Evaluation of Monitoring Traps for *Drosophila suzukii* (Diptera: Drosophilidae) in North America

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ABSTRACT *Drosophila suzukii* Matsumura (Diptera: Drosophilidae), a recent invasive pest of small and stone fruits, has been detected in more than half of the U.S. states, and in Canada, Mexico, and Europe. Upon discovery, several different trap designs were recommended for monitoring. This study compared the trap designs across seven states/provinces in North America and nine crop types. Between May and November 2011, we compared a clear cup with 10 side holes (clear); a commercial trap with two side holes (commercial); a Rubbermaid container with mesh lid and rain tent (Haviland), and with 10 side holes and no tent (modified Haviland); a red cup with 10 side holes (red); and a white container with mesh lid and rain tent (Van Steenwyk). Although fly catches among traps varied per site, overall, the Haviland trap caught the most *D. suzukii*, followed by the red, Van Steenwyk, and clear trap. The modified Haviland and commercial trap had low captures. Among five crop types in Oregon, a clear cup with mesh sides (Dreves) also was tested and caught the most flies. Traps with greater entry areas, found in mesh traps, caught more flies than traps with smaller entry areas. In terms of sensitivity and selectivity, traps that caught more flies likewise caught flies earlier, and all traps caught 26–31% *D. suzukii* out of the total *Drosophila* captured. Future trap improvements should incorporate more entry points and focus on selective baits to improve efficiency and selectivity with regard to the seasonal behavior of *D. suzukii*.

RESUMEN La *Drosophila* de las alas manchadas, *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae), es una plaga reciente que ataca frutas pequeñas así como "frutas con hueso" o drupas. Esta especie se ha reportado en Canadá, México y aproximadamente en la mitad de los Estados Unidos. Varios grupos han recomendado el uso de diferentes tipos de trampas para el monitoreo de esta especie. El objetivo de este estudio fue comparar diferentes tipos de trampas populares en siete estados/provincias en América del Norte, monitoreando nueve tipos de cultivos de Mayo a Noviembre del 2011. Se utilizaron las siguientes seis trampas: un vaso transparente con diez orificios laterales (transparente), la trampa comercial para la *Drosophila* de alas manchadas la cual posee dos orificios laterales (comercial), un contenedor plástico tipo Rubbermaid al cual se le ha modificado la tapa, colocándosele una malla fina o cedazo y un techo tipo tienda de campaña (Haviland). Se utilizó también una modificación a la trampa Haviland, la cual posee orificios en los laterales del contenedor y carece de la malla y el techo (Haviland modificada), un vaso plástico color rojo con diez orificios en los lados (rojo) y un contenedor de plástico color blanco con una malla en la tapa y un techo tipo tienda de campaña (Van Steenwyk). Las capturas variaron entre los sitios bajo estudio, sin embargo,

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la trampa tipo Haviland fue la que presentó más capturas de *D. suzukii*, seguida por el rojo, Van Steenwyk y transparente. Las trampas que presentaron el menor número de capturas fueron la tipo Haviland modificada y la comercial. En Corvallis, Oregon, se utilizó una trampa más; la cual consistió en un contenedor transparente con malla en los lados (Dreves). En cinco cultivos diferentes, esta trampa fue la que presentó el mayor número de capturas. Las trampas con mayores áreas de entrada, trampas con mallas o cedazos, parecen ser más efectivas que las que poseen únicamente orificios en los laterales. En términos de sensibilidad y selectividad, las trampas que capturaron más moscas fueron las mismas que capturaron a los primeros individuos. En todas las trampas *D. suzukii* representó el 26–31% del total de *Drosophilas* capturadas. Se requieren de futuros estudios que incorporen trampas con un mayor número de orificios de entrada, así como que se enfoquen en los cebos que son más selectivos; con el fin de mejorar su eficiencia y selectividad considerando para ello el comportamiento estacional de *D. suzukii*.

