Comparison of a Synthetic Chemical Lure and Standard Fermented Baits for Trapping *Drosophila suzukii* (Diptera: Drosophilidae)

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ABSTRACT We determined the attractiveness of a new chemical lure compared with fermented food baits in use for trapping *Drosophila suzukii* Matsumura, spotted wing drosophila (Diptera: Drosophilidae), in Connecticut, New York, and Washington in the United States and at Dossenheim in Germany. The chemical lure (SWD lure) and food baits were compared in two types of traps: the dome trap and a cup trap. Regardless of trap type, numbers of male and female *D. suzukii* trapped were greater with the SWD lure compared with apple cider vinegar (ACV) baits at the Washington and New York sites, and were comparable with numbers of *D. suzukii* captured with a wine plus vinegar bait (W + V) at Germany site and a combination bait meant to mimic W + V at the Connecticut site. Averaged over both types of attractants, the numbers of *D. suzukii* captured were greater in dome traps than in cup traps in New York and Connecticut for both male and female *D. suzukii* and in Washington for male *D. suzukii*. No such differences were found between trap types at the Washington site for female and Germany for male and female *D. suzukii*. Assessments were also made of the number of large (>0.5 cm) and small (<0.5 cm) nontarget flies trapped. The SWD lure captured fewer nontarget small flies and more large flies compared with ACV bait in New York and fewer nontarget small flies compared with W + V in Germany, although no such differences were found in Washington for the SWD lure versus ACV bait and in Connecticut for the SWD lure versus the combination bait, indicating that these effects are likely influenced by the local nontarget insect community active at the time of trapping. In New York, Connecticut, and Germany, dome traps caught more nontarget flies compared with cup traps. Our results suggest that the four-component SWD chemical lure is an effective attractant for *D. suzukii* and could be used in place of fermented food-type baits.

KEY WORDS spotted wing drosophila, *Drosophila suzukii*, trap, lure, nontarget insect

Spotted wing drosophila, *Drosophila suzukii* Matsumura (Diptera: Drosophilidae), is of east Asian origin and has spread rapidly throughout much of North America (Walsh et al. 2011, Burrack et al. 2012), including all principal fruit-growing regions, as well as much of Europe (Calabria et al. 2012, Cini et al. 2012). In the western United States, it has rapidly become a serious pest of many fruit crops, in particular cherries and many types of berries, with estimated potential damage of US$511 million/yr to small fruit growers (Bolda et al. 2010, Walsh et al. 2011). In the eastern United States, *D. suzukii* has caused significant economic losses in raspberry, blackberry, strawberry, cherry, and blueberry crops (Burrack et al. 2013; G.M.L. and R.S.C., unpublished data).

The detection and monitoring of *D. suzukii* is important for making pest management decisions (Beers et al. 2011, Dreves 2011, Isaacs 2011). Monitoring has mostly used various designs of cup traps containing fermented food baits such as vinegars, wines, and yeast–sugar solutions (Walsh et al. 2011, Cini et al. 2012). Apple cider vinegar (ACV) has been the most widely recommended bait because of its ubiquity, simplicity, and ease with which flies may be observed, although it is not an optimized lure for catching *D. suzukii* (Lee et al. 2012). A comparison of multiple trap designs by using ACV as bait in seven states/provinces of North America suggested that trap design could be improved to increase the numbers of *D. suzukii* captured and thus improve the sensitivity of early season detection of the fly (Lee et al. 2012). Early detection of the fly or confidence of its absence may be critical to an effective integrated pest management (IPM) program in some crops. In eastern Washington and Oregon cherry orchards, for example, poor overwintering success and low spring populations of *D. suzukii* may allow some cherry growers to escape *D. suzukii*

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damage if cherries are harvested before *D. suzukii* reach damaging densities.

Limited information is available for lure/trap designs that are effective in detecting adult *D. suzukii* flies before first incidence of fruit infestation (but see Dalton et al. 2011, Isaacs et al. 2012). A more consistently attractive and easy-to-use bait or lure, and a trap design that is most effective in capturing attracted flies, will likely improve the early season *D. suzukii* detection in support of IPM. With this in mind, we recently isolated and identified a four-component essential chemical blend that is attractive to *D. suzukii* (Cha et al. 2013b), based on analysis and study of the headspace volatiles (Cha et al. 2012) of a wine and vinegar (W + V) bait that was significantly more attractive than vinegar baits (Landolt et al. 2012a,b). That four-component chemical blend (herein referred to as the SWD lure, composed of acetic acid, ethanol, acetoin, and methionol) was as attractive as the mixture of W + V in field trapping experiments conducted in Oregon and Mississippi (Cha et al. 2013b). The principal objective of this study was to evaluate the effectiveness of this SWD lure compared with fermentation or food baits that have been in use for monitoring *D. suzukii* at three locations in the United States and one location in Germany.

