzukii* reared out (gray bar graphs) from each sample (20 fruits/sample, 20 samples/week/site) in (a) four blueberry sites and (b) four raspberry sites over the 10-wk trapping period. Within each time frame, different letters on means indicate significant differences by Tukey–Kramer tests at $P < 0.05$. * indicates the first *D. suzukii* reared out dates from collected (a) blueberry and (b) raspberry fruits.

was captured using dome traps that had large openings (Cha et al. 2013), suggesting that using small entrance hole was effective in physically eliminating large nontarget insects.

Although improvements are needed for early warning in other crops, our study suggests that the Scentry trap may provide adequate early detection at least in blueberry in more northern latitudes where adult *D. suzukii* are not captured in traps during winter and early spring. Based on Table 1, Dough, Scentry, and Trécé traps all captured *D. suzukii* adults earlier than *D. suzukii* fruit infestation in blueberries and the quality of one system over another varied only in number of *D. suzukii* and nontarget insects captured by different trapping systems. For early detection alone, capturing one *D. suzukii* is as informative as capturing 1,000 *D. suzukii* but it does appear that a more attractive trapping system can capture *D. suzukii* earlier and be

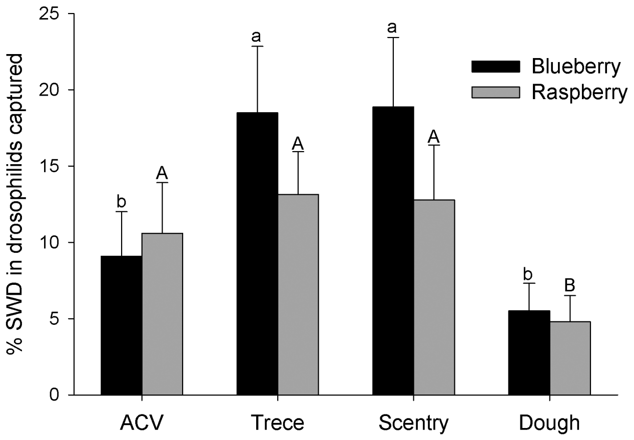

Fig. 3. Summary of % mean selectivity (± SE) of different traps for *D. suzukii*, calculated by number of *D. suzukii* among all the drosophilids captured by each trap. Different letters on means indicate significant differences by Tukey–Kramer tests at $P < 0.05$.

more efficient when the *D. suzukii* population is low such as in early season. Ultimately, the decision on which trapping system to use for early detection will depend on not only the sensitivity of early detection but also the consideration of price, user-friendliness, selectivity, and reliability.

Based on the results presented in this study, however, there is the possibility of capturing female *D. suzukii* weeks before any ripe fruit is present in blueberries. This could lead blueberry growers, in most years, to initiate chemical control as soon as ripe fruit is available, which is similar to the situation in locations where adult *D. suzukii* can be trapped all year. However, our data shows that at most of the blueberry sites, infestation was not detected until one or more weeks after ripe fruit was present. One alternative would be to rely on first male captures in blueberries. First male captures by Scentry, Dough, and Trécé traps were 9, 6, and 2 d ahead of the first fruit damage respectively, which more closely match the timing of infestation in this crop than first capture of females in blueberries. There is also the added advantage that male *D. suzukii* are easier to identify than females. Relying on first male captures to initiate chemical control in summer raspberries would not be advisable based on our results since males were typically not captured until weeks after detection of infestation. The best performing trap in raspberries captured female flies at the same week as the week raspberry infestation was detected.

Finally, we recognize that, although both Trécé and Scentry lures are based on the same chemistry, the Trécé trap and lure was not as effective as the Scentry trap and lure in our study. This may be due to formulation or trap design. Currently there are new formulations of Trécé lures in development that will replace the lure used in this study, so they need to be further tested for their effectiveness. On the other hand, in terms of the 'too early detection problem' discussed above, Trécé trap could be a good alternative for Scentry trap for early detection in blueberries. In blueberries, Trécé trap captured first *D. suzukii* 11 d earlier than first fruit infestation, while Scentry trap captured first *D. suzukii* 21 d earlier. This suggests that Trécé might be better option if first spraying is solely based on early detection in blueberries. It should be also mentioned that in this study we used two traps to determine the early detection. However, it is likely that the probability of *D. suzukii* detection will increase with increasing number of traps. Therefore, future study will evaluate the number of Scentry traps necessary for detection of *D. suzukii* presence before the detection of *D. suzukii* infestation in raspberries.

Pest monitoring is foundational to the development of effective IPM programs. Developing a reliable, easy to use monitoring system for *D. suzukii* has proven challenging due to low tolerance for infestation coupled with relatively low selectivity of current lures and traps. Moreover, for some crops and in some regions the current monitoring technology is not sufficiently attractive to provide early-warning of imminent risk of infestation. However, this study shows that at least for blueberries growing in more northern latitudes, where *D. suzukii* is typically not trapped during late winter and spring, commercial trapping systems and home-made lures (based on fermenting dough) are sufficiently sensitive to detect the presence of adults a week or more before infestation providing growers time to respond. Our results for raspberries indicate there is more of a risk of infestation occurring prior to detection of adult activity with these monitoring systems.

Supplementary Material

Supplementary data are available at *Journal of Economic Entomology* online.

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