KEY WORDS *Drosophila suzukii*, detection, monitoring, trapping

Drosophila suzukii Matsumura (Diptera: Drosophilidae), also commonly called "spotted wing drosophila," is a recent invasive pest threatening small and stone fruit industries. Unlike most other *Drosophila* flies that infest damaged or rotting fruit, the serrated ovipositor of *D. suzukii* enables females to lay eggs inside ripe and ripening fruit. This fly was described in Japan in 1916 as a pest on cherries (*Prunus* spp.; Kanzawa 1935). *D. suzukii* was first detected in mainland North America in California in 2008 and has subsequently been detected in Oregon, Washington, Florida, and British Columbia, Canada, in 2009 (Walsh et al. 2011). As of 2012, it had been detected in a total of 28 U.S. states, two Canadian provinces, Mexico, France, Germany, Italy, Slovenia, Spain, and Switzerland (H.J.B. and A.J.D., unpublished data; Isaacs 2011; Lee et al. 2011; NAPIS 2012, see reported pest status of *D. suzukii*).

As a response to its rapid spread and potential for significant economic losses (Bolda et al. 2010), many regions initiated trapping programs and recommended that growers monitor for *D. suzukii* in their crops. Currently, traps are mostly homemade containers with holes or mesh entry points baited with liquid lures such as apple cider vinegar, yeast sugar solution, wine, or other combinations of fruit and fermenting solutions. One commercial trap for *D. suzukii* was developed in 2010 and marketed in 2011. Stakeholders expressed concern over different trapping recommendations made by various research and extension groups, and suggested that one trap standard be recommended (J. Brunner, personal communication; Dreves 2011). In response, a multi-investigator study comparing various trap designs all baited with apple cider vinegar was conducted across 16 sites in North America, in multiple crops and months during 2011. Although apple cider vinegar is not an optimized lure for catching *D. suzukii*, it is clear, affordable, convenient, and has caught numerous flies. The study addressed short and long-term goals to 1) determine which trap(s) performed better to help those that wanted to adjust their 2012 monitoring program and 2) provide insight on trap features to evaluate for future trap improvement. Trap performance was evaluated primarily by the number of flies caught, secondarily by early season sensitivity and species selectivity, and lastly a discussion of cost and convenience of use. Physical trap features associated with the more effective traps (e.g., size, color) could then be suggested for future hypothesis-driven and controlled studies where one feature is varied and tested at a time.

Limited information is available on *D. suzukii* trapping in terms of baits, pheromones, and physical trap design. In Japan, two-part combinations of molasses and wine, and three-part combinations with vinegar were considered effective in attracting *D. suzukii* (Kanzawa 1935, 1939). Interestingly, grape (*Vitis* spp.) wine combinations worked well in cherries, but not well in grapes where rice (*Oryza sativa* L.) wine combinations were better. Kanzawa (1939) suggested that grape wine was inferior as a bait in grapes most likely due to the surrounding odor of fermenting grapes masking the odor of the bait. Recently, the combination of 'Merlot' wine and apple cider vinegar was shown to synergistically attract *D. suzukii* (Landolt et al. 2011). Other *Drosophila* species have been attracted to cornmeal–yeast baits, or blends of ethanol, acetic acid, and 2-phenyl ethanol (Hutner et al. 1937, Reed 1938, Zhu et al. 2003). Pheromones have not yet been identified for *D. suzukii.* Other *Drosophila* species have short-range aggregation or courtship pheromones, but none have been reported useful for trapping (Landolt et al. 2011). For physical trap design, traps with narrow neck types were considered better than traps with wide openings because the narrow holes prevented bait evaporation and entry of larger insects compared with *D. suzukii* (Kanzawa 1939). Recently, dome traps (Trappitt trap, Agrisense Ltd., Pontypridd, United Kingdom) caught more *D. suzukii* than a clear trap with four 1-cm holes on the side (Landolt et al. 2011). Whether trap designs also could vary in effectiveness by crop or location is not known. A trap that is the same color as the fruit may be at a disadvantage if this creates competition for visual cues, or it may be at an advantage if flies are more responsive to the same fruit color. Certain trap designs may volatilize more readily than others, causing them to perform differently in warmer or cooler climates.