A common undesirable outcome of trapping insects with food materials is the bycatch of numerous nontarget insects. For example, only 26–31% of total *Drosophila* spp. captured, regardless of seven different trap designs baited with ACV at seven different locations across North America, were *D. suzukii* (Lee et al. 2012). This "noise" could make it more difficult for growers and pest managers to correctly identify and thus detect *D. suzukii.* As other *Drosophila* spp. are generally not considered pests (Zhu et al. 2003), false-positives are a concern, and control measures may be implemented that are unnecessary. Large numbers of additional taxa of flies, as well as other insects, respond to these types of baits, adding to the difficulty of maintaining traps for *D. suzukii.* This has led, for example, to designs incorporating screening to exclude larger insects from traps (Lee et al. 2012).

The consideration of selectivity, in addition to sensitivity, could thus be an important design aspect for an improved *D. suzukii* trapping system. We expect that a subset of chemicals isolated and identified from a food material and determined to be attractive for a pest insect, such as our SWD chemical lure, may improve the selectivity of the trap over the original food bait. This is because hundreds of volatile chemicals are released from such food materials (Natera et al. 2003, Aznar and Arroyo 2007) and different subsets of these chemicals are potentially involved in the insect recognition of and attraction to the resource (Bruce et al. 2005). Therefore, we hypothesize that a more-simplified and better-defined chemical lure isolated from a food source will attract a narrower range of nontarget insects than the original material. A secondary objective of this study was to determine if the numbers of nontarget insects are reduced with the SWD lure compared with the fermented food bait in use.

We report here the results of four field experiments that compared 1) the attractiveness of our four-component SWD lure with the attractiveness of locally recommended standard fermented food baits for *D. suzukii* by using a dome trap and a locally recommended cup trap at four geographic locations: Connecticut, New York, and Washington in the United States and Dossenheim in Germany; 2) the effectiveness of the dome trap versus cup-type traps for capturing *D. suzukii* attracted by the SWD lure and by fermented food baits; and 3) nontarget fly response to the SWD lure versus fermented food bait. Fruiting stages at different trapping locations varied with ripening, ripe, and/or overripe fruits available at the time of trapping.

Materials and Methods

Experimental Design. Trapping experiments were conducted at four locations: Connecticut, New York, and Washington in the United States and Dossenheim in Germany. All four experiments compared a four-component chemical lure (the SWD lure; Cha et al. 2013b) with a local standard fermented food bait in a dome trap and a cup-style local standard trap used for monitoring *D. suzukii.* Thus, each experiment was conducted as a two by two factorial design involving four treatment combinations: 1) SWD lure in a dome trap, 2) the local standard bait in a dome trap, 3) SWD lure in a cup trap, and 4) the local standard bait in a cup trap. The local bait and cup-style trap varied with the location (see Local Standard Baits Tested and Local Standard Traps Tested sections). In all tests, a randomized complete block design was used, with 10 replicate blocks. Insects were removed from traps weekly and drowning solutions were replaced weekly. Vials containing chemical lure were not replaced during the 2-wk trapping period. Captured flies were categorized and counted as male *D. suzukii*, female *D. suzukii*, small flies (<0.5-cm-long flies other than *D. suzukii*), and large flies (>0.5-cm-long flies). Although the majority of the small nontarget flies were drosophilids, we did not identify the flies by species and thus categorized those as small flies.

Chemical Lure. In all tests, the four-component chemical lure (SWD lure) was composed of acetic acid, ethanol, acetoin, and methionol (Cha et al. 2013b). Acetic acid (99.8%, CAS No. 64-19-7; Fisher, Pittsburgh, PA) and ethanol (200 proof, CAS No. 64-47-5; Pharmco, Brookfield, CT) were provided in the drowning solution of the trap, at concentrations of 1.6 and 7.2% by volume, respectively, in water. Acetoin (3-hydroxybutan-2-one, ≥96%, CAS No. 513-86-0; Sigma–Aldrich, St. Louis, MO) and methionol (3-methylsulfanylpropan-1-ol, ≥98%, CAS No. 505-10-2; Penta, Livingston, NJ) were dispensed from separate 4-ml polypropylene vials (Nalgene Nunc International, Rochester, NY), each with a 3-mm-diameter hole in the vial lid and a piece of cotton on the bottom. One milliliter of neat methionol was loaded into the vial. Acetoin is a solid at room temperature. Therefore, it was dissolved in water 1:1 (wt:wt) at 70°C before

Table 1. Summary of trap parameters for *Drosophila suzukii*

	Standard bait		Cup-type traps			Drowning solutions	
Site	Bait	Component	Cups	Hole diameter	No. holes	Cup	Dome
WA	ACV	100% ACV	Clear Solo 480 ml	9.5 mm	4	50 ml	300 ml
NY	ACV	100% ACV	Clear 960 ml deli	5 mm	12	150 ml	300 ml
CT	VGA	37% ACV 56% grape J. 6% ethanol	Red Solo 540 ml	5 mm	12	80 ml	300 ml
GER	W + V	60% red wine 40% ACV	Clear Jokey 870 ml	3 mm	20	150 ml	250 ml

WA, Washington; NY, New York; CT, Connecticut; GER, Germany; ACV, apple cider vinegar; W + V, wine + vinegar; grape J, grape juice. All cup traps were fitted with clear or translucent covers; holes were on the sides of cups.

loading 2 ml per vial. These vials were suspended with wire near the top of the inside of the trap.

