Effect of Trap Design, Bait Type, and Age on Captures of *Drosophila suzukii* (Diptera: Drosophilidae) in Berry Crops

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J. Econ. Entomol. 107(4): 1508–1518 (2014); DOI: http://dx.doi.org/10.1603/EC13538

ABSTRACT Field experiments were conducted in commercial southern highbush blueberries and wild blackberries to evaluate the attractiveness of different trap designs, bait types, and bait age on captures of the spotted wing drosophila, *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae). During the 2012 trap design study, the five treatments evaluated were four 1-liter clear plastic cup traps (with and without a yellow visual stimulus or odorless dish detergent) and the fifth treatment was a Pherocon AM yellow sticky card trap. Cup traps were baited with 150 ml of apple cider vinegar (ACV) and the Pherocon AM trap had a 7.4-ml glass vial containing ACV. In 2013, the Pherocon AM yellow sticky card was omitted because of low spotted wing drosophila captures in 2012. The four treatments evaluated were four 1-liter cup traps with and without a yellow visual stimulus. One cup trap (with a yellow stimulus) was baited with yeast + sugar in place of ACV and the other cup traps were baited with ACV. In both years, there were no differences in spotted wing drosophila captures among cup traps baited with ACV with and without yellow visual stimulus. However, the cup trap baited with yeast + sugar and yellow visual stimulus captured more spotted wing drosophila than the ACV-baited cup traps irrespective of visual stimulus or detergent. In another study, four baits including 1) ACV, 2) yeast + sugar mixture, 3) yeast + flour mixture (yeast, sugar, water, whole wheat flour, and ACV), and 4) wine + vinegar mixture (rice vinegar and merlot wine) were evaluated in a commercial blueberry planting using 1-liter clear plastic cup traps (as described above). The experiment was repeated in wild blackberries but the yeast + flour bait was replaced with ACV + merlot wine + sugar. Results indicated that the two yeast baits captured significantly more spotted wing drosophila and more nontarget organisms than the vinegar baits. In the final study, although we found that the attraction of ACV and yeast + sugar to spotted wing drosophila did not change with bait age, the attraction to other Drosophilidae flies decreased with age. The ease of implementing a trap-and-lure system for spotted wing drosophila is discussed.

KEY WORDS *Zaprionus indianus*, yeast, bait, spotted wing drosophila, blueberry

The spotted wing drosophila, *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae), is an invasive pest from eastern Asia and is threatening the U.S. blueberry industry. Economic losses in blueberries have been estimated at 10–15% in Florida in 2012 (eFly SWD Working Group 2012) and potential losses as high as 40% in California in 2008 (Bolda et al. 2010). *D. suzukii* can complete its lifecycle in as few as 8 d (Kanzawa 1939, Walsh et al. 2011), and therefore populations can increase quickly. It is multivoltine and has been estimated to undergo up to 10 and 13 generations a year in California and Japan, respectively, under optimal climatic conditions (Kanzawa 1939, Walsh et al. 2011). Thus, effective management programs must be developed to combat this invasive pest. Current management practices for *D. suzukii* involve the use of broad-spectrum insecticides mainly organophosphates and synthetic pyrethriods with short preharvest intervals (PHI's) combined with an intensive monitoring program.

Effective monitoring is the cornerstone for a successful integrated pest management (IPM) program because it aims to detect pest populations before economic thresholds are reached and effective control actions can be implemented. Current monitoring methods for spotted wing drosophila use a trap-and-lure system that uses visual and olfactory cues of *Drosophila.* Yellow has been shown to be attractive for many insects including plant-feeding dipterans because it constitutes a foliage-type stimulus (Prokopy and Owens 1983). Recent laboratory studies investigating differences in color preference for spotted wing drosophila showed a higher affinity toward darker colors such as red, burgundy, and black compared with lighter colors like white and light blue (Basoalto et al. 2013). However, field studies showed that clear

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traps can be just as effective as red traps of the same design in a number of spotted wing drosophila host fruits (Lee et al. 2012).

The effectiveness of a trap is dependent on several factors in addition to color including size, attractant, and ease of handling (Liburd et al. 1998). Several types of traps have been tested for spotted wing drosophila including handmade plastic cups with 1 to 10 entry holes (the most commonly recommended), traps with mesh entries, and plastic cups with tents to provide shade and prevent water from entering (Kanzawa 1939, Wu et al. 2007, Lee et al. 2012). Dome traps and commercial "spice" jar traps have also been evaluated (Landolt et al. 2012a, Basoalto et al. 2013) with varying degrees of success. Other trap modifications include the addition of a yellow sticky card hanging inside the trap and odorless dish detergent to the drowning solution to help prevent fly escape (Landolt et al. 2012a,b; Lee et al. 2012; Van Timmeren and Isaacs 2013).

Fermentation products have been used for many years to attract other *Drosophila* spp. including ethanol, acetic acid, and methanol (Reed 1938, Becher et al. 2010, Lebreton et al. 2012). Initial studies conducted in Japan showed that spotted wing drosophila was attracted to rice wine, red grape wine, and cherry wine as well as molasses mixed with a home-brewed red grape wine, cherry juice, sugar water, and a variety of botanical oils (Kanzawa 1935). Accordingly, studies have been conducted to evaluate the relative attractiveness of various types of alcohols and vinegars to spotted wing drosophila. Landolt et al. (2012a) found that apple cider vinegar (2% acetic acid; ACV) was more attractive than red grape wine (Merlot 7.2% ethanol) when used alone. In addition, the mixture of ACV and Merlot (60:40 ratio) acted additively to attract more spotted wing drosophila than either product alone. Similarly, Landolt et al. (2012b) found that a mixture of rice vinegar and Merlot wine was more attractive than mixtures of other wines and ACV.