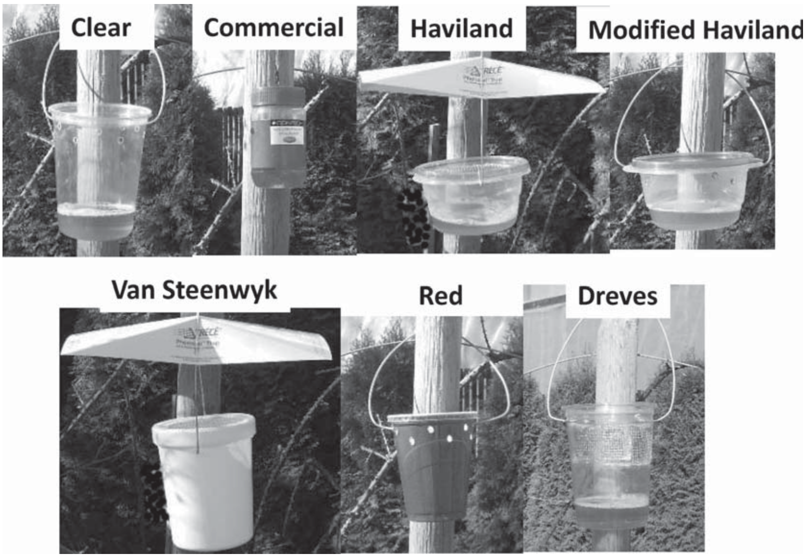

Fig. 1. Photos of the clear, commercial, Haviland, modified Haviland, red, Van Steenwyk, and Dreves traps.

Materials and Methods

The following six traps were evaluated at 16 sites across North America: clear, commercial, Haviland, modified Haviland, red, and Van Steenwyk trap (Fig. 1; Table 1). These sites were in nine crop types and seven states/provinces in North America: British Columbia (BC), California (CA), Michigan (MI), North Carolina (NC), Oregon (OR), Utah (UT), and Washington (WA) (Table 2). A seventh trap, Dreves, was tested simultaneously and randomly rotated with other traps at five sites in the Mid-Willamette Valley in OR: blackberry *Rubus* spp., blueberry *Vaccinium* spp., raspberry *Rubus* spp., strawberry *Fragaria* x *ananassa* Duchesne, and wine-grape *Vitis vinifera* L. Traps varied in color, volume, entry point(s), and inclusion of a tent for protection from rain or irrigation (Table 1). Most traps were baited with 150 ml of apple cider vinegar with 5% acidity (Table 1). The exceptions were 50 ml in the smaller commercial trap following manufacturer's recommendations at all sites, and 250 ml in the Haviland and Van Steenwyk trap at only the tart cherry UT site due to rapid evaporation. The commercial trap could not hold 150 ml without the bait spilling out of the holes, and 150 ml was used in other traps based on researchers and scouts using 50–250 ml of apple cider vinegar in their 2010 sampling. Approximately 4 ml of unscented Ultra Pure + Clear dishsoap (Colgate-Palmolive Co., New York, NY) was added per 3.78 liters of vinegar to break the surface tension.

For each site, traps were replicated in three to six blocks. Blocks were set up in one variety, or in multiple varieties of one crop type with similar ripening times. Four experimental farms with mixed varieties of one crop type (blackberry, raspberry, or cherry) also were included (Table 2). Each block was a minimum of 40 m apart from other blocks or in separate fields. Traps were placed 2–3 m apart in shady spots of crops where fruits hang. Traps were serviced each week, vinegar was replaced, and traps were randomly reassigned to a position. Trapping was initially planned to coincide with color change through harvest, but because of experimental constraints or low populations of *D. suzukii*, trapping occurred at different periods as footnoted in Tables 2 and 3.