Local Standard Baits Tested. Standard baits were either an ACV- or a W + V-type bait, summarized in Table 1. In Washington, the standard bait was undiluted ACV (5% acidity; Safeway Inc., Pleasanton, CA) (Washington State University Extension 2010). In New York, the standard bait was also undiluted ACV (5% acidity; Wegmans Food Markets, Inc., Rochester, NY) (Cornell Fruit, Pest Alerts, http://www.fruit.cornell.edu/berry/pestalerts/drosophilapestalert.html). In Connecticut, a combination bait (referred to as the VGA bait) composed of 37% ACV (V; 5% acidity, IGA, Chicago, IL), 56% grape juice (G; reconstituted Welch's 100% white grape juice, Welch Foods Inc., Concord, MA), and 6% ethanol (A as in alcohol) was used as a standard bait. The VGA bait mimicked a mixture of 60% wine and 40% vinegar (Cha et al. 2012; Landolt et al. 2012a,b). In Germany, the standard bait was a mixture of 60% red wine (12% ethanol, Les Chais Réunis à Béziers, France) and 40% ACV (5% acidity, Kaufland GmbH & Co KG, Neckarsulm) (W + V bait; Landolt et al. 2012a,b).

Dome Trap. The Dome trap (Trappitt trap, Agrisense Ltd., Pontypridd, United Kingdom) was used at all sites. In brief, the dome trap is yellow on the bottom one-third and clear on the top two-thirds, with a 5-cm-diameter bottom hole (area of trap opening = 19.6 cm^2) for entry of attracted insects. The trap bottom held 300 ml of drowning solution (except 250 ml in Germany, Table 1), which was either an aqueous mixture of 7.2% ethanol + 1.6% acetic acid for treatment 1) or the local standard bait for treatment 2) listed in the Experimental Design section. All of the drowning solutions contained a small amount of soap to reduce the surface tension and enhance retention of *D. suzukii* in traps. Boric acid (1%; Fisher, Santa Clara, CA) was added to inhibit microbial growth.

Local Standard Traps Tested. All four local standard traps tested were cup-style traps, summarized in Table 1. In Washington, a cup trap made from a Solo 480-ml clear plastic cup (Lake Forest, IL) with four 9.5-mm-diameter holes (total area of trap openings = 2.8 cm^2) and covered by a clear plastic lid was used (Washington State University Extension 2010). In New York, a cup trap made from a 960-ml clear plastic Deli cup and lid (Fabri-Kal Corporation, Kalamazoo, MI) with 12 5-mm-diameter holes in the side of the cup, ≈2.5 cm below the top (total area of trap openings = 2.4 cm^2), was used. In Connecticut, a cup trap that was a Solo 540-ml red polystyrene cup (Lake Forest, IL) with 12 5-mm-diameter holes in the side of the cup near the top (total area of trap openings = 2.4 cm^2) and covered by a clear plastic lid was used. In Germany, a cup trap from a Jokey 870-ml transparent polypropylene cup and lid (JEBT 850, www.jokey.com) with 20 3-mm-diameter holes in two rows on the side of the cup (total area of trap openings = 1.4 cm^2) was used. The cup traps held 50, 150, 80, and 150 ml of drowning solution in Washington, New York, Connecticut, and Germany, respectively, which was either a mixture of 7.2% ethanol + 1.6% acetic acid in water for treatment 3) or the local standard bait for treatment 4) listed in the Experimental Design section.

Washington Experiment. The SWD lure was compared with undiluted ACV and the dome trap was compared with the 480-ml clear cup trap. Four trap treatments were: 1) the dome trap baited with the SWD lure (300 ml 7.2% ethanol + 1.6% acetic acid in water as a drowning solution plus a vial of acetoin and a vial of methionol), 2) the dome trap baited with ACV (300 ml undiluted ACV as a drowning solution), 3) the cup trap baited with the SWD lure (50 ml 7.2% ethanol + 1.6% acetic acid in water as a drowning solution plus a vial of acetoin and a vial of methionol), and 4) the cup trap baited with ACV (50 ml undiluted ACV as a drowning solution). Drowning solutions in all four treatments contained 1% boric acid and 0.0125% unscented dishwashing detergent (Palmolive Clear and Clean Spring Fresh Dishwashing Soap, Colgate-Palmolive Company, New York, NY). The 10 blocks of traps with these four treatments (40 traps total) were set up at the Washington State University Experiment Station in Puyallup, WA, on 10 November 2012 and were maintained until 24 November. Traps were placed along woodlot edges, at the edge of blackberry patches, or on fence lines at a height of 1 m, with traps 10 m apart within blocks and trap blocks at least 100 m apart. Overripe and dried-out fruits were abundant on blackberry canes and ground at the time of this trapping experiment.