Esters are produced by the yeast *Saccharomyces cerevisiae* during the fermentation of fruits and serve as attractants for many species of insects. Generally, *Drosophila* spp. use yeasts mainly as a source of food for the larvae and nutrients for egg production, and others use it as nuptial gifts in courtships (Hamby et al. 2012). Becher et al. (2012) suggested that *Drosophila melanogaster* Meigen is attracted to volatiles associated with yeasts found on host fruits, not the volatiles associated with fruits themselves. In the current study, we evaluate the use of yeasts as an attractant for *D. suzukii.*

Common trap-and-lure systems designed for spotted wing drosophila trapping show inconsistent performance. Ineffective trap-and-lure systems may fail to detect spotted wing drosophila populations early enough for control actions to be taken or may underestimate the extent of a spotted wing drosophila problem in the field. To compare the performance of different baits for monitoring *D. suzukii,* we carried out a study in north-central Florida in blueberries and wild blackberries. Bait treatments included mixtures of wine + vinegar (based on Landolt et al. 2012b), ACV + wine + sugar (based on Anonymous 2013), yeast + flour (an actively fermenting mixture based on Cowles 2013), yeast + sugar, and AVC, all with the addition of dish detergent to break the surface tension of the bait. In addition, we evaluated the effectiveness of trap designs using the standard ACV bait with and without yellow visual stimuli (sticky card or nonsticky band) as a visual attractant and dish detergent as a method of preventing fly escape. Finally, we evaluated how long the two most popular baits (ACV and yeast + sugar) will remain active in the field before replacement.

Materials and Methods

Effect of Trap Design in Capturing Spotted Wing Drosophila. The effects of adding a yellow visual stimulus as an attractant and dish detergent as a method of preventing fly escape to the spotted wing drosophila trap baited with ACV were evaluated in blueberry plantings during the spring of 2012 and 2013. Both studies were conducted in commercial blueberry plantings. Experimental designs were completely randomized block (blocked by cultivar group) with four plot replicates. Each plot consisted of one double-planted row ≈2 m in width and at least 60 m in length. A buffer zone of at least 15 m separated each plot. Southern highbush blueberries are usually planted in a repeating pattern of alternating rows of different cultivars to enhance cross-pollination. Therefore, each experimental plot consisted of the same set of 2–3 cultivars of southern highbush blueberries. Standard blueberry production practices with regards to watering regime, fertilizers, fungicide applications, and pruning were followed (Childers 2005). Bushes were planted ≈1 m apart and the height ranged from 1 to 1.5 m. Trapping studies began when berries were ripe (based on fruit size and color) and spotted wing drosophila populations were present (based on monitoring program captures); therefore, starting dates differed at each location.

2012. The study was conducted in two different locations. Experiment 1 was conducted in a high tunnel blueberry system using conventional strategies in Alachua County, FL, from 25 January until 10 April 2012. Experiment 2 was conducted from 19 April to 10 May 2012 in the fields of an organically managed planting located in Citrus County, FL.

Five trap designs (treatments) were evaluated, all baited with ACV. One trap was a yellow Pherocon AM sticky card (15.2 by 20.3 cm) used for monitoring apple maggot and other flying insects (Great Lakes IPM, Vestaburg, MI). The other four traps were handmade from 0.95-liter clear plastic deli cups with lids (Solo, Urbana, IL) and each container had 10 0.64-cm holes along the upper rim. Modifications of the plastic deli container (basic cup trap described above), included the addition of a small (7.6 by 7.6 cm) yellow sticky card (Great Lakes IPM, Vestaburg, MI) hanging inside to prevent flies from escaping and to act as a visual stimulus, a yellow visual stimulus band (30 cm

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Table 1. Bait mixtures for trap and bait comparison studies

Bait	Ingredient	Manufacturer	Amount
ACV	ACV	5% acetic acid, Winn Dixie, Jacksonville, FL	150 ml
Yeast + sugar	Yeast	Fleischmann's RapidRise Yeast, ACH Food Companies, Inc., Cordova, TN	14.8 g
	Sugar	White granulated, Publix, Lakeland, FL	39.4 g
	Water	Tap	710 ml
Yeast + flour	Yeast	Fleischmann's RapidRise Yeast, ACH Food Companies, Inc., Cordova, TN	29.6 g
	Sugar	White granulated, Publix, Lakeland, FL	118.3 g
	Wheat flour	King Arthur Flour Co., Inc., Norwich, VT	59.1 g
	ACV	5% acetic acid, Winn Dixie, Jacksonville, FL	29.6 ml
	Water	Tap	710 ml
Wine + vinegar	Rice Vinegar	25% Acetic acid, Korea	280 ml
	Red Grape Wine	Merlot 12% ethanol, Carlo Rossi, Modesto, CA	420 ml
ACV + wine + sugar	ACV	5% Acetic acid, Winn Dixie, Jacksonville, FL	112.5 ml
	Red grape wine	Merlot 12% ethanol, Carlo Rossi, Modesto, CA	37.5 ml
	Sugar	White granulated, Publix, Lakeland, FL	4 g

All baiting liquids included 0.3 ml of odorless dish detergent (Palmolive Pure and Clear, Colgate-Palmolive Company, New York, NY). Each trap had 150 ml of respective baiting liquid.

in width by 4.5 cm in height foamboard) wrapped around the inside middle of the cup, and odorless dish detergent (Palmolive Pure and Clear, Colgate-Palmolive Company, New York, NY) to the bait to act as a surfactant to help reduce the surface tension of the ACV and prevent fly escape (Table 1). Therefore, the five trap treatments were as follows: 1) basic cup, 2) cup + yellow stimulus band, 3) cup + yellow stimulus band + detergent, 4) cup + yellow sticky card inside, and 5) yellow sticky card (noncup trap). Cup traps were baited with 150 ml of ACV that also acted as a drowning solution. The Pherocon AM yellow sticky card was baited with a 7.4-ml glass vial (Fisher, Pittsburg, PA) containing ACV. Bait was released through the 1-cm hole on the top of the vial.