Weekly captures of adult *D. suzukii* in each trap type were averaged per block, and $\log_{10}(x + 1)$ transformed to meet the assumption of homogeneous variances. Inferences about date were not made because trapping occurred at different dates across sites. Females comprised 34–73% of captures (Table 2, excluding sites with <10 flies), and both sexes were combined in the analyses because trends were similar for both sexes. One block from cherry BC and one block from peach BC had zero values throughout the experiment and were omitted from the analysis. First, the six traps tested at all 16 sites were analyzed in Proc Glimmix in SAS 9.2 (SAS Institute 2008) with trap, state, crop(state) [crop as a nested variable in state], trap*state, trap*crop(state) as fixed effects and block(crop, state) as a random effect. Degrees of freedom were calculated with a Kenward Rogers adjustment, and trap means were separated by lsmeans and Tukey's honestly significant difference (HSD) tests. Trap*state and trap*crop(state) interactions were significant, and the effect of trap type was compared for each site. Second, the seven traps, including Dreves tested at five sites in OR, were analyzed with trap, crop, trap*crop as fixed effects, and block(crop) as a random effect. Third, trap features, such as entry area, volatilization area, height from bait to top of bait, and headspace of each trap type, were tested by regression as independent variables with the average number of flies captured per trap type as the dependent variable. Categorical analyses were also done by replacing "trap" with "feature" as an effect in the Proc Glimmix

Table 1. Description of traps used for monitoring *D. suzukii*

Trap name	Container	Source	Vol (ml)	Bait vol (ml)	Entry point(s)	Entry area (mm^2)	Volatiliation area (cm^2)	Ht above bait (cm)	Headspace above bait (ml)	Rain tent
Clear	Clear deli cup and lid	Solo Cup Co., Lake Forest, IL	946	150	Ten 0.5-cm holes on side	196	64	11.5	796	No
Commercial	Commercial trap	Contech Enterprises Inc., Victoria, BC, Canada	210	50	Two 0.64-cm holes on side	64	17	7.2	160	No
Haviland	Clear plastic bowl and clear red lid	Rubbermaid, Huntersville, NC	760	150[a]	8.5-cm top opening with 0.32-cm hardware cloth	5675	90	5.5	610	Yes[b]
Modified Haviland	Clear plastic bowl and clear red lid	Rubbermaid	760	150	Ten 0.5-cm holes on side	196	90	5.5	610	No
Red	Red cup and clear lid	Solo Cup Co.	532	150	Ten 0.5-cm holes on side	196	38	7	382	No
Van Steenwyk	Soild white tub and lid	Consolidated Plastics, Stow, OH	946	150[a]	8.5-cm top opening with 0.32-cm hardware cloth	5675	71	10.7	796	Yes[b]
Tested simultaneously at five OR sites										
Dreves	Clear deli cup and lid	Solo Cup Co.	946	150	Two 4- by 8-cm openings on side with 0.32-cm hardware cloth	6400	64	11.5	796	No

[a] At the tart cherry UT site, 250 ml was added due to rapid evaporation.
[b] A white wax cardboard tent 22.9 by 27.9 cm (Trécé, Adair, OK) was placed over the mesh lidded Haviland and van Steenwyk traps for protection from rain or irrigation.

models. Fourth, the proportion of *D. suzukii* out of total *Drosophila* captured in traps was recorded in raspberry NC, blueberry OR, and cherry WA sites. The untransformed proportions were analyzed with trap as a fixed effect, and crop and block(crop) as random effects.

Results and Discussion

The six trap types tested at 16 sites differed significantly in the number of flies captured (Fig. 2a). Means separation among trap types varied by site (Table 3); but overall, the Haviland trap caught the most *D. suzukii,* followed by the red, Van Steenwyk, and clear traps, with lower captures in the modified Haviland trap and lowest captures in the commercial trap (Fig. 2a). Differences were significant among states and crops, and included in the model if trap designs might vary in performance between crops or locations. General conclusions by state and crop were not made because each state was represented by different crops. The seven trap types tested at five OR sites differed significantly, and means separation varied by site (Fig. 2b; Table 3). Overall, the Dreves trap caught more flies than the other traps.