New York Experiment. The SWD lure was compared with undiluted ACV and the dome trap was compared with the 960-ml clear cup trap. The four experimental treatments were similar to the Washington experiment, with differences in the amount of the standard bait/drowning solution and the type of surfactant used. The standard bait of undiluted ACV was used at a dose of 300 ml per dome trap and 150 ml per cup trap. The drowning solution for the traps with the SWD lure was applied at the same dose of 300 ml per dome trap and 150 ml per cup trap. An unscented dishwashing detergent (Free & Clear Natural Dish liquid, Seventh Generation, Burlington, VT) was added at 0.01% of the drowning solution as a surfactant. The 10 blocks of traps with these four treatments (40 traps total) were set up at the Darrow Farm at New York Agricultural Experiment Station in Geneva, NY, and a commercial fruit farm in Geneva, NY, on 2 October 2012 and were maintained until 18 October 2012. Traps were placed next to raspberry plantings with ripe and overripe fruit present, at a height of 0.6 m off the ground, with traps ≈10 m apart within blocks and the two sites >1 km apart.

Connecticut Experiment. The SWD lure was compared with the VGA bait and the dome trap was compared with the 540-ml red cup trap. The four treatments were similar to the New York experiment, with differences in the type of local standard bait (VGA bait instead of ACV) and the amounts of the standard bait/drowning solution. The VGA bait was used at a rate of 300 ml per dome trap and 80 ml per cup trap. The drowning solution for the traps with the SWD lure was applied at the same doses of 300 ml per dome trap and 80 ml per cup trap. Traps were maintained in various locations within the Valley Laboratory research farm fields (vineyard with ripe and overripe grapes, tomato field with rotting tomatoes, and edge of woods; five, three, and two replicates, respectively) from 5 to 19 October, 2012. Traps were placed at a height of 1 m, with traps at least 3 m apart within blocks and trap blocks at least 10 m apart.

Germany Experiment. The SWD lure was compared with a mixture of 60% red wine and 40% ACV (W + V bait; Landolt et al. 2012a,b) and the dome trap was compared with the 870-ml transparent cup trap. The four treatments were similar to the New York experiment, with differences in the type of local standard bait (W + V bait instead of ACV) and the amounts of the standard bait/drowning solution. The W + V bait was used at a rate of 250 ml per dome trap and 150 ml per cup trap. The drowning solution for the traps with the SWD lure was applied at the same dose of 250 ml per dome trap and 150 ml per cup trap. The 10 blocks of traps with these four treatments (40 traps total) were set up at the experimental field of the JKI research station at Dossenheim on 9 October 2012 and were maintained until 23 October 2012. Traps were placed in a raspberry planting with ripening fruits present (ripe fruits were picked twice a week) at a height of 1 m and hung on peach trees at a height of 1.5 m off the ground. Traps in both crops were ≈4 m apart.

Statistical Analysis. Numbers of male and female *D. suzukii* and small and large nontarget flies trapped over 2 wk were totaled for each replicate and analyzed with block as a random factor and different trap types (dome trap or cup trap) and lure types (SWD chemical lure or local standard bait) as two fixed factors by using Proc Mixed (SAS Institute 2009). Insect capture data were square root transformed to improve normality and homoscedasticity (Zar 1984). The treatment means were compared by using the Tukey–Kramer test (SAS Institute 2009).

Results

Washington Experiment. The greatest numbers of male and female *D. suzukii* were captured in dome traps baited with the SWD lure (Fig. 1a and b). For both dome and cup traps, numbers of flies captured were 3.1 times greater with the SWD lure compared with the ACV bait (bait main effect: $F_{1,27} = 49.88$, $P < 0.001$ for female *D. suzukii;* $F_{1,27} = 51.01$, $P < 0.001$ for male *D. suzukii*). For both chemical lure and vinegar bait, numbers of female *D. suzukii* captured with the dome trap were not significantly different (trap main effect: $F_{1,27} = 2.00$, $P = 0.168$), but numbers of male *D. suzukii* in dome traps were 1.5 times greater than in cup traps (trap main effect: $F_{1,27} = 6.30$, $P = 0.018$). No significant interactions were found between the bait type and trap type for numbers of male and female *D. suzukii* trapped ($F_{1,27} = 1.48$, $P = 0.235$ for female and $F_{1,27} = 3.62$, $P = 0.068$ for male *D. suzukii*).

In the Washington trapping experiment, >90% of all the flies captured were *D. suzukii.* No significant effects of bait ($F_{1,27} = 3.35$, $P = 0.078$ for small nontarget flies and $F_{1,27} = 2.47$, $P = 0.127$ for large flies) or trap type ($F_{1,27} = 1.17$, $P = 0.288$ for small nontarget flies and $F_{1,27} = 0.12$, $P = 0.728$ for large flies) and interaction between bait and trap type ($F_{1,27} = 2.22$, $P = 0.148$ for small nontarget flies and $F_{1,27} = 0.30$, $P = 0.588$ for large flies) were found on numbers of nontarget small flies (Fig. 2a) and large flies (Fig. 2b) captured.