2013. The study was repeated at the same commercial high tunnel and field locations as in 2012 between 18 April to 23 May 2013 (experiment 3) and 3–22 May 2013 (experiment 4) in Alachua and Citrus counties, respectively. Based on the low captures from the 2012 trapping study, the Pherocon AM yellow sticky card was omitted. In addition, the cup trap with the yellow stimulus band (without detergent) performed similar to all other cup traps in 2012 and was also omitted. The four trap treatments evaluated were as follows: 1) basic cup trap, 2) cup + yellow stimulus band + detergent, 3) cup + yellow sticky card inside, and 4) cup + yellow sticky card inside baited with a 150 ml yeast + sugar mixture (Table 1). All other traps were baited with 150 ml ACV.

Relative Attractiveness of Various Baits to Spotted Wing Drosophila in Blueberries and Wild Blackberries. The effectiveness of baits used to monitor spotted wing drosophila was evaluated in a commercial organic southern highbush blueberry farm and in wild blackberries *Prunus* spp. in Citrus and Alachua counties, respectively. The blueberry experiment was conducted from 8 May to 27 May 2013. Four baits (treatments) were evaluated: 1) ACV, 2) yeast + sugar mixture, 3) yeast + flour mixture (contents listed in Table 1), and 4) wine + vinegar (contents listed in Table 1). The wine + vinegar bait was based on a 60:40 mixture of Merlot red wine and rice vinegar with the addition of detergent (Landolt et al. 2012b). The wine + vinegar consisted of concentrated rice vinegar (25% acetic acid), whereas Landolt et al. (2012b) used diluted vinegar (4%), resulting in a bait with lower acetic acid concentration. All baits were evaluated using the basic plastic cup trap.

The wild blackberry experiment was conducted between 21 May and 17 June 2013. The four baits evaluated were identical to the blueberry experiment except that the yeast + flour mixture was replaced with a mixture of ACV + wine + sugar (contents listed in Table 1). All treatments were evaluated with 150 ml of bait solution per trap.

Four monitoring traps each baited with their respective bait treatments were placed at 20-m intervals in a completely randomized experimental design with four replicates. Traps in the blueberry experiment were placed within the center of the field. In the blackberry experiment, traps were placed along the edge of mixed vegetation containing wild blackberry, shrubs, and trees that were growing between two cultivated blueberry fields. The traps were hung in the shaded areas of the shrub canopies.

Effect of Bait Age and Type on Spotted Wing Drosophila Trap Captures in Blueberries. Attractiveness of 7-d-old bait versus 14-d-old bait of ACV or yeast + sugar to spotted wing drosophila adults was compared in a field study. The experimental set up was a 2 by 2 factorial randomized complete block design with four replications. The two main factors were bait type (ACV and yeast + sugar) and the minor factors were age (7 and 14 d old) baiting liquid. Treatments were randomized within blocks with two traps representing each treatment ACV (TRT 1) or yeast + sugar (TRT 2). There were four blocks totaling 16 traps. Each week all the traps were serviced and the insects were sieved and placed into individual vials. The baiting solution (ACV or yeast + sugar) in one of the two traps (in each treatment) was replaced with new bait (7 d old). The other trap had the same baiting solution from the previous week in the trap (14 d old). The

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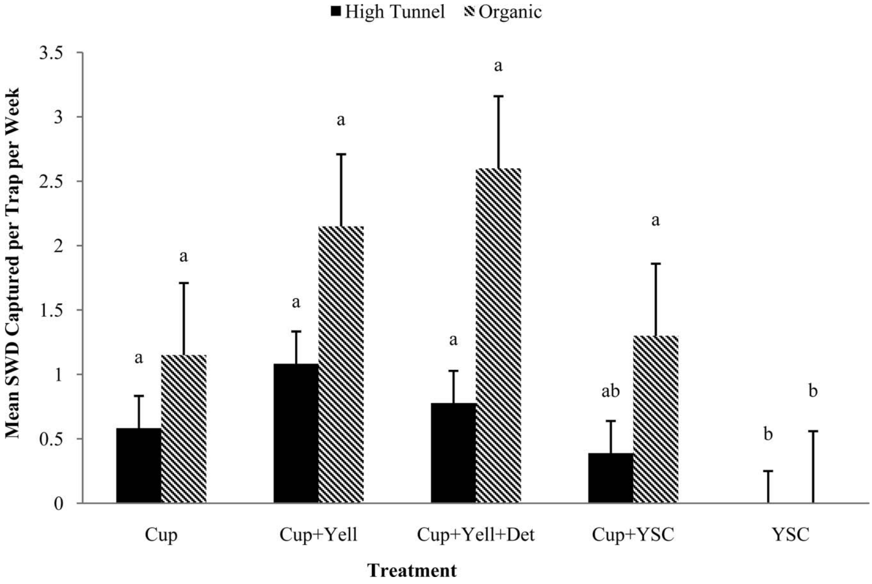

Fig. 1. Mean (±SE) spotted wing drosophila (SWD) captured per trap per week in a highbush blueberry high tunnel system (solid bars, experiment 1) and in an organically managed field system (striped bars, experiment 2) during 2012. Basic cup trap (Cup), cup trap with a yellow stimulus (Cup+Yell), cup trap with yellow stimulus and odorless dish detergent (Cup+Yell+Det), cup trap with a yellow sticky card inside (Cup+YSC), and a yellow sticky card only (YSC). Bars with the same letters are not significantly different at $P \leq 0.05$.

experiment was conducted for 5 wk in mixed cultivars of southern highbush blueberry planting that were ≈ 5 yr old. Blueberry rows were ≈ 150 m in length planted with a double row of blueberry bushes with 1 m between the rows. Traps were spaced ≈20 m between the rows.