The Haviland trap consistently caught significantly more flies than the modified Haviland trap across crops and states (Table 3), these two traps use the same container and bait amount, suggesting that a difference in entry area may increase efficiency. When evaluating all trap types, the number of captured flies increased as the entry area of traps increased based on marginally significant regressions (Fig. 3a) and significant categorical analyses (Fig. 3b). Although other features also varied between the seven traps, the entry area may partly explain why traps with mesh openings (Haviland and Dreves) often caught more flies than traps with holes (clear, commercial, and red). An increasing trend was still observed with the commercial trap omitted from the analysis considering it had 50 ml instead of 150 ml of bait and the smallest area of volatilization (Fig. 3b, without first bar; effect of entry area $F_{2,80} = 22.0$, $P < 0.001$). Interestingly, the number of flies caught per unit area of entry was high among traps with holes versus mesh: 14.2 flies per cm^2 for clear, 7.4 for commercial, 8.0 for modified Haviland, 13.6 for red, 0.743 for Haviland, and 0.47 for Van Steenwyk based on 16 sites. Whether adding six more holes to the clear or red traps would lead to catches similar to the Haviland trap remains to be determined. Other trap features, such as the volatilization area of the bait, height between the bait line and top of trap, and headspace volume above the bait in traps (Table 1) did not significantly vary with the number of flies caught (data not shown). However, controlled examination of each of these features as well as keeping other features consistent would be necessary in future studies to draw firmer conclusions. These features may still be relevant even though it could not be supported by our regression analyses comparing highly different trap designs. The commercial trap caught the fewest flies, and three features may

Table 2. Trapping information for *D. suzukii* in North America

Site name	Crop (blocks)	Location (state/province, county/vicinity–city)	Apple cider vinegar	Dates in 2011 (collections)	♀:♂%, total[a]
Blackberry OR	Mixed blackberry cultivars (3)	Oregon, Benton and Linn counties–Corvallis	Safeway	15 July–23 Sept. (10)	63:37, 3,730
Blackberry WA	Wild Himalayan blackberry (3)	Washington, Benton Co.–Prosser	Walmart	2 Aug.–22 Sept. (8)	58:43, 249
Blueberry MI	'Bluecrop' (1), 'Jersey' blueberry (2)	Michigan, Allegan Co.–Fennville	Meijer	19 Sept.–28 Oct. (5)[b]	34:66, 2,097
Blueberry OR	'Blueray' (3) and 'Jersey' blueberry (3)	Oregon, Benton Co.–Corvallis	Fred Meyer	7 July–5 Oct. (15)[c]	43:57, 6,906
Cherry BC	'Lapins' cherry (3, 1 block omitted from analysis)	British Columbia, Okanagen Valley–Oliver, Similkameen Valley–Cawston	Allen's	8 June–27 July (6)	100:0, 2
Cherry CA	Mixed cherry cultivars (4)	California, Yolo Co.–Winters	Safeway	18 May–20 July (9)[c]	43:57, 7,247
Cherry OR	'Bing' cherry (3)	Oregon, Hood River Co.–Hood River	Western Family	22 Sept.–3 Nov. (6)[b]	34:66, 21,155
Cherry WA	'Sweetheart' and 'Staccato' cherry (1), 'Bing' and 'Chelan' (1), 'Rainier' and pollenizer (1), 'Bing (1), 'Bing' and 'Sweetheart' (1)'Rainier' and pollenizer (1)	Washington, Chelan Co.–Entiat, Douglas Co.–Orondo, E. Wenatachee, and Rock Island	Heinz	21 July–18 Nov. (17)[b]	37:63, 4,183
Tart cherry UT	'Montmorency' tart cherry (3)	Utah, Davis Co.–Kaysville	Western Family	16 June–19 Oct. (17)[c]	0:100, 9
Grape OR	'Pinot noir' grape (3)	Oregon, Yamhill Co.–Corvallis	Heinz	24 Aug.–13 Oct. (7)	60:40, 1,521
Grape WA	'Concord' grape (3)	Washington, Benton Co.–Prosser	Walmart	1 Sept.–18 Oct. (7)	73:27, 79
Orange CA[d]	Navel oranges (3)	California, Kern Co.–Bakersfield	Heinz	18 Oct.–29 Nov. (7)	54:46, 7,599
Peach BC	'Cresthaven' peach (3, 1 omitted)	British Columbia, Okanagen Valley–Oliver	Allen's	13 July–24 Aug. (6)	45:55, 44
Raspberry NC	Mixed raspberry cultivars (3)	North Carolina, Ashe Co.–near Laurel Springs	Harris Teeter	23 June–13 Oct. (16)	52:48, 8,643
Raspberry OR	Mixed raspberry cultivars including 'Meeker' (3)	Oregon, Benton and Linn counties–Corvallis	Safeway	24 June–2 Sept. (10)	48:52, 1,873
Strawberry OR	'Hood' (1), 'Totem' strawberry (2)	Oregon, Linn Co.–Corvallis	Safeway	3 June–21 July (7)	36:64, 28