New York Experiment. The greatest numbers of *D. suzukii* captured were in dome traps baited with the SWD lure (Fig. 1c and d). As in the Washington test, the numbers of *D. suzukii* flies captured were greater with the SWD lure than the ACV bait for both trap types (bait main effect: 3.1 times greater for female *D. suzukii:* $F_{1,27} = 29.52$, $P < 0.001$; 3.9 times greater for male *D. suzukii:* $F_{1,27} = 66.73$, $P < 0.001$). For both bait types, numbers of flies captured were greater with the dome trap than with the cup trap (trap main effect: 4.1 times greater for female *D. suzukii:* $F_{1,27} = 37.10$, $P < 0.001$; 3.0 times greater for male *D. suzukii:* $F_{1,27} = 70.04$, $P < 0.001$). Similar to Washington, no significant interactions were found between the bait type and trap type for numbers of male and female *D. suzukii* trapped ($F_{1,27} = 0.13$, $P = 0.726$ for female and $F_{1,27} = 0.10$, $P = 0.758$ for male *D. suzukii*).

In the New York trapping experiment, up to 30% of all the flies captured with ACV bait and >60% of all the flies captured by the SWD lure were *D. suzukii.* For both trap types, the SWD lure captured 3.9 times fewer nontarget small flies than traps baited with ACV (bait main effect: $F_{1,27} = 41.47$, $P < 0.001$), and the effect was stronger with the dome trap than with the cup trap (bait and trap interaction: $F_{1,27} = 5.36$, $P =$

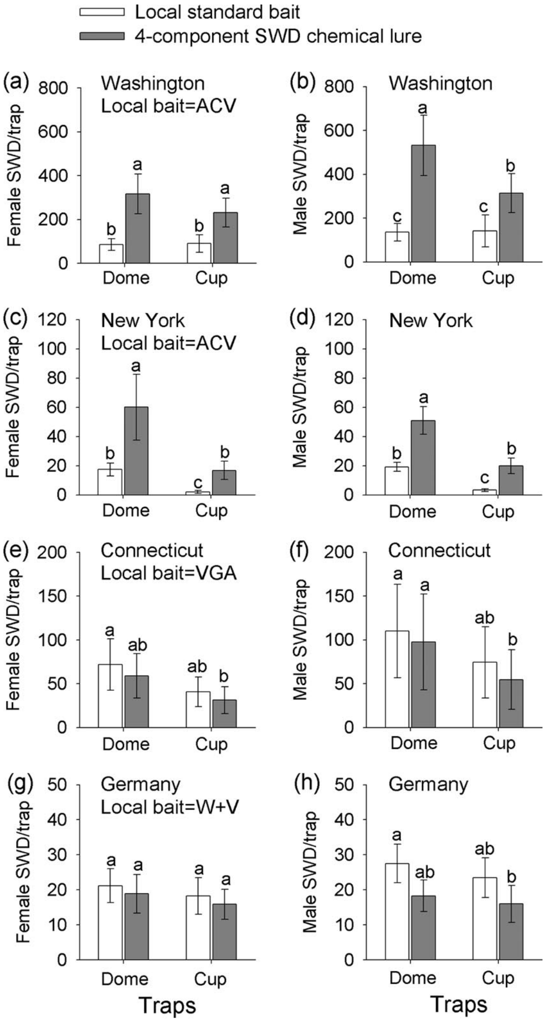

Fig. 1. Mean (±SE) numbers of female (a, c, e, and g) and male (b, d, f, and h) *Drosophila suzukii* flies captured in dome traps and cup traps baited with the four-component SWD chemical lure or with a local standard bait at Washington (WA), New York (NY), Connecticut (CT), and Germany (GER). Apple cider vinegar (ACV) was the local standard bait at WA and NY. A combination bait of ACV, grape juice, and ethanol (VGA bait) was the local standard at CT. A mixture of wine and vinegar (W + V) bait was the local standard at GER. Clear cup trap was the local standard trap at WA, NY, and GER. Red cup trap was the local standard trap at CT. For each graph, different letters on bars indicate significant differences by Tukey–Kramer tests at $P < 0.05$. Statistical tests are based on square-root-transformed data. Means from untransformed data are shown.

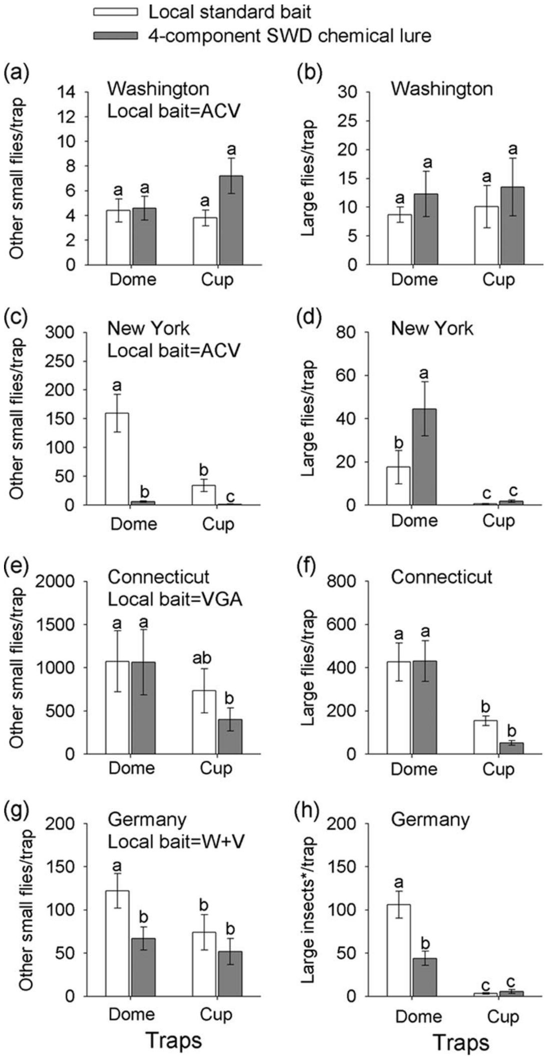

Fig. 2. Mean (±SE) numbers of small nontarget flies (<0.5 cm) (a, c, e, and g), large nontarget flies (>0.5 cm) (b, d, and f), and large nontarget insects* (>0.5 cm) (h) captured in dome traps and cup traps baited with the four-component SWD chemical lure or with a local standard bait at Washington (WA), New York (NY), Connecticut (CT), and Germany (GER). ACV was the local standard bait at WA and NY. A combination bait of ACV, grape juice, and ethanol (VGA bait) was the local standard at CT. A mixture of wine and vinegar (W + V) bait was the local standard at GER. Clear cup trap was the local standard trap at WA, NY, and GER. Red cup trap was the local standard trap at CT. For each graph, different letters on bars indicate significant differences by Tukey–Kramer tests at $P < 0.05$. Statistical tests are based on square-root-transformed data. Means from untransformed data are shown. (*Large insects included large flies, which were not counted separately.)

0.029; Fig. 2c). In contrast, the greatest numbers of large flies captured were in dome traps baited with the SWD lure (Fig. 2d). For both trap types, the SWD lure captured 2.6 times more large flies than traps baited with ACV (bait main effect: $F_{1,27} = 7.36$, $P = 0.011$). For both large and small nontarget flies, the dome traps captured more nontarget flies than cup traps for both bait types (trap main effect: 5.0 times more for small flies: $F_{1,27} = 67.90$, $P < 0.001$; 26.9 times more for large flies: $F_{1,27} = 46.58$, $P < 0.001$). No significant interaction was found between bait type and trap type for numbers of large flies captured ($F_{1,27} = 1.88$, $P = 0.182$).

Connecticut Experiment. Numbers of female and male *D. suzukii* trapped with the SWD lure were not statistically different from the numbers of flies captured with the VGA bait (bait main effect: $F_{1,27} = 3.60$, $P = 0.069$ for female *D. suzukii;* $F_{1,27} = 3.55$, $P = 0.070$ for male *D. suzukii;* Fig. 1e and f). For both the SWD lure and VGA bait, numbers of flies captured were greater with the dome trap than with the cup trap (trap main effect: 1.6 times more for female *D. suzukii:* $F_{1,27} = 8.76$, $P = 0.006$; 1.8 times more for male *D. suzukii:* $F_{1,27} = 13.75$, $P = 0.001$). No significant interactions were found between the bait type and trap type for numbers of male and female *D. suzukii* trapped ($F_{1,27} = 0.98$, $P = 0.331$ for female and $F_{1,27} = 0.01$, $P = 0.921$ for male *D. suzukii*).

In terms of nontarget flies captured, unlike Washington or New York tests, <15% of all the flies captured were *D. suzukii* at the Connecticut sites. For both trap types, the SWD lure and the VGA bait caught similar numbers of nontarget small flies (bait main effect: $F_{1,27} = 2.17$, $P = 0.152$) and large flies (bait main effect: $F_{1,27} = 3.56$, $P = 0.070$). Similar to the New York experiment, for both bait types, 1.9 times greater numbers of nontarget small flies (trap main effect: $F_{1,27} = 9.44$, $P = 0.005$; Fig. 2e) and 4.2 times greater numbers of large flies (trap main effect: $F_{1,27} = 43.52$, $P < 0.001$; Fig. 2f) were captured in the dome trap than in the cup trap. No significant interactions were found between the bait type and trap type for numbers of small nontarget flies and large flies trapped ($F_{1,27} = 1.46$, $P = 0.237$ for small nontarget flies and $F_{1,27} = 2.79$, $P = 0.106$ for large flies).

Germany Experiment. For both dome and cup trap types, numbers of female *D. suzukii* trapped with the SWD lure were not statistically different from the numbers of flies captured with the W + V bait (bait main effect: $F_{1,27} = 0.78$, $P = 0.386$; Fig. 1g). Averaged over dome and cup trap types, numbers of male *D. suzukii* trapped with the SWD lure were 33% lower than the numbers of flies captured with the W + V bait (bait main effect: $F_{1,27} = 7.28$, $P = 0.012$). Within trap types, however, numbers of male *D. suzukii* trapped with the SWD lure were not statistically different from the numbers of flies captured with the W + V bait (Fig. 1f). For both the SWD lure and W + V bait, numbers of flies captured with the dome trap were not significantly different from the numbers of flies captured with the cup trap (trap main effect: $F_{1,27} = 1.61$, $P = 0.215$ for female *D. suzukii;* $F_{1,27} = 1.87$, $P = 0.182$ for male *D. suzukii*). No significant interactions were found between the bait type and trap type for numbers of male and female *D. suzukii* trapped ($F_{1,27} = 0.00$, $P = 0.988$ for female and $F_{1,27} = 0.00$, $P = 0.982$ for male *D. suzukii*).

In the trapping experiment in Germany, 34% of all the flies counted were *D. suzukii.* The greatest numbers of small nontarget flies captured were in dome traps baited with W + V bait (Fig. 2g). Large insects, including large muscid flies, which were not counted separately, were trapped mostly in the dome traps, especially when baited with W + V bait (H.V., unpublished data; Fig. 2h). For both trap types, 65% more nontarget small flies (bait main effect: $F_{1,27} = 14.87$, $P < 0.001$) and 55% more large insects (bait main effect: $F_{1,27} = 12.98$, $P = 0.001$) were captured with the W + V bait than the SWD lure. For both bait types, 33% more nontarget small flies (trap main effect: $F_{1,27} = 17.32$, $P < 0.001$) and 16.9 times more nontarget large insects (trap main effect: $F_{1,27} = 213.48$, $P < 0.001$) were captured in the dome trap than in the cup trap. Significant interactions between the bait type and trap type were not found for numbers of small nontarget flies trapped ($F_{1,27} = 2.02$, $P = 0.167$) and were found for numbers of large insects trapped ($F_{1,27} = 22.55$, $P < 0.001$).

Discussion

Traps baited with the four-component chemical blend (SWD lure) consistently captured greater numbers of *D. suzukii* than traps baited with the ACV bait that has been recommended in New York and Washington for monitoring *D. suzukii* (Cornell Fruit, Pest Alerts, http://www.fruit.cornell.edu/berry/pestalerts/drosophilapestalert.html; Washington State University Extension 2010). The SWD lure performed similar to W + V bait in Germany and to the combination bait (VGA bait) in Connecticut that was designed to mimic W + V bait, which is more attractive than vinegar alone (Landolt et al. 2012a,b). These results are consistent with those of Cha et al. (2013b) showing that the SWD lure was comparable with a mixture of wine and vinegar for trapping *D. suzukii* in Oregon and Mississippi. In addition, these results and those of Cha et al. (2013b) indicate that the traps baited with the SWD blend consistently captured more *D. suzukii* than the traps baited with ACV bait and therefore, will likely provide better detection of early season populations of *D. suzukii.* Potential advantages of using synthetic bait in place of actual food baits—that is, simplicity of use and reduced vulnerability to spoilage or change in attractancy—may further improve the monitoring and management effort, once work to develop controlled release dispensers and to optimize lure parameters such as release rate and component ratios has been completed.

In Germany, the locally recommended bait for trapping *D. suzukii* was not ACV but a W + V bait, as demonstrated by Landolt et al. (2012a,b). In Connecticut, the locally recommended bait for trapping *D. suzukii* was the VGA bait (combination of vinegar, grape juice, and ethanol) that was designed by R. S. Cowles for use by New England fruit extension specialists to mimic W + V bait, in the absence of authority to purchase and use wine. White grape juice for the VGA bait was chosen for its light color, which facilitates observation of trapped insects. In the current study, the SWD lure performed similarly with W + V bait and VGA bait in luring *D. suzukii,* consistent with previous findings of similarity of the SWD lure and the W + V bait (Cha et al. 2013b). These results also suggest that the VGA bait may be comparable with a W + V bait, although this comparison has not been made experimentally.

Unlike in the New York or Washington experiments, a red cup trap was used in Connecticut, as a red cup trap generally performed better than clear cup traps in capturing *D. suzukii* attracted to ACV (Lee et al. 2012; J.C.L., unpublished data). In this study, we did not compare clear cup traps with red cup traps, and cannot make any conclusions regarding the responses of *D. suzukii* to trap color and opacity. It has been shown that *Drosophila* flies rely on multimodal integration of sensory cues in the resource location and selection processes (Gilbert and Kuenen 2008), suggesting that visual cues can play important roles when orienting to olfactory cues (Cha et al. 2013a). Studies are needed to thoroughly define the visual cues that are important to food- and host-seeking *D. suzukii.* Undoubtedly, many types of alterations to trap design might be evaluated as possible improvements over the current traps used in this study. For example, a recent study showed the importance of colors and visual patterns on the efficiency of trapping *D. suzukii* by using traps baited with ACV (Basoalto et al. 2013).