Sample Collection. Samples were collected weekly in all experiments except for the bait age experiment (see sampling procedures described above). Sample collection consisted of pouring all liquid bait according to treatment and replicate into a labeled collection container in the field and refilling the trap with 150 ml of fresh bait. Yellow sticky cards and baits in vials were also replaced weekly with fresh cards and bait, respectively, in the 2012 trapping studies. Male and female spotted wing drosophila were identified and counted for each sample collected (Triplehorn and Johnson 2005, Markow and O'Grady 2006, Vlach 2010). Other flies (Drosophilidae), pests, and beneficial insects, and other arthropods were recorded and identified to family.

Data Analysis. Data from trap design and bait studies (each experiment separately) were analyzed using a two-way repeated measure analysis of variance (JMP ver. 9 SAS Institute, 2002, 2013, Cary, NC). Counts of spotted wing drosophila were log transformed to $ln(x + 0.5)$ to normalize the distribution and homogenize the variances before analysis.

In experiment 4 (2013 trapping study) and the bait study in blueberries, the interaction effect (treatment × time) was significant, however it was omitted owing to limited data points. In all other analyses, if the factor interaction (trap × time, bait type × time, or bait age × type) tested was not significant, it was omitted in the final analyses. Significant mean differences were separated with Tukey's honestly significant difference test and considered significant when $P \leq 0.05$.

Levene's test for equal variances was conducted to determine differences between males and female spotted wing drosophila (SAS Institute 2013). A *t*-test for unequal variances was used to determine significant differences in means at $P \leq 0.05$.

Results

Effect of Trap Design on Capturing Spotted Wing Drosophila. In 2012, treatment had a significant effect on the mean spotted wing drosophila captured in the high tunnel ($F = 4.26$; df = 4, 15; $P = 0.0168$) and in the organically managed field ($F = 6.34$; df = 4, 15; $P = 0.0034$; Fig. 1). The Pherocon AM yellow sticky card did not capture any spotted wing drosophila in either experiment. The basic cup trap, cup + yellow stimulus, and cup + yellow stimulus + detergent captured significantly more spotted wing drosophila than the Pherocon AM yellow sticky card in the high tunnel blueberries. The cup + yellow sticky card inside was not significantly different from the Pherocon AM yellow sticky card. In the organically managed field in the 2012 study, all of the cup treatments captured significantly more spotted wing drosophila than the yellow sticky card. There were no significant differences among the four cup treatments in either experiment. Overall, the high tunnel and organic field showed similar trends for mean spotted wing drosophila captured among treatments.

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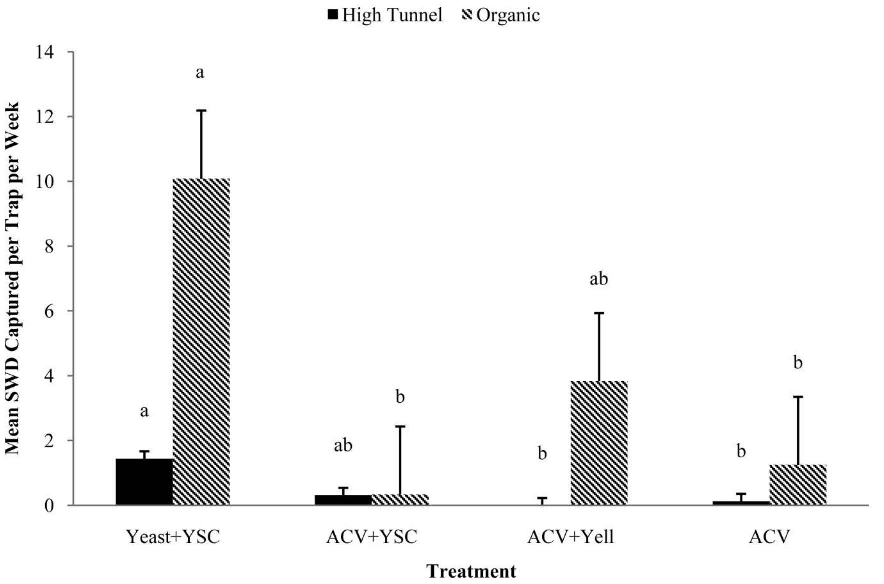

Fig. 2. Mean (±SE) spotted wing drosophila (SWD) captured per trap per week in a highbush blueberry high tunnel system (solid bars, experiment 3) and in an organically managed field system (striped bars, experiment 4) during 2013. Basic cup trap with a yellow sticky card inside baited with a yeast + sugar mixture (Yeast+YSC), cup trap with a yellow sticky card inside with ACV bait (ACV+YSC), cup trap with a yellow stimulus band with ACV and odorless dish detergent (ACV+Yell), and a basic cup trap with ACV and odorless dish detergent (ACV). Bars with the same letters are not significantly different at $P \leq 0.05$.

The number of females caught was significantly greater than the number of males in the basic cup ($t = 2.7$; df = 42.1; $P = 0.0097$) and cup with the yellow stimulus and the dish detergent ($t = 2.2$; df = 47.8; $P = 0.0321$) in the high tunnel blueberries. No significant differences were found between females and males captured in each treatment in the organically managed field.

In 2013, treatment had a significant effect on spotted wing drosophila captures in the high tunnel ($F = 6.18$; df = 3, 12; $P = 0.0088$) and the organically managed field ($F = 6.490$; df = 3, 12; $P = 0.0074$; Fig. 2). In the high tunnel, the yeast-baited cup + yellow sticky card inside captured significantly greater number of spotted wing drosophila than the ACV-baited cup + yellow stimulus and the basic cup trap. However, the ACV-baited cup + yellow sticky card trap was not significantly different than any of the other trap treatments. A similar situation was observed in the organically managed field, the yeast-baited trap captured significantly more spotted wing drosophila than the ACV-baited cup + yellow sticky card and the basic cup trap, whereas the ACV-baited cup + yellow stimulus was not significantly different than the other traps. No significant differences in number of females and males captured were observed in any of the traps in 2013.