[a] Females, males, and total counts from all traps with six or seven treatments.
[b] Trapping started postharvest.
[c] Trapping continued postharvest, with typical harvest completed around mid-Aug. in 2011 in tart cherry UT, early Sept. in blueberry OR, and no defined harvest period in cherry CA comprised of mixed cherry cultivars.
[d] Oranges are not a host, infestations occur among fallen oranges on the ground. Trapping occurred before harvest.

Table 3. Weekly captures of *D. suzukii* in traps (mean ± SD), *P* values when comparing six traps at each site, or seven traps at the five OR sites (in bold)

Trap	Blackberry OR	7 traps	Blackberry WA	Blueberry OR[a]	**7 traps**	Blueberry MI[b]	Cherry BC	Cherry CA[a]	Cherry OR[b]	Cherry WA[b]	
Clear	12.0 ± 3.99ab[c]	**bc**	1.63 ± 2.38	9.87 ± 8.01bc	**de**	17.2 ± 4.73c	0.00 ± 0.00	24.2 ± 9.42b	240.6 ± 212ab	8.33 ± 8.54ab	
Commer.	2.50 ± 1.73c	**d**	1.17 ± 1.80	2.63 ± 1.05d	**f**	10.2 ± 1.00d	0.00 ± 0.00	21.7 ± 2.51b	14.3 ± 4.60c	0.82 ± 0.75d	
Haviland	15.2 ± 2.76ab	**abc**	1.13 ± 1.42	20.1 ± 4.59a	**ab**	38.2 ± 5.74a	0.00 ± 0.00	61.4 ± 23.3a	387.9 ± 232a	16.8 ± 19.3a	
Mod. Hav.	8.20 ± 4.23bc	**dc**	3.58 ± 6.10	6.67 ± 2.46c	**e**	19.8 ± 4.00bc	0.00 ± 0.00	21.9 ± 9.73b	115.3 ± 77.3b	3.03 ± 2.02c	
Red	28.1 ± 9.89a	**ab**	0.63 ± 0.87	13.9 ± 4.56ab	**bc**	30.3 ± 7.49ab	0.08 ± 0.12	36.4 ± 9.09ab	169.3 ± 143ab	3.81 ± 3.34bc	
Van Steen.	12.3 ± 7.85ab	**bc**	2.17 ± 3.43	11.6 ± 3.16b	**dc**	24.1 ± 6.52bc	0.08 ± 0.12	38.4 ± 17.8ab	247.8 ± 179ab	9.60 ± 10.4a	
Dreves	42.1 ± 16.3	**a**		27.2 ± 5.77	**a**						
Overall[d]	16.1	17.2	1.72	10.8	13.1	23.3	0.03	34.0	195.9	7.07	
P value	<0.001	**<0.001**	0.649	<0.001	**<0.001**	<0.001	0.588	<0.001	<0.001	<0.001	
Trap	Tart cherry UT[a]	Grape OR	**7 traps**	Grape WA	Orange CA[e]	Peach BC	Raspberry NC	Raspberry OR	**7 traps**	Strawberry OR	**7 traps**
Clear	0.04 ± 0.07	8.33 ± 3.24a	**a**	0.48 ± 0.16	111.4 ± 28.9a	0.29 ± 0.26ab	27.0 ± 0.71ab	5.37 ± 2.24abc	**bcd**	0.05 ± 0.08	
Commer.	0.00 ± 0.00	3.38 ± 0.72b	**b**	0.19 ± 0.33	12.6 ± 2.54c	0.00 ± 0.00b	2.65 ± 0.28c	1.10 ± 0.56c	**d**	0.10 ± 0.08	
Haviland	0.06 ± 0.10	13.0 ± 3.05a	**a**	1.14 ± 0.49	66.2 ± 6.67ab	1.94 ± 1.50a	58.1 ± 37.2a	11.4 ± 6.09ab	**ab**	0.33 ± 0.32	
Mod. Hav.	0.00 ± 0.00	13.7 ± 2.18a	**a**	0.48 ± 0.33	50.2 ± 19.4ab	0.13 ± 0.18ab	14.8 ± 6.87b	2.63 ± 0.31bc	**dc**	0.00 ± 0.00	
Red	0.02 ± 0.03	11.0 ± 0.14a	**a**	0.57 ± 0.14	85.8 ± 44.6ab	0.06 ± 0.09b	47.8 ± 12.3a	14.7 ± 10.2a	**ab**	0.19 ± 0.22	
Van Steen.	0.06 ± 0.06	14.9 ± 3.16a	**a**	0.90 ± 0.44	35.6 ± 11.8b	0.19 ± 0.09ab	29.7 ± 6.77ab	8.60 ± 4.87ab	**abc**	0.19 ± 0.33	
Dreves		9.33 ± 1.59	**a**					18.7 ± 4.31	**a**	0.48 ± 0.70	
Overall[d]	0.03	10.7	10.5	0.63	60.3	0.46	30.0	7.29	8.92	0.14	0.19
P value	0.651	<0.001	**<0.001**	0.053	<0.001	0.036	<0.001	0.002	**<0.001**	0.138	**0.23**

[a] Trapping continued postharvest, with typical harvest completed mid-August in 2011 in tart cherry UT, early September in blueberry OR, and no defined harvest period in cherry CA made up of mixed cherry cultivars.
[b] Trapping started postharvest.
[c] Letters denote significant difference by Tukey's HSD on log-transformed data.
[d] Overall mean of weekly catches from six or seven trap types from all blocks.
[e] Oranges are not a host, infestations occur among fallen oranges on the ground. Trapping occurred before harvest.

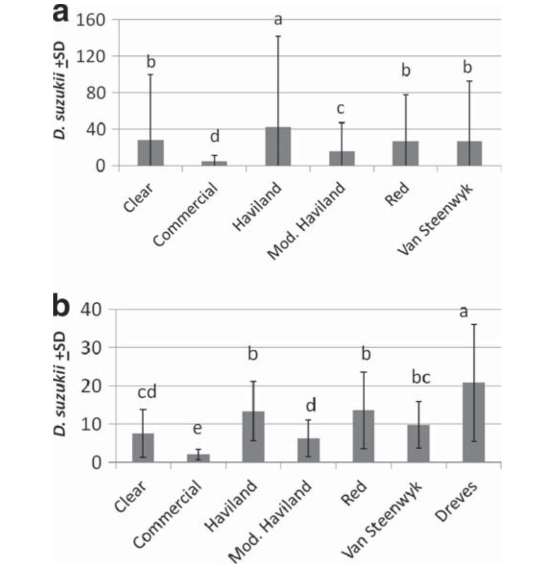

Fig. 2. Weekly capture of *D. suzukii* (mean ± SD) from six traps tested among 16 sites in North America (a), and seven traps tested among five sites in Corvallis, OR (b). Six trap comparison: trap $F_{5,185} = 77.9$, $P < 0.001$; state $F_{6,37} = 56.2$, $P < 0.001$; trap*state $F_{30,185} = 6.7$, $P < 0.001$; crop(state) $F_{9,37} = 20.1$, $P < 0.001$; trap*crop(state) $F_{45,185} = 6.5$, $P < 0.001$. Seven trap comparison: trap $F_{6,78} = 58$, $P < 0.001$; crop $F_{4,12} = 48$, $P < 0.001$; trap*crop $F_{24,78} = 5.9$, $P < 0.001$. Untransformed data are shown; letters denote significant differences by Tukey's HSD on log-transformed data.

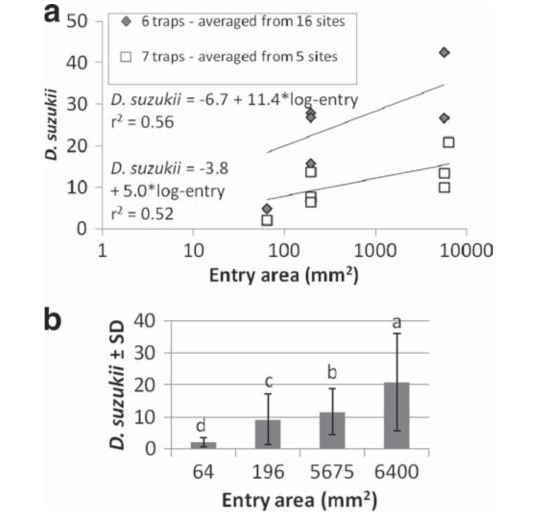

Fig. 3. Log-regression of entry area of traps with the mean number of *D. suzukii* captured (a) and the mean capture (±SD) of *D. suzukii* grouped by the entry area of traps from seven traps at five OR sites (b). Regression with six data points ($F_{1,4} = 5.2$; $P = 0.085$) and with seven data points ($F_{1,5} = 5.3$; $P = 0.069$) (a). Effect of entry area $F_{3,93} = 54.2$; $P < 0.001$. Untransformed data are shown; letters denote significant differences by Tukey's HSD on log-transformed data. Other effects not listed (b).

be responsible: the recommended rate of apple cider vinegar was one third of other traps, the volatilization area of the bait was considerably smaller, and two entry holes limited volatilization and entry of flies. There was no clear advantage of the red-colored traps although the red trap was statistically similar to the Haviland trap at nine sites (Table 3). Previous greenhouse and field studies suggested that red traps were sometimes preferable over clear or white traps when all other trap features were equal (J.C.L., unpublished data). The red-colored traps in this study (commercial, red) were smaller in size than the other traps which may have limited volatilization.

Trap sensitivity and selectivity are important attributes in addition to trap efficiency. Among 13 sites with 43 blocks total (excluding blueberry MI, cherry CA, and cherry OR where all/most traps caught from the start), the Van Steenwyk trap caught the first *D. suzukii* within 20 blocks (includes ties between two or three traps), the Haviland in 19, the clear in 13, the red in 11, the modified Haviland in four, and the commercial trap in two blocks. As a general observation, traps that caught flies earlier (Van Steenwyk and Haviland) also caught many flies, and traps that caught flies later (modified Haviland and commercial) also caught the fewest flies. None of the traps were selective, and *D. suzukii* comprised only 26–31% of the total *Drosophila* captured, with no differences among trap types (Fig. 4). This may be expected because acetic acid is attractive to other *Drosophila* flies (Zhu et al. 2003) and is a component of apple cider vinegar.

To facilitate use by growers and integrated pest management practitioners, traps need to be convenient to purchase or construct, service, place in the plant canopy, and store. Commercial traps cost ≈US$3.10 each but were the least effective trap catching only ≈11% relative to the Haviland trap. Until a more effective trap is commercialized, the costs required to purchase supplies and ease of making traps are factors of consideration. The approximate material cost of each trap with a wire holder not including labor is US$0.80 for clear, US$1.25 for Dreves, US$2.70 for Haviland (with tent), US$1.20 for modified Haviland, US$0.65 for red, and US$3.40 for Van Steenwyk (with tent). Although the costs of all traps were low, clear and red traps with holes were far quicker to construct than those with mesh openings. Therefore, clear and

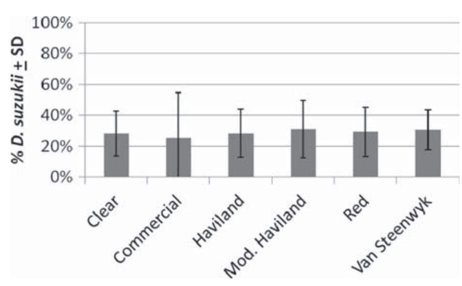

Fig. 4. Percentage of *D. suzukii* captured out of all *Drosophila* (mean ± SD) among blueberries OR, cherries WA, and raspberries NC. Treatment $F_{5,70} = 0.31$, $P = 0.91$.

red traps may still be a design of interest for those who prefer to quickly construct traps. Investigators in this study had reported that the traps with tents (Haviland and Van Steenwyk) were often blown over and cumbersome to service, and the shallow bowl of the modified Haviland frequently spilled. All traps are stackable for convenient storage, although red traps became too brittle for reuse.

This multistate and multicrop trap study suggests that traps with mesh openings, which also have greater entry areