Using Red Panel Traps to Detect Spotted Wing Drosophila and its Infestation in US Berry and Cherry Crops

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Using Red Panel Traps to Detect Spotted Wing Drosophila and its Infestation in US Berry and Cherry Crops

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Abstract

Spotted-wing drosophila (SWD), *Drosophila suzukii* Matsumura (Diptera: Drosophilidae), is an invasive pest of thin-skinned fruits in the United States. Monitoring traps are an integral part of SWD integrated pest management, allowing early detection and timely management of this pest. An ideal monitoring trap should be easy to use, effective in capturing SWD, sensitive and selective to male SWD which are easy to identify due to their spotted wings, and able to predict fruit infestation from trap captures. Deli-cup-based liquid traps (grower standard), which make in-situ observations difficult, were compared with red-panel sticky traps, both baited with commercial lures (Scentry, Trécé Broad-Spectrum (BS), and Trécé High-Specificity (HS)), across several US states in blueberries (lowbush, highbush, and rabbiteye), caneberries (blackberry and raspberry), and cherry crops during 2018 and 2021. Results showed that red-panel traps effectively captured SWD, were able to detect male SWD early in the season while also being selective to male SWD all season-long, and linearly related male SWD trap captures with fruit infestation. Although Scentry and Trécé BS lures were equally effective, Trécé BS and Trécé HS were more selective for male SWD in red panel traps than liquid traps. In conclusion, due to its ease of use with less processing time, red-panel trap is a promising tool for detecting and identifying male SWD in-situ and for predicting fruit infestation. However, further research is needed to refine the trap captures and fruit infestation relationship and elucidate the trap-lure interactions in berry and cherry crops.

Keywords: trapping system, commercial lures, broad-spectrum lure, high-specificity lure, fruit infestation

Drosophila suzukii Matsumura (Diptera: Drosophilidae), also commonly known as spotted-wing drosophila (SWD), is an invasive pest of many soft thin-skinned small fruits in the United States (Tait et al. 2021). Initially found in the continental United States in 2008 (Hauser 2011), this drosophilid species is particularly problematic due to the female's ability to infest ripening and intact fruits with its serrated ovipositor (Atallah et al. 2014, Asplen et al. 2015, Tait et al. 2021). In addition, due to its wide host-range and the ability to move back and forth between cultivated crops and non-crop wild hosts (Lee et al. 2015, Urbaneja-Bernat et al. 2020), SWD survives through the off-season making it a successful and significant pest of berry crops (Bal et al. 2017, Ballman and Drummond 2017). This pest is estimated to have caused $56.7 million in losses in blueberries in the U.S., $174.8 million in cherries (Bolda et al. 2010), $39.8 million in raspberries (Farnsworth et al. 2017), and Walsh et al. (2011) estimated that, assuming a 20% yield loss across all SWD-susceptive fruits, damage from this pest could cause $511 million in economic losses. Calendar-based chemical control is the primary measure to suppress SWD populations (Haviland and Beers 2012, Farnsworth et al. 2017, Iglesias and Liburd 2017, Hunter and Sial 2019). These intensive insecticide applications have led to insecticide resistance in SWD populations (Diepenbrock et al. 2016). Thus, integration of monitoring tools with effective lures is important for early detection and timely management of this pest (Landolt et al. 2012, Lee et al. 2013, Cha et al. 2018, Cloonan et al. 2019).

Previous studies on SWD have focused on the development of trapping designs that can capture and retain more flies (Lee et al. 2012, 2013). However, handling the trap contents to identify and count SWD becomes tedious when there is a high number of non-target drosophilids with similar morphology as SWD (Lee et al. 2013). Moreover, it is nearly impossible to identify SWD female from other drosophilids in-situ. In contrast, SWD males have spotted wings which distinguish them from female drosophilids and other male drosophilids with no spotted wings. The ease of identifying male SWD without significant training and equipment makes them ideal for basing action thresholds on their counts. One such thresholds developed for wild blueberry in Maine uses the cumulative average of male SWD. The cumulative average of male SWD is based on three Red Solo ® cups baited with a mixture of yeast and sugar (Drummond et al. 2019). Growers can use the cumulative average male at a site to predict the probability of having infestation the following week; for example, a cumulative average of 3.5 or 7 males results in a 10% or 25% chance of having infestation, respectively, the following week. Thus, further research is needed to develop a trap that is sensitive and selective to SWD, especially to SWD males. If focusing on thresholds based on numbers of males, sensitivity, and selectivity of traps to SWD males early in the season should be prioritized.

Currently, a liquid trap (32-oz deli-cup) is most commonly used to monitor SWD in small fruit crops (Tait et al. 2021). These traps have an attractant such as a fermenting bait solution or lure pouch to attract SWD, such that attracted flies enter through small holes in the cup and are retained in a drowning solution (soapy water) (Lee et al. 2012, Burrack et al. 2020, Tait et al. 2021). However, the liquid traps have some downsides, such as difficulty in making in-situ counts due to the need to handle the drowning solution (Burrack et al. 2020). Therefore, alternative trap types have recently gained some attention such as panel traps with a sticky surface, where flies get attracted and captured in the sticky surface, making in-situ counting easier (Kirkpatrick et al. 2017).

In addition to ease of use, the SWD monitoring trap should also be informative for relating captures with fruit infestation. Therefore, a trap should be sensitive and selective for male SWD and be positively correlated to fruit infestation. However, the ability to attract male

SWD mainly lies in the olfaction and visual cues deployed by the trap and lure combination (Burrack et al. 2020). Initially, fermenting bait solutions such as apple cider vinegar, wine, and a mixture of yeast and sugar were used in a cup trap as both olfaction cues and a drowning solution (Landolt et al. 2012a, Landolt et al. 2012b, Lee et al. 2013). However, four attractive components were identified from the headspace of wine and vinegar (Cha et al. 2012, 2013, 2014, 2015, 2017) and incorporated into commercial synthetic lures (Cha et al. 2018). Generally, these commercially available lures have replaced fermenting bait solutions (Cha et al. 2018, Tonina et al. 2018). Currently, SWD monitoring traps, including the red panel traps, use commercially available lures, such as Scentry® (Scentry from hereon; Scentry Biologicals, Inc., Billings, MT), Trécé Broad-Spectrum® (Trécé BS from hereon; Trécé Inc., Adair, OK), and Trécé High-Specificity® (Trécé HS from hereon; Trécé Inc.), as olfaction cues (Burrack et al. 2015, Cha et al. 2018). Such commercial lures are based on a four-component blend comprised of a mixture of acetic acid, ethanol, acetoin, and methionol (Cha et al. 2014) that was isolated from the headspace of wine and vinegar (Landolt et al. 2012). Previous studies have showed that traps with red color as visual cues were more attractive to SWD than other tested colors and the red-panel traps attracted more male SWD than female SWD in berry crops (Kirkpatrick et al. 2018). In addition, the trap captures of male SWD in liquid traps with Scentry and Trécé lures were correlated with low levels of fruit infestation in NY blueberries and raspberries increasing the reliability of monitoring traps to detect SWD fruit infestation (Cha et al. 2018).

Our study aimed at comparing the red-panel traps with the grower's standard liquid trap baited with different commercial lures (Scentry, Trécé BS, and Trécé HS) in several berry and cherry crops throughout the US. Traps were evaluated for their 1) ability to detect male SWD population during early season and season-long, and 2) selectivity to male SWD compared to non-target captures, and 3) ability to relate male SWD captures with fruit infestation.

Materials and Methods

Study sites and experimental design

This study was conducted across multiple cropping systems (blueberry: *Vaccinium* spp., Ericaceae, blackberry, raspberry: *Rubus* spp., Rosaceae, and cherry: *Prunus avium*, Rosaceae) in five US states (NC, NJ, OR, NY, and ME) in 2018 (total of 16 field sites) and 11 US states (NC, NJ, NY, OR, ME, VA, MD, NH, MI, GA, and FL) in 2021 (total of 27 field sites) (Table 1). The studies started two weeks before harvest, continued for four weeks during harvest, and ended two weeks after harvest. Although we aimed at keeping our methods as consistent as possible across states, the number of sites, treatments, replications, sampling frequency, start and end dates, and fly counts (male SWD, female SWD, and/or other drosophilids) differed among states, crops, and years due to differences in crop phenology, site size and availability, and other unforeseen factors.

Trap designs

Liquid traps were constructed with a 32-oz (~ 1 L) deli cup with equally spaced 12 entry holes on the side of the cup (Kirkpatrick et al. 2017). The drowning solution was made by mixing 0.1% of unscented detergent soap (unscented Seventh Generation soap; www.seventhgeneration.com, Burlington, VT, USA) in 210 ml of tap water. Red panel traps were obtained from Trécé Inc and measure 14 × 25 cm^2 with sticky surfaces on both sides. In contrast to traps used in 2021, , red panel traps used in 2018 study had reduced sticky surface area around the edges of the trap (i.e. had no glue on 1-2 cm from edge to center). Both liquid and red panel traps were hung 0.5-1 m above the ground using a twist tie and placed in the middle of the canopy of the plant for all the crops except for lowbush blueberry where traps were placed above the plant canopy. In liquid traps, lures were hung inside of the lid that goes on of the cup and in red panel traps, lures were hung on the upper non-sticky surface, however in 2021-GA blueberry, lures were hung on the lower side of the trap. Trap contents were collected weekly and the drowning solutions were replaced weekly, and lures were replaced every 4-5 weeks; the drowning solution of the liquid trap was collected in a 16-oz (473 ml) deli-cup and labeled, and a transparent plastic wrap was wrapped around the red-panel traps, to facilitate processing after collection from the field.

Lure types

Lures used in both trapping designs (liquid and panel traps) contained the four-component blend consisting of acetic acid, ethanol, acetoin and methionol (Cha et al. 2012, 2013, 2014, 2015, 2017) However, concentrations and ratios of the formulation and dispensing technology differed among lures (undisclosed proprietary information). For instance, the Scentry lure comes as a clear plastic pouch (9×7 cm^2) with a yellowish formulation inside and volatiles are emitted from all sides of the pouch. Similarly, the Trécé BS lure also comes as a plastic pouch (7×7 cm^2); however, the volatiles are emitted only from one side of the pouch that has the protective peel-off layer. The side where volatiles are emitted from is red-colored, adding a visual cue to the lure. In contrast, the Trécé HS lure comes as a red-colored case (9 cm^2) with three separate tablet-shaped compartments (2-cm diameter each) with the formulations inside and has a peel-off cover on one side. Because of commercial availability, in 2018 only the Scentry lure was tested, while all three lures were tested in 2021.

Sample processing

Trap samples were brought back to the laboratory and the number of male and female SWD and other drosophilids were counted under a dissecting microscope. Liquid trap samples were first filtered through a 160-micron mesh cloth and were then transferred into a gridded Petri dish with 70% ethanol for counting. A transparent plastic sheet with a gridded or checkerboard pattern was placed on the sticky trap to conveniently count the flies under the microscope.

Ripe berries were collected from the area within 5-10 m from where traps were placed. The number of berries per sample varied between crops and states, 226 g berries in 2018-NJ-Highbush30 berries in 2018-NC-Blackberry, 30-40 berries in 2018-NY-Raspberry, 100-250 berries in 2021-NY-Highbush, and 110-151 g berries in 2021-ME-Lowbush. Berries were taken to the lab, incubated for one week under ambient conditions, and the number of larvae and pupae were counted through the salt-extraction method (Shaw et al. 2019) .

Statistical analysis

All data were analyzed in JMP Pro v.16, SAS Institute Inc, Cary, NC, USA. Data from 2018 and 2021 were analyzed separately for each crop (Table 1).

To determine the SWD capture during early season, only the data for first week of fly captures were compared between traps in 2018, and among traps and lures in 2021 via non-parametric test, Wilcoxon/Kruskal-Wallis Test. However, in 2018-raspberry, only three male SWD were captured in the third week (7/16/2018) in liquid traps, so fourth week trap counts were used for the statistics. In 2021-cherry, although red panel traps with Trécé BS captured one male SWD in one of the OR sites in the fifth week, and two male SWD in sixth- and seventh-week data, most of the male SWD occurred after the seventh week, so eighth week data were used for the statistics. In 2021-blackberry, second week data were used for the statistics due to no captures in the first week. Means of male and female SWD captures were compared using Tukey-Kramer HSD at alpha=0.05.

To determine the season long SWD capture rate, male and female SWD captures were pooled over weeks and analyzed with a mixed model using trap as a fixed effect in 2018 and traps and lures as fixed effects in 2021. Random effects were state, field, site, and replications. Data were fit to several distribution models (Normal, Poisson, Negative binomial, and zero-inflated Poisson and Negative binomial) and the best model was chosen based on least AICC value. In some instances where neither of the above-mentioned models fit to the data, data were log(x+1) transformed. When there were significant differences between treatments, means were separated with Tukey's Honestly Significant Difference (HSD) means separation test at alpha=0.05. In 2021-blackberry and cherry, because of low fly captures, the effects of traps and lures on male and female SWD captures were analyzed through a non-parametric test, Wilcoxon/Kruskal-Wallis Test. In 2021, because there was no trap effect, male SWD captures in cherry and female SWD captures in blueberry were pooled over trap and tested for the lure effect.

To determine the selectivity of traps and lures to SWD male and female, the proportions of male and female SWD and non-SWD flies were derived by dividing the respective values with the total drosophilids (sum of male SWD, female SWD, and non-SWD). Then, the proportions of male and female SWD were regressed upon week in a linear model for highbush blueberry, lowbush blueberry, and raspberry in 2018 (weeks:1-8) and blackberry, blueberry (highbush and rabbiteye), cherry, and lowbush blueberry in 2021 (weeks:1-14). ANCOVA was used to compare the intercepts and slopes between the lines of liquid and red panel traps with trap and week as fixed effects, by crop in 2018 and by crop and lure in 2021. If the trap effect and interaction of trap and week effects are not significant, then the intercepts and slopes are the same for both traps respectively.

To determine the relationship between male SWD trap captures and fruit infestation, number of SWD males in the trap, and the number of SWD immatures from fruits collected on the same day/week of trap collection, were regressed in a linear model for highbush blueberry, blackberry, and raspberry in 2018 and highbush and lowbush blueberry in 2021. To compare the coefficients of regression model parameters between liquid and red panel traps, SWD immatures from fruit samples were fitted in a linear model with trap (grouping variable) and trap captures (X-variable) as fixed effects. Untransformed data are presented in the figures with mean ± SE.

Results

SWD captures during early season

In 2018, only the Scentry lure was tested. In lowbush (Figure 1a) and highbush (Figure 1b) blueberry, both liquid and red panel traps captured male and female SWD similarly, in the first week of trap captures. In blackberry, liquid traps captured more male and female SWD than red panel traps (Figure 1c, female: χ^2_1=6.14, p=0.01; male: χ^2_1=5, p=0.02). In raspberry, liquid traps captured more male SWD than red panel traps and both liquid and red panel traps captured similar female SWD (Figure 1d: χ^2_1=5.05, p=0.01).

In 2021, red panel traps captured more male and female SWD than liquid traps in lowbush blueberry (Figure 2a) when baited with the Scentry lure (female: χ^2_1=8.6, p=0.03; male: χ^2_1=10.9, p=0.01), however trap catches were similar between liquid and red panel traps when baited with the Trécé BS lure. In cherry (WA) (Figure 2b), liquid traps captured more female

SWD than red panel traps with both Scentry and Trécé BS lures (Scentry: χ^2_1=7.81, p=0.005; Trécé BS: χ^2_1=5.48, p=0.02), whereas red panel traps captured more male SWD than liquid traps when baited with the Trécé HS lure (χ^2_1=5.98, p=0.01); male SWD captures were similar between two traps with Scentry lures. In cherry (OR), although red panel traps captured male and female SWD with the Scentry lure and only female SWD with the Trécé BS lure, there were no trap counts from liquid traps to compare with. In blackberry (Figure 2d) and blueberry (Figure 2e), liquid and red panel traps captured male and female SWD similarly with Scentry, Trécé BS, and Trécé HS lures.

Season-long SWD captures

In 2018, liquid traps captured more female SWD than red-panel traps in lowbush blueberry (Figure 3a: $F_{1,50}$=6.98, p=0.01), blackberry (Figure 3b: $F_{1,50}$=6.98, p=0.01), highbush blueberry (Figure 3c: $F_{1,214}$=51.62, p<0.0001). In lowbush blueberry (Figure 3a) and blackberry (Figure 3b), liquid and red panel traps captured similar male SWD, whereas in highbush blueberry (Figure 3c) and raspberry (Figure 3d), liquid traps captured more male SWD than red panel traps (highbush: $F_{1,662}$=17.44, p<0.0001; raspberry: $F_{1,80}$=4.99, p=0.028).

In 2021, there was a trap lure interaction in male and female SWD captures in lowbush blueberry (trap×lure: female: $F_{1,87}$=9.04, p=0.003; male: $F_{1,88}$=11.93, p=0.0009), female SWD captures in cherry (trap×lure: female: $F_{1,180}$=23.28, p<0.0001), and male SWD captures in blueberry (trap×lure: male: $F_{2,1308}$=5.5, p=0.004). In lowbush blueberry, red panel traps captured more male and female SWD than liquid traps with the Scentry lure (Tukey HSD, α=0.05), whereas the captures were similar between liquid and red panel traps with the Trécé BS lure (Figure 4a). In cherry, liquid traps captured more female SWD than red panel traps with the

Scentry lure (Tukey HSD, α=0.05), whereas all other captures between liquid and red panel traps were similar with Scentry, Trécé BS, and Trécé HS lures (Figure 4b). Among lures, Scentry captured more male SWD than Trécé BS and Trécé HS lures (χ^2_2=117.26, p<0.0001). In blackberry, liquid traps captured more female SWD than red panel traps with the Trécé BS lure (χ^2_1=8.28, p<0.004), whereas all other captures were similar between liquid and red panel traps with the Scentry and Trécé BS lures (Figure 4c). In blueberry, red panel traps captured more male and female SWD than liquid traps with the Scentry and Trécé BS lures (Tukey HSD, α=0.05), whereas trap captures were similar between liquid and red panel traps with the Trécé HS lure (Figure 4d). Among lures, Scentry and Trécé BS lures equally captured more female SWD than the Trécé HS lure (Tukey HSD, α=0.05).

Selectivity to male SWD over week

In 2018, in highbush blueberry, red panel traps had significantly higher selectivity (intercept, 60.69±23.77 %, t-ratio=2.55, p=0.01) than liquid traps during early week (ANCOVA: F=127.17, df=1, p<0.001, Figure 5) and the selectivity of red panel traps remained similar over the week (Slope, 2.77±4.67 %, t-ratio= 0.59, p=0.56). In lowbush blueberry, only liquid trap captures were available, and the selectivity of liquid traps increased linearly from zero, at a rate of 8.85±2.79 % (t-ratio=3.17, p=0.004) increase each week (Figure 5). In raspberry, the selectivity of both liquid and red panel traps increased linearly with similar intercepts (ANCOVA: F=2.3, df=1, p=0.13) and slopes (ANCOVA: F=0.34, df=1, p=0.56) (Figure 5).

In 2021, in blackberry, the selectivity of red panel traps was significantly higher (45.26±6.63, t-ratio=6.83, p<0.0001) than liquid traps during early week when baited with the Trécé BS lure (ANCOVA: F=88.08, df=1, p<0.0001), The selectivity of red panel traps with the

Trécé BS lure decreased at a rate of -2.65±1.07 % (t-ratio=-2.48, p=0.02) each week, however, the selectivity of red panel traps was never below liquid traps throughout the season (Figure 6a).

In blueberry (Figure 6b), although liquid and red panel traps with the Scentry lure had zero selectivity during the first week, ANCOVA showed red panel traps had higher selectivity than liquid traps during early season (F=16.69, df=1, p<0.0001) and the selectivity of two traps increased linearly with similar rates throughout the season (F=3.57, df=1, p=0.06). Whereas red panel traps with the Trécé BS lure had significantly higher selectivity than liquid traps during early season (ANCOVA: F=65.51, df=1, p<0.0001),) and the rate of increase of selectivity over the season was significantly higher in red panel traps than liquid traps (ANCOVA: F=5.88, df=1, p=0.01). Red panel traps with the Trécé HS lure showed no significant linear relationship between selectivity and week, whereas liquid traps with the Trécé HS lure had a significant increase in selectivity over the week (Slope, 4.22±1.51: t-ratio=2.79, p=0.008) from zero percent in the first week (p=0.39).

In cherry (Figure 6c), only red panel traps with Trécé BS and Trécé HS lures showed a significant linear relationship between selectivity and week. Red panel traps with the Trécé BS lure had selectivity below zero percent during the first week but increased linearly during the later season at a rate of 2.07±0.37 % (t-ratio=5.66, p<0.0001) each week. In red panel traps with Trécé HS lure, the selectivity was high during the first week (Intercept: 22.22±5.32, t-ratio=4.18, p<0.0001) and the selectivity remained similar throughout the week (Slope: -1.03±0.86, t-ratio=-1.19, p=0.24).

In lowbush blueberry (Figure 6d), due to high variation, a significant linear relationship could not be established for selectivity over week, however, numerically, red panel traps had higher selectivity than liquid traps throughout the season.

Relation of fruit infestation with male SWD captures

In 2018-highbush blueberry, only red panel traps in 'Marucci In' site in NJ showed a significant linear relationship between male SWD captures and fruit infestation, where number of immatures in fruits increased at a rate of 0.40±0.00 (t-ratio= 56.25, p=0.0003) immatures for each male SWD in red panel traps (Figure 7a). In blackberry (Site=Sandhills), only liquid traps showed a significant linear relationship where number of immatures in fruits increased at a rate of 0.54±0.07 (t-ratio=8.00, p<0.0001) immatures for each male SWD (Figure 7b).

In raspberry (Site=Tomions), both liquid and red panel traps showed a significant linear relationship. In liquid traps, SWD immatures increased linearly with male SWD captures at a rate of 0.89±0.36 (t-ratio=2.45, p<0.02) immatures for each male SWD. Whereas the linear relationship was much stronger (r^2=0.89) in red panel traps than liquid traps (r^2=0.2),) where SWD immatures increased at a rate of 7.99±0.58 (t-ratio=13.78, p<0.0001) immatures for each male SWD. The intercept (ANCOVA-trap: F=12.49, df=1, p=0.0009) and slope (ANCOVA-treatment*male SWD: F=34.13, df=1, p<0.0001) of lines of red panel traps were significantly higher than liquid traps (Figure 7c). In 2021-highbush (Site=Gands) and lowbush blueberry (Site=Mont.), there was no significant relationship between SWD immatures and male SWD captures with either lure type (Figures 7d, e).

Discussion

In this study, red panel traps performed similar to, and sometimes superior to, liquid traps for their efficiency in capturing male SWD early, while being selective to male SWD season-long in US berry and cherry crops. Moreover, an increase in male SWD captures in red panel and liquid traps corresponded to increases in fruit infestation in highbush blueberry and raspberry, and the red panel trap captures were more sensitive to fruit infestation than liquid traps in raspberry.

Although red panel traps were more selective to male SWD than liquid traps, the selectivity was variable between crop and lure type, as has been previously reported in liquid traps (Cloonan et al. 2019). For example, during early weeks, red panel traps with the Scentry lure had selectivity as high as 60% in highbush blueberry, whereas for the same trap-lure combination, it was close to zero selectivity in blueberry (highbush and rabbiteye). During early weeks, red panel traps with the Trécé BS lure had selectivity of 45% in blackberry, whereas the same trap-lure combination in blueberry had selectivity close to zero during early weeks. The red panel-Trécé HS lure combination had poor selectivity in blueberry whereas the same combination in cherry had selectivity of 22% during early weeks. These results indicate the selectivity to male SWD is crop and time-specific, and that combinations of red-panel traps with Scentry or Trécé BS lures are more selective to male SWD in blueberry, red-panel-Trécé BS lure combination in blackberry, and red-panel-Trécé HS lure combination in cherry.

Since the liquid and red-panel traps function differently, there was an interaction effect between trap designs and lure types on SWD captures by crop type. The reason for differences in capture rates might be because the amount of volatilization of the chemicals depends on the material matrix of the lure, the placement of the lure (inside or outside of the trap), surface area exposed, environmental conditions (temperature and humidity), and crop types (Jaffe et al. 2018, Burrack et al. 2020). Therefore, further research is needed to determine the effect of biotic and abiotic conditions in the trap-lure interactions to capture SWD in these crops.

The volatiles in the commercial lures are released in a constant rate throughout the season with modern dispensing technology (Cha et al. 2013). Therefore, the increase in male SWD captures as the season progresses does not necessarily mean that the ability of a lure to attract male SWD increases over the season. The increase in selectivity over the week may instead be due to an increase in overall SWD population in the berry field, and the lures were effective in differentiating the population change.

In blackberry, although liquid trap captures predicted fruit infestation with fewer male captures, the selectivity of liquid traps with either lure type was poor. Whereas red panel traps with the Trécé BS lure was highly selective for male SWD season-long. However, a relationship could not be established between red panel trap captures and fruit infestation in the current study. Thus, further research is needed to fine-tune this relationship before red panel traps can fully be used as part of an SWD monitoring program in blackberry.

Results from this study corroborate with previous studies showing a relationship between male SWD captures in red panel traps and SWD fruit infestation in berry fields. In this study, every two male SWD captures in red panel traps corresponded to one SWD immature in blueberries and blackberries collected from a sampling area of 5-10 m. However, in raspberry, every two male SWD captures in red panel traps corresponded to ~15 SWD immatures in berries from a given sampling area. A significant linear relationship with intercept starting from zero % means red panel traps did not capture male SWD when there was no fruit infestation, increasing its reliability as a decision-making tool.

In our current study, although fruit infestation increased with increasing male SWD trap captures, a numerical expression of this relationship could not be established in all the tested crops. One reason for this poor relationship might be that there were not enough fruits collected from the field, or that the infestation was too low to be visible in some crop sites. Thus, further research is needed to refine the trap captures and fruit infestation relationship to use red panel traps as monitoring and decision-making tool. Overall, since red panel traps are superior to liquid traps in terms of handling of the drowning solution with reduced processing time, red-panel traps seem to be an efficient monitoring tool in blueberry, due to its ease of installing and making in-situ counts and make control decisions. Future work should continue to fine-tune the use of these red panel traps with the available commercial lures to establish a clear relationship between male SWD capture and fruit infestation for each crop type.

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Table 1. Information about the SWD trap comparison study conducted in several states and sites with a variable number of treatments and replications during fruiting season of various crops in 2018 and 2021.

State	Crop	Sites	Treatments	Replicates	Dates (sampling frequency)
2018					
NC	Blackberry	1	4	5	21 Jun–27 Jul (6)
NJ	Blueberry[1]	4	4	4	13 Jun–25 Jul (6)
NJ	Blueberry[1]	6	2	5	13 Jun–18 Aug (10)
OR	Blueberry[1]	1	4	5	28 Jun–8 Aug (7)
NY	Summer Raspberry	1	2	10	2 Jul–15 Aug (6)
ME	Wild Blueberry	3	5	3	3 Aug–5 Sep (5)
2021					
VA	Blackberry	1	4	3	28 Jun–30 Aug (12)
OR	Cherry	2	1	3	13 May–28 Jul (11)
WA	Cherry	1	6	5	28 Sep–3 Nov (6)
NH	Blueberry[1]	1	5	4	24 Jun–29 Jul (6)
MD	Blueberry[1]	2	4	3	27 May–12 Aug (12)
NJ	Blueberry[1]	1	3	5	31 May–3 Aug (10)
MI	Blueberry[1]	9	6	1	14 Jun–17 Aug (8)
OR	Blueberry[1]	1	4	4	15 Jul–11 Aug (4)
NY	Blueberry[1]	4	6	4	8 Jun–31 Aug (13)
GA	Blueberry[2]	3	8	4	27 May–22 Jul (8)
FL	Blueberry[3]	1	4	4	23 Mar–29 Apr (6)
ME	Wild Blueberry	1	6	4	15 Jul–17 Aug (6)

[1]Northern Highbush, [2]Rabbiteye, [3]Southern Highbush

Figure Captions

Fig. 1. Trap captures of male and female SWD (mean±SE) during early week on liquid and red panel traps with Scentry lure in a) lowbush blueberry, b) highbush blueberry, c) blackberry, and d) raspberry fields in 2018. Asterisk signs indicate significant difference (Tukey-Kramer, α=0.05).

Fig. 2. Trap captures of male and female SWD (mean±SE) during early week on liquid and red panel traps with Scentry, Trécé BS, and Trécé HS lures in a) lowbush blueberry, b) cherry, c) blackberry, and d) highbush and rabbiteye blueberry fields in 2021. Asterisk signs indicate significant difference (Tukey-Kramer, α=0.05).

Fig. 3. Season-long trap captures of male and female SWD (mean±SE) on liquid and red-panel traps baited with Scentry lure in a) lowbush blueberry, b) blackberry, c) highbush blueberry, and d) raspberry fields in in2018. Asterisk signs indicate significant difference (Tukey-HSD, α=0.05).

Fig. 4. Season-long trap captures of male and female SWD (mean±SE) on liquid and red-panel traps baited with Scentry, Trécé BS, and Trécé HS lures in a) lowbush blueberry, b) cherry, c) blackberry, and d) blueberry fields in 2021.inAsterisk signs indicate significant difference (Tukey-HSD/Tukey-Kramer, α=0.05).) Horizontal lines represent pooled result and the lines with different letters are significantly different (Tukey-HSD, α=0.05).

Fig. 5. Linear relationship of % male SWD captures relative to total Drosophila captured (selectivity) in liquid and red-panel traps with Scentry lure over 1-8 weeks in a) highbush

blueberry, b) lowbush blueberry, and c) raspberry fields in 2018. Asterisk signs indicate the regression line(s) are significant.

Fig. 6. Linear relationship of % male SWD captures relative to total Drosophila captured (selectivity) in liquid and red-panel traps with Scentry, Trécé BS, and Trécé HS lures over 1-14 weeks in a) blackberry, b) blueberry, c) cherry, and d) lowbush blueberry fields in 2021. Asterisk signs indicate the regression line(s) are significant.

Fig. 7. Linear relationship of SWD immatures in fruits with SWD male in liquid and red panel traps with Scentry and Trécé BS lures collected from the same field sites in a) highbush blueberry, b) blackberry, and c) raspberry fields in 2018, and in d) highbush blueberry and e) lowbush blueberry in 2021. Asterisk signs indicate the regression line(s) are significant.

Fig. 1

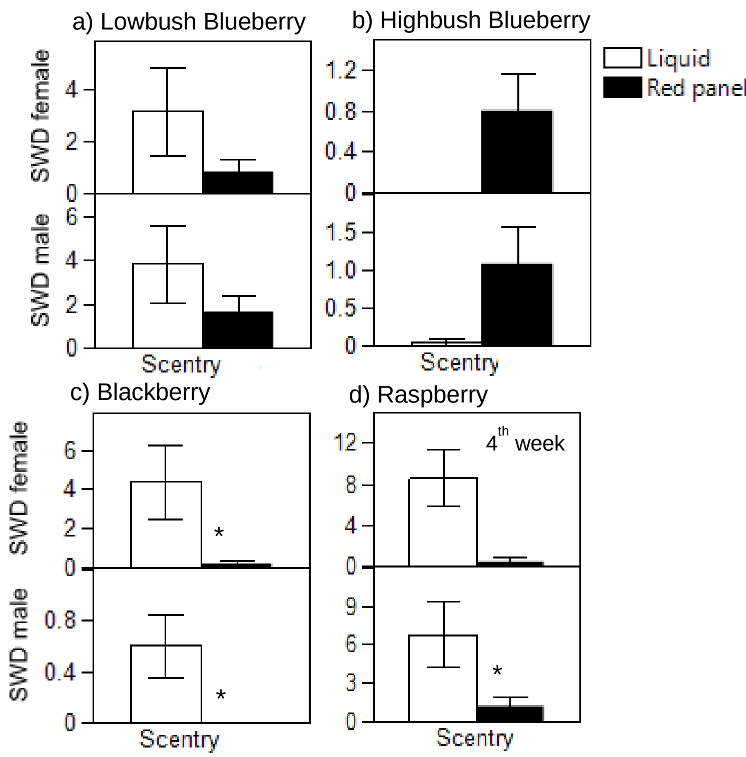

a) Lowbush Blueberry
b) Highbush Blueberry
Liquid
Red panel
SWD female
SWD male
Scentry
c) Blackberry
d) Raspberry
4th week
*
SWD female
SWD male
Scentry

Fig. 2

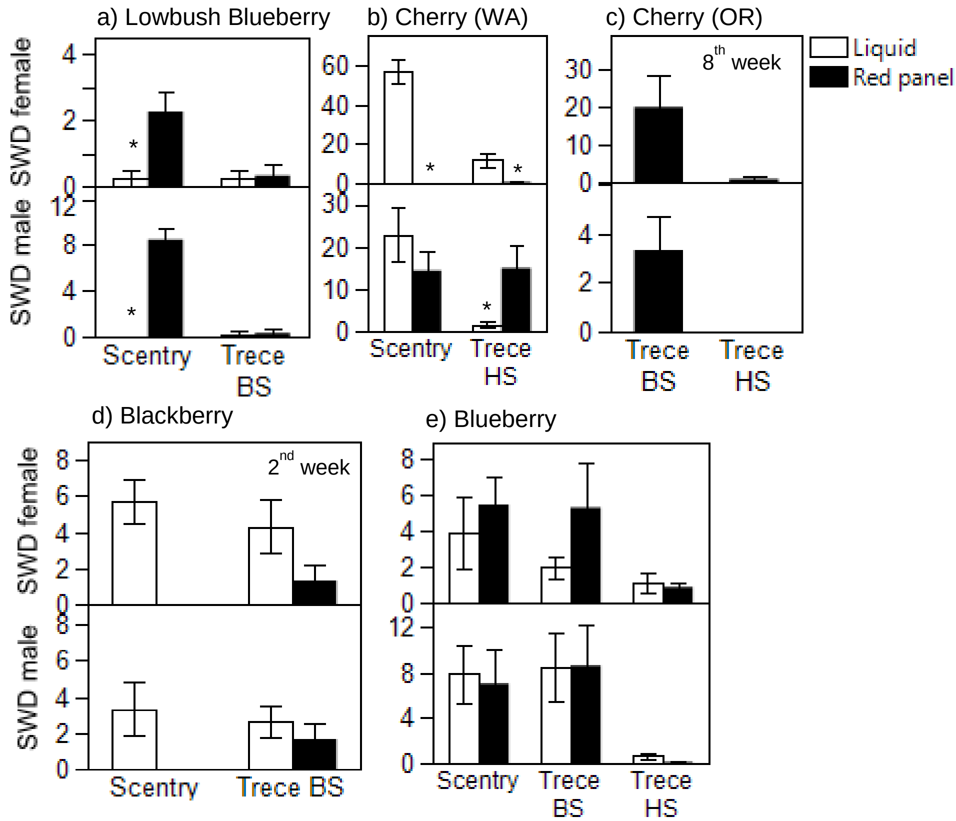

a) Lowbush Blueberry
b) Cherry (WA)
c) Cherry (OR)
Liquid
Red panel
8th week
SWD female
SWD male
Scentry
Trece BS
Trece HS
d) Blackberry
e) Blueberry
2nd week

Fig. 3

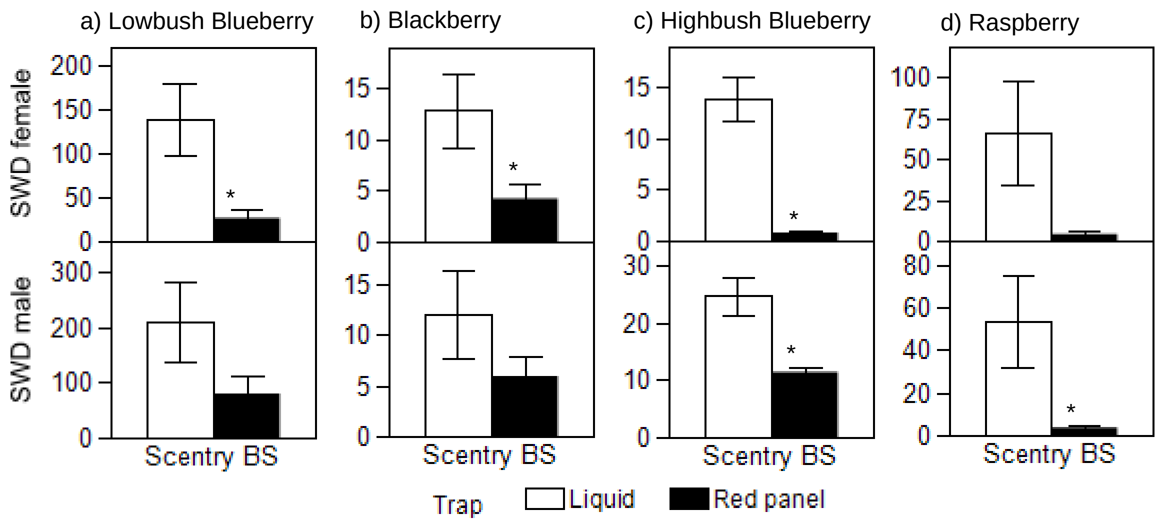

a) Lowbush Blueberry
b) Blackberry
c) Highbush Blueberry
d) Raspberry
SWD female
SWD male
0
50
100
150
200
300
5
10
15
20
25
30
40
60
75
80
*
Scentry BS
Trap
Liquid
Red panel

Fig. 4

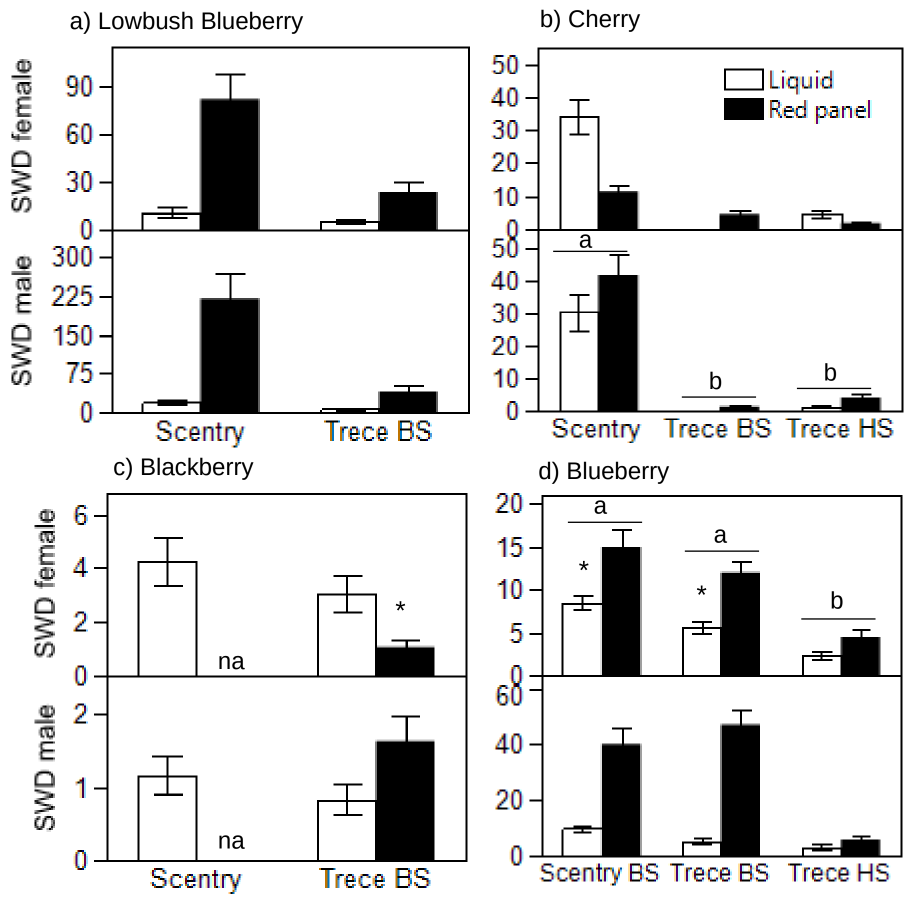

a) Lowbush Blueberry
SWD female
90
60
30
0
SWD male
300
225
150
75
0
Scentry
Trece BS
b) Cherry
Liquid
Red panel
50
40
30
20
10
0
a
b
b
Scentry
Trece BS
Trece HS
c) Blackberry
SWD female
6
4
2
0
na
*
SWD male
2
1
0
na
Scentry
Trece BS
d) Blueberry
20
15
10
5
0
a
a
b
*
*
60
40
20
0
Scentry BS
Trece BS
Trece HS

Fig. 5

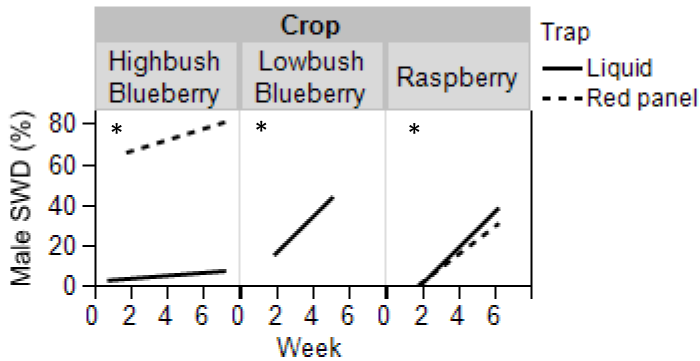

Crop
Highbush Blueberry
Lowbush Blueberry
Raspberry
Trap
Liquid
Red panel
Male SWD (%)
80
60
40
20
0
*
*
*
0 2 4 6 0 2 4 6 0 2 4 6
Week

Fig. 6

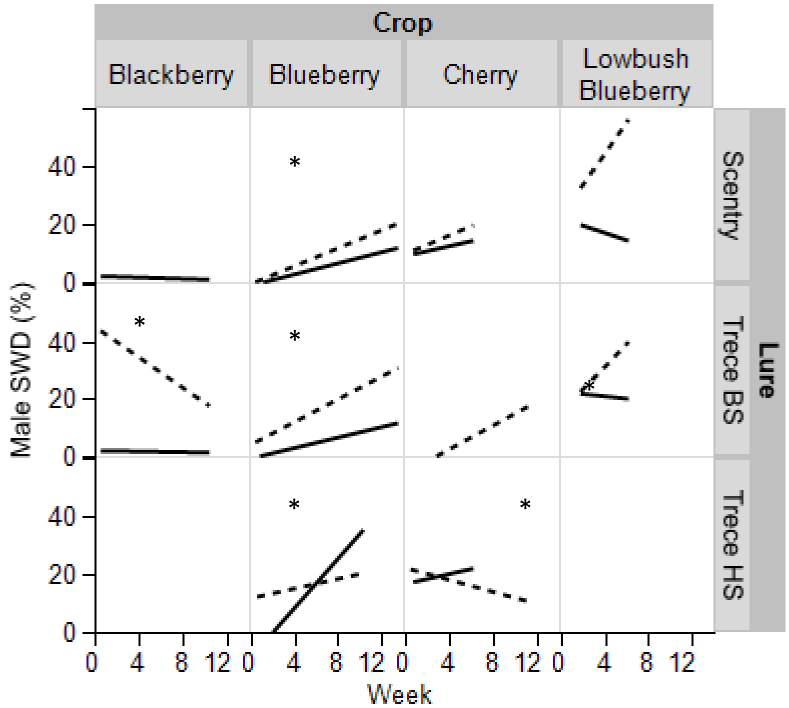
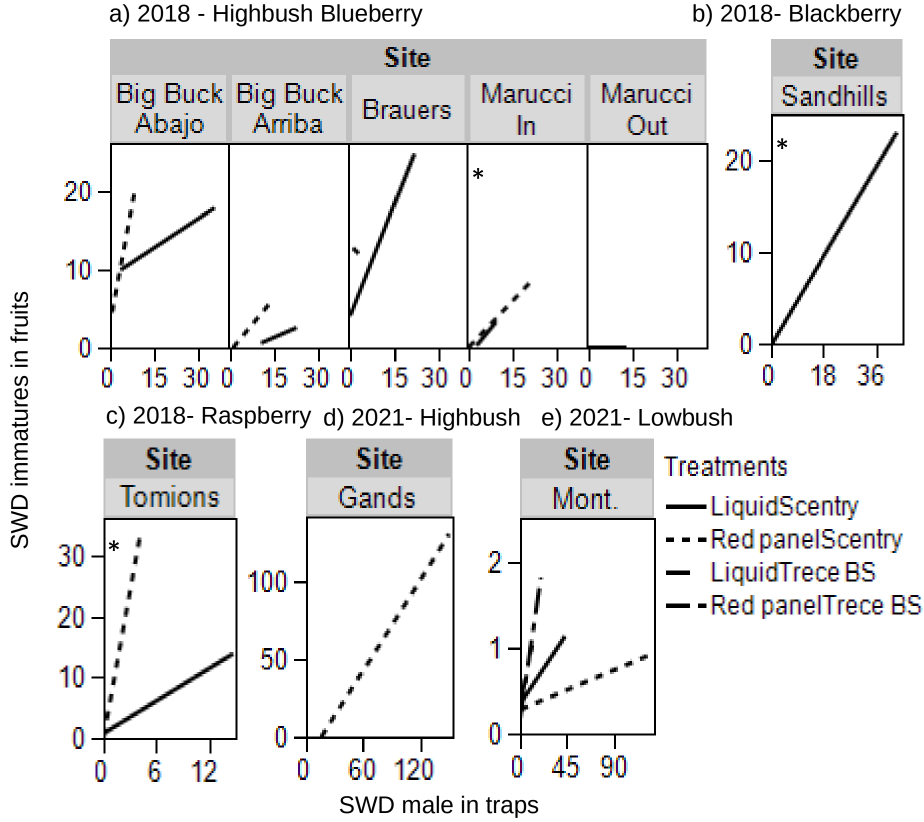

Crop
Blackberry
Blueberry
Cherry
Lowbush Blueberry
Scentry
Trece BS
Trece HS
Lure
Male SWD (%)
Week
0
20
40
0
4
8
12
*

Fig. 7



a) 2018 - Highbush Blueberry
b) 2018- Blackberry
Site
Big Buck Abajo
Big Buck Arriba
Brauers
Marucci In
Marucci Out
Sandhills
c) 2018- Raspberry
d) 2021- Highbush
e) 2021- Lowbush
Tomions
Gands
Mont.
SWD immatures in fruits
SWD male in traps
Treatments
LiquidScentry
Red panelScentry
LiquidTrece BS
Red panelTrece BS