Relative Attractiveness of Various Baits to Spotted Wing Drosophila in Blueberries and Wild Blackberries. Results from the blueberry bait study showed significant differences among the bait treatments ($F = 13.76$; df = 3, 11.99; $P = 0.0003$; Fig. 3a). Both yeast + flour and yeast + sugar baits had significantly greater mean spotted wing drosophila captures than ACV and the wine + vinegar mix. Captures of male and female flies did not differ significantly in any of the treatments.

The bait treatments in blueberries also attracted other dipteran species, specifically the recent invasive *Zaprionus indianus* Gupta (Drosophilidae) and other nontarget flies in the family Drosophilidae (excluding spotted wing drosophila and *Z. indianus*). The number of *Z. indianus* captured was significantly greater in the yeast + flour mix than all other bait treatments ($F = 8.85$; df = 3, 11.93; $P = 0.0023$; Fig. 3b). Significantly more nontarget drosophilids were captured in the yeast + flour mix than in the trap with ACV or wine + vinegar ($F = 13.42$; df = 3, 12.23; $P = 0.0004$). The yeast + sugar bait was not significantly different than any of the other baits.

In the wild blackberry study, type of bait ($F = 5.35$; df = 3, 57; $P = 0.0026$) and time ($F = 19.63$; df = 3, 57; $P < 0.0001$) significantly affected the number of spotted wing drosophila captured in the traps. Yeast + sugar-baited traps caught significantly more spotted wing drosophila adults than traps baited with the wine + vinegar mixture or ACV but they were similar to those baited with ACV + wine + sugar (Fig. 4).

In terms of capturing other insects in the wild blackberries, the yeast + sugar-baited traps caught more insect species than all the other baits. Specifically, the yeast + sugar-baited traps caught significantly more spotted wing drosophila males, Thripidae (Thysanoptera), Nitidulidae (Coleoptera), and Collembola than all the other treatments (Table 2). Traps with

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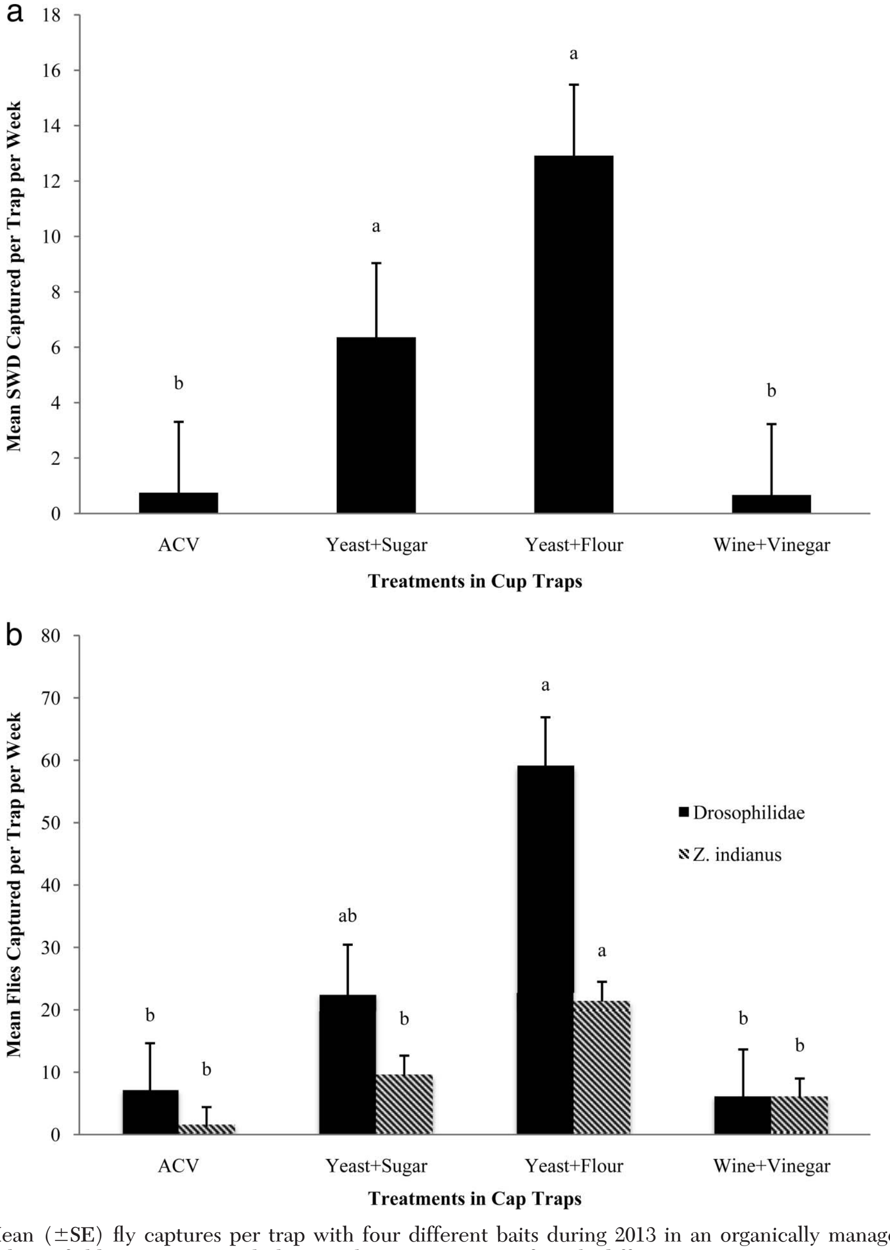

Fig. 3. Mean (±SE) fly captures per trap with four different baits during 2013 in an organically managed southern highbush blueberry field system. Bars with the same letters are not significantly different at $P \leq 0.05$. (a) Mean spotted wing drosophila (SWD) captures per trap per week. (b) Mean captures of other flies (Drosophilidae) (solid bars) and *Z. indianus* (striped bars) per trap per week.

different baits captured similar numbers of nontarget drosophilid flies.

Effect of Bait Age and Type on Spotted Wing Drosophila Trap Captures in Blueberries. The mean (±SE) number of pests and beneficial arthropods captured in traps baited with 7- and 14-d-old ACV and yeast + sugar is shown in Table 3. There was no significant interaction between the type of the bait and the age of the bait, and therefore the results presented are for the main effects only. Neither the type of the bait ($F = 3.15$; df = 1, 45; $P < 0.08$) nor its age ($F = 3.15$; df = 1, 45; $P < 0.08$) significantly affected the total number of spotted wing drosophila captured in the traps within the blueberry field. However, both bait type ($F = 8.61$; df = 1, 45; $P < 0.0053$) and age of the bait ($F = 11.45$; df = 1, 45; $P = 0.0015$) significantly affected the number of other Drosophilidae (excluding spotted wing drosophila) captured in traps (Table 3). Traps baited with yeast + sugar captured higher numbers of Drosophilidae (excluding spotted wing drosophila) than ACV-baited traps and 7-d-old bait was significantly more attractive than 14-

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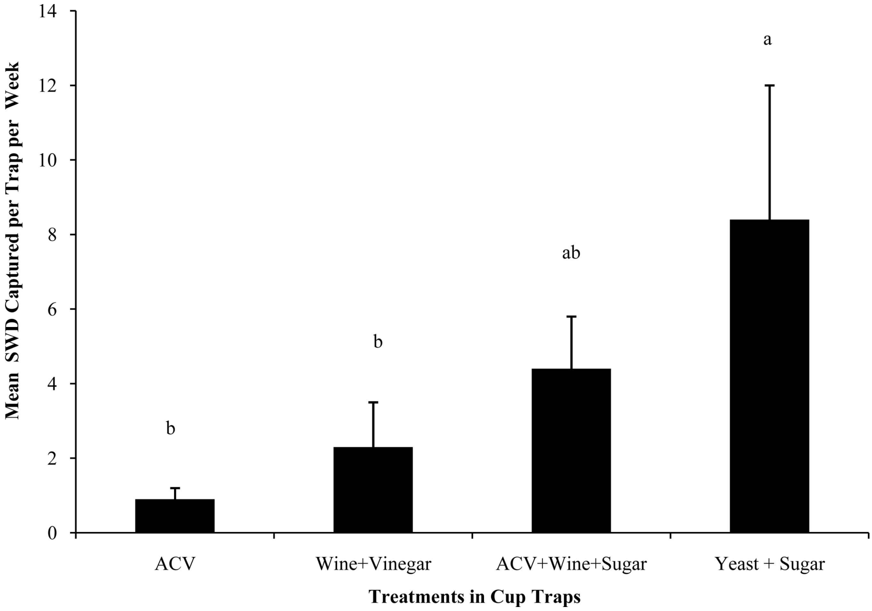

Fig. 4. Mean (±SE) *D. suzukii* (SWD) adults attracted to traps baited with four different baits.

d-old baits for both ACV and yeast + sugar baits. In addition, the type of the bait significantly affected other nontarget arthropods attracted to the traps including number of insect species within the following families: Thripidae, Formicidae (Hymenoptera), Nitidulidae, Anthocoridae (*Orius* spp.) (Hemiptera), and Sarcophagidae and Uliidae (Diptera) (Table 3). The age of the bait only had a significant effect on the numbers of *Orius* spp., nitidulids, and other nontarget flies (Drosophilidae). Neither the bait type nor the age affected the number of Collembola, Chrysopidae (Neuroptera), and Chrysomelidae (Coleoptera) captured in traps. Generally, yeast + sugar traps yielded more nitidulids than those baited with ACV and 7-d-old yeast + sugar bait was more attractive to nitidulids than the 14-d-old bait (Table 3). Although 7-d-old yeast + sugar traps caught the highest number of *Orius* spp., both bait type and age did not significantly influence the traps catches.

Discussion

Our findings indicate that neither the yellow visual stimulus nor detergent increases spotted wing drosophila captures when using the basic cup trap (0.95-liter clear plastic deli containers with lids) baited with ACV. The modified ACV-baited traps (yellow visual stimulus band, yellow sticky card, and detergent) were not significantly different from the basic unmodified ACV-baited trap in either year. The result is consistent with previous findings that the color yellow does not increase ACV-baited trap captures of spotted wing drosophila (Lee et al. 2011, Basoalto et al. 2013). In our 2013 trap comparison study, the trap with the yellow sticky card and the yeast + sugar captured significantly more spotted wing drosophila than the same trap baited with ACV in the organically managed blueberry farm. These results suggest that the type of bait is a more important factor in attracting spotted

Table 2. Mean (±SEM) of different arthropods captured in the four different baits in wild blackberries

Arthropod	ACV	Wine + vinegar	ACV + wine + sugar	Yeast + sugar	*F*; *P*
Drosophilidae	23.4 ± 6.7	43.1 ± 19.6	46.5 ± 12.8	55.5 ± 18.4	0.5; 0.79
Spotted wing drosophila male	0.5 ± 0.3b	0.8 ± 0.5b	1.3 ± 0.4b	4.2 ± 1.5a	4.04; 0.01*
Spotted wing drosophila female	0.4 ± 0.2	1.4 ± 0.7	3.2 ± 1.5	5.4 ± 2.3	2.39; 0.07
Zaprionus	0.4 ± 0.3	0.9 ± 0.5	0.3 ± 0.2	1.4 ± 0.6	1.32; 0.28
Thripidae	0.1 ± 0.1b	0.2 ± 0.1b	0.0 ± 0.0b	9.3 ± 3.0a	9.25; <0.0001*
Chrysomelidae	0.3 ± 0.1	0.3 ± 0.2	0.4 ± 0.2	0.0 ± 0.0	1.14; 0.24
Chrysopidae	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.4	1.0; 0.4
Formicidae	0.7 ± 0.3b	0.7 ± 0.5b	4.4 ± 1.3a	5.4 ± 1.2a	6.78; 0.0005*
Nitidulidae	0.6 ± 0.2b	0.7 ± 0.3b	1.6 ± 1.0b	19.1 ± 6.8a	6.97; 0.0004*
Sarcophagidae	0.1 ± 0.1	0.6 ± 0.2	2.3 ± 1.1	1.3 ± 0.5	2.42; 0.08
Orius spp.	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.8 ± 0.6	1.37; 0.26
Uliidae	0.1 ± 0.1	0.3 ± 0.3	1.6 ± 0.7	1.2 ± 0.5	2.56; 0.06
Aranae	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	2.22; 0.09
Collembola	0.3 ± 0.1b	0.3 ± 0.3b	0.0 ± 0.0b	3.8 ± 1.3a	6.79; 0.0005*