Our nontarget results provided mixed support for the hypothesis that a chemically defined lure would attract a narrower range of nontarget insects, suggesting that the selectivity of a chemical lure or food-based bait is influenced by the nontarget insect community structure that varies temporally and spatially. In other words, the differences in the number of nontarget insects captured appear to be affected by two confounding factors in our study—the abundance of nontarget insects and the make-up of species that are present in the surrounding area at the time of trapping. For example, in Washington, >90% of all the flies captured were *D. suzukii,* probably because there were not many nontarget flies active in the late season. In New York, although the SWD lure caught fewer small nontarget flies than ACV bait, the lure was more attractive than ACV bait to large flies. This indicates that the differences in chemical attraction by various nontarget species at a specific time and location determine the abundance of nontarget insects trapped. However, as we did not identify nontarget flies by species, we cannot answer questions related to this issue directly. For example, in the Connecticut trial, it is not clear whether the SWD lure and VGA baits caught similar nontarget species in similar numbers or simply caught different species of nontarget flies. In terms of trap design, at both New York and Connecticut, dome traps caught greater numbers of small and large nontarget flies than cup traps, consistent with the results of *D. suzukii.* With regard to nontarget captures of larger insects, small openings have the advantage to reduce their number considerably. Therefore, large openings may be covered with mesh to permit entry of drosophilids while excluding larger insects and still maintaining adequate surface area for volatile release.

One important improvement needed for current *D. suzukii* monitoring and detection efforts is the ability to detect adult *D. suzukii* flies before first incidence of fruit infestation. Previous studies suggest that the detection sensitivity may be improved by a better trap design. For example, although Lee et al. (2012) did not directly compare *D. suzukii* damage in relation with trap captures, they did show that greater numbers and size of holes across seven different trap designs were positively related to greater numbers of *D. suzukii* captured. Our results also support this trend: dome traps with a relatively wider area of opening (area of opening: 19.6 cm^2) captured generally greater numbers of *D. suzukii* compared with cup traps (area of opening: 1.4–2.8 cm^2) regardless of bait types in Washington, New York, and Connecticut, although this difference was not observed in Germany. This may also be true for nontarget flies—numbers of nontarget flies in the two groups (>5 mm and <5 mm) should be dependent, in part, on the diameter of trap openings or holes. It is unclear from this study how much differences in catch of SWD and nontarget flies between trap designs were because of differences in physical design of traps or because of the differences in volume of the bait/drowning solution between the dome (250–300 ml) and local cup trap (50–150 ml). Meanwhile, at New York and Washington, where ACV was chosen as the local standard bait, numbers of *D. suzukii* captured in dome traps, which performed better than cup traps, could still be increased when the traps were baited with the SWD lure compared with when baited with ACV bait, suggesting that both a more attractive lure and more effective trap design will improve *D. suzukii* detection.

The short trapping window (2 wk) and late season trapping (fall) of our study are two factors that limit the interpretation of our findings. Although experiments were replicated at four different geographic locations with varying hosts and fruiting phenologies, the limited seasonality of our study raises questions of the generalization of our results to earlier in the cropping season. This may be especially true if attraction of *D. suzukii* to olfactory cues changes over time because, for example, of competition between lures and fruits or differences in fly hunger levels because of varied abundance of foods. The SWD blend is based on food-finding olfactory cues, and it is likely to be effective both in early and late season and both for reproducing and nonreproducing flies (Cha et al. 2013b). Therefore, we are optimistic that the result from the current study can be generalized to early season *D. suzukii* monitoring for improved early detection sensitivity. Certainly, further studies are necessary to confirm whether fly responses to the SWD lure are relatively similar throughout different fruit-cropping seasons.

Fermented food materials, either artificial or their natural counterparts, are chemically complex, and generally attractive to many insect taxa. Captures of nontarget species that occur during the isolation, identification, and development of insect-feeding attractants based on such food materials may provide new opportunities for the discovery and development of chemical lures for other, originally nontarget insect pests. For example, African fig fly, *Zaprionus indianus* Gupta (Diptera: Drosophilidae), was captured in traps baited with W + V and the SWD lure (Cha et al. 2013b) and in this study in Connecticut, both with the

VGA and SWD lure baits (21 and 15 *Z. indianus* captured with the VGA and SWD lure baits, respectively). It is possible for additional attractant discoveries to come to light as studies are conducted to develop the SWD lure or other chemical attractants based on *D. suzukii* responses to fermented food baits.

Although a simple and more species-specific lure such as insect sex pheromone or the SWD chemical lure is desirable to monitor a specific target insect pest, chemically complex baits may be desirable for multiple-species surveillance or monitoring. The first detection of *D. suzukii* in New England resulted from inadvertent capture of flies in traps baited with whole-wheat bread dough intended for monitoring strawberry sap beetles, *Stelidota geminata* (Say) (Coleoptera: Nitidulidae) (Maier 2012). In some crops, such as strawberries, both species are pests, so monitoring both pest populations with one trap could be beneficial. In another example, Yamazaki (1998) assessed noctuid moth and thyatirid moth diversity in habitats with traps baited with fermented molasses bait. Landolt et al. (2006) captured 97 species of Lepidoptera in Alaska with a chemical lure originating from fermented food bait, and Brockerhoff et al. (2013) highlighted the use of such lures for pest detection and surveillance programs. We suggest then that there may be additional opportunities to investigate and use what we now consider nontarget insect responses to both the food baits for *D. suzukii* and the chemical lures for *D. suzukii* based on those baits.

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