* Indicate that treatments were significant at $P < 0.05$.

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Table 3. Mean (±SEM) of spotted wing drosophila and other nontarget arthropods recorded in traps in a blueberry field as affected by the bait type (ACV and yeast + sugar) and age of the bait (7 and 14 d old)

	ACV		Yeast + sugar		Statistics (*F*; *P*)	
	7	14	7	14	Bait type	Age of the bait
Drosophilidae (excluding spotted wing drosophila)	8.2±1.6	3.3 ± 1.6	23.3 ± 5.6	6.8 ± 3.0	8.61; 0.0053*	11.45; 0.0015*
Total spotted wing drosophila	0.1±0.1	0.1 ± 0.1	0.8 ± 0.3	0.1 ± 0.1	3.15; 0.08	3.15; 0.08
Spotted wing drosophila male	0.1±0.1	0.0 ± 0.0	0.7 ± 0.3	0.0 ± 0.0	2.24; 0.14	3.54; 0.07
Spotted wing drosophila female	0.0±0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.67; 0.42	0.0; 1.00
Thripidae	0.9±0.7	4.8 ± 2.5	7.8 ± 4.0	25.4 ± 14.2	3.86; 0.05*	1.53; 0.22
Chrysomelidae	1.3±0.6	0.7 ± 0.2	0.8 ± 0.4	0.3 ± 0.1	1.07; 0.3	3.53; 0.06
Chrysopidae	0.0±0.0	0.2 ± 0.2	0.3 ± 0.1	0.2 ± 0.2	1.22; 0.28	0.00; 1.00
Formicidae	0.0±0.0	0.0 ± 0.0	0.8 ± 0.3	0.2 ± 0.2	7.14; 0.01*	3.64; 0.06
Nitulidae	9.2±3.7	0.3 ± 0.1	103.7 ± 47.5	0.5 ± 0.2	4.80; 03*	5.28; 0.02*
Sarcophagidae	0.3±0.2	0.1 ± 0.1	1.1 ± 0.7	0.8 ± 0.4	4.27; 0.04*	0.47; 0.5
Anthocoridae	0.2±0.1	0.0 ± 0.0	0.6 ± 0.2	0.2 ± 0.1	4.14; 0.05*	6.47; 0.01*
Uliidae	0.0±0.0	0.0 ± 0.0	0.3 ± 0.1	0.2 ± 0.1	7.64; 0.0082*	0.83; 0.36
Collembola	0.1±0.1	0.8 ± 0.4	0.3 ± 0.2	2.0 ± 2.0	0.60; 0.44	1.21; 0.28

* Indicate that treatments were significant at $P \leq 0.05$.

wing drosophila flies than the trap design modifications tested. The yellow sticky card placed inside the cup trap may catch a few spotted wing drosophila; however, this tends to complicate matters as identification of spotted wing drosophila on the card can be difficult. We noticed that specimens captured on the cards tend to desiccate rapidly, requiring immediate identification, whereas flies captured in the ACV drowning solution maintained their color and overall appearance. This is an important finding because additional time would be required by growers to insert yellow foamboards or yellow sticky cards with the hope that this tactic will increase the effectiveness of the trap in detecting spotted wing drosophila. The addition of detergent is also a common practice thought to improve spotted wing drosophila captures. However, our results indicate that the detergent could be omitted and the efficacy of the trap system would remain unaffected, reducing the time and cost of constructing the traps.

The results of the bait studies both in the blueberries and wild blackberries showed that the yeast baits (yeast + sugar and yeast + flour) were more attractive than the vinegar baits (ACV and wine + vinegar). Yeast + sugar trap has been reported to capture more spotted wing drosophila than ACV baiting liquid (Walsh et al. 2011, Dreves et al. 2012). Becher et al. (2012) showed that *D. melanogaster* is attracted to volatiles associated with yeasts found on host fruits but not the volatiles associated with fruits themselves, which may explain the use of baker's yeast in spotted wing drosophila monitoring studies where sugar water with baker's yeast has been reported to be highly attractive to spotted wing drosophila (Walsh et al. 2011).

The association of yeasts and *Drosophila* spp. is well-known (Markow and O'Grady 2008, Saerens et al. 2010, Becher et al. 2012, Hamby et al. 2012). Adults and larvae of spotted wing drosophila and other drosophilids will feed upon the associated yeasts and bacteria as well as the fruit material from damaged or fallen berries (Markow and O'Grady 2008, Hamby et al. 2012). In addition, yeast in the absence of fruit has shown to be sufficient for attraction, oviposition, and larval development of *D. melanogaster* (Becher et al. 2012).

ACV bait on its own captured fewer spotted wing drosophila than the yeast baits. Adding wine and sugar to ACV, however, increased the attractiveness of this bait to spotted wing drosophila, resulting in spotted wing drosophila captures comparable to the yeast + sugar baited traps. Landolt et al. (2012a) also found that a mixture of ACV and Merlot (60:40 ratio) acted additively to attract more spotted wing drosophila than either product alone. It is unclear whether the addition of sugar in the ACV + wine + sugar bait influenced spotted wing drosophila captures. In both studies, addition of rice vinegar to ACV did not improve the performance of the traps in terms of capturing more spotted wing drosophila. Although *Drosophila* spp. are known to be attracted to acetic acid or acetic acid-containing substrates for oviposition purposes (Joseph et al. 2009), ACV may not be the best baiting liquid to use early in the season when spotted wing drosophila population is low (Kleiber et al. 2012).

Wild blackberries, *Prunus* spp., are the dominant species surrounding blueberry plantings in central Florida and may have impacted (increased) spotted wing drosophila population in the field over time. Wild blackberries are not harvested or managed and the bushes support a high fruit load (Rull and Prokopy 2005) with a high percentage of fermenting fruit. The odors emitted from the fermenting blackberries may mask baits such as the wines and vinegars used in this study, resulting in no differences between bait types.

The decision to use one bait over another may be a personal decision related to certain obvious advantages and disadvantages. For instance, vinegar and wine baits are generally clear or can be easily rinsed from specimens and permit quick identification in the field or laboratory. Finally, vinegar and wine baits act as excellent preservatives for collected specimens. The big disadvantage is that spotted wing drosophila captures may be slightly lower than yeast-based baits. *D. suzukii* capture rates for yeast-based baits are fairly

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high but these baits are cloudy and have sediments that make identification difficult and extensive. The whole wheat flour in the yeast + flour mix also made identifying and counting spotted wing drosophila challenging because its color was similar to the color of the flies and the grains were too large to be sifted out.

Our research indicates that when ACV and yeast + sugar baits are left in the field for 14 d, the capture rates of other Drosophilidae flies (excluding spotted wing drosophila) are decreased by >50%. However, the age of the bait did not seem to affect the capture rates for spotted wing drosophila when using ACV, which could be because of low spotted wing drosophila population in the field at the time of the study. Overall, bait age affected trap captures for all nontarget insects trapped except for thrips. As the yeast + sugar bait aged in the field (14 d old), it produced a particularly foul odor (to the human nose) that appeared to be unattractive to spotted wing drosophila as evidenced by low captures. During fermentation, yeasts produce elevated levels of carbon dioxide that may be a repellant to some *Drosophila* species. Studies have shown that *Drosophila* have their carbon dioxide receptors inhibited by the fruity odors produced by ripening or ripe fruits allowing them to be able to locate food under such circumstances (Turner and Ray 2009). We do not know if the high levels of carbon dioxide in the yeast + sugar or yeast + flour in absence of fruity odors and diminished yeast levels may have played a role in making the bait unattractive after a period of time in the field.

None of the baits tested in the current study are specific to spotted wing drosophila and attract many other species of insects lured to sweet or fermenting odors (Landolt 1995). Other drosophilids are especially attracted to the odors of fermenting fruit and yeasts (Reed 1938; Zhu et al. 2003; Budick and Dickenson 2006; Markow and O'Grady 2008; Becher et al. 2010, 2012; Landolt et al. 2012a,b; Lebreton et al. 2012; Steck et al. 2012). The yeast + flour and yeast + sugar baits were particularly attractive to other flies (Drosophilidae) including the invasive species *Z. indianus*, Nitidulidae, Thripidae, Anthocoridae, and Formicidae. Identifying spotted wing drosophila can become arduous in traps with high numbers of nontarget species. Trap designs can be modified to reduce the number of nontarget species, such as reducing the size of the entry holes to prevent entry of larger insects. However, unless a specific bait for spotted wing drosophila is developed, other vinegar flies and small nontargets will likely be found in spotted wing drosophila traps. Although acetic acid, ethanol, acetoin, and methaniol have been identified as the attractant compounds in wine and vinegar by Cha et al. (2014), a commercial blend is not yet available.

A significant finding from this study was the presence of *Z. indianus* in both southern highbush blueberries and blackberries. The reason for the higher captures of *Z. indianus* in yeast + flour than in ACV bait or wine + vinegar is unclear, but requires further investigation. In addition, the extent of injury and damage of *Z. indianus* to southern highbush and blackberries needs further investigation. Regardless, this species appears to be a late season pest because higher numbers were caught later in the season (when temperatures were warmer).

Until more research is available, the basic cup trap would be recommended as it requires less time to construct and is less expensive than the cup trap modifications evaluated in this study. Because the evaluated baits are not specific to spotted wing drosophila and vary in their attractiveness, the recommended bait remains a personal decision based on the advantages and disadvantages discussed. Currently, no threshold has been developed for spotted wing drosophila in small fruit plantings. The presence of a single spotted wing drosophila fly initiates control actions. At the beginning of the spotted wing drosophila host plant season, the population of spotted wing drosophila is low as it begins to migrate into fields from surrounding areas (Ohrn and Dreves 2012; L.E.I. and O.E.L., unpublished data). An effective trap-and-lure system must be able to capture spotted wing drosophila as soon as this migration begins, so control actions can be taken immediately. This system must also be able to detect surviving flies after control actions have been implemented to determine whether actions have been successful. The populations of spotted wing drosophila in Florida have increased since the first detection in 2009 (Liburd and Iglesias 2013); however, the population has remained relatively low compared with some other states (Ohrn and Dreves 2012, Cowles 2013). Further studies aimed to identify key compounds specifically attractive to spotted wing drosophila will lead to a more selective bait for monitoring this highly destructive pest.

Acknowledgment

We would like to acknowledge Drs. Lukasz Stelinski and Robert McSorley for reviewing earlier drafts of this manuscript. We would also like to thank all participating growers and the assistants of the Small Fruit and Vegetable IPM Laboratory at the University of Florida. The project was funded by the U.S. Department of Agriculture–Sustainable Agriculture Research and Education (USDA–SARE) Graduate Student Research Grant, the Florida Blueberry Growers Association (BBGA), and the Florida Specialty Crop Block Grant program.

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Received 9 December 2013; accepted 22 April 2014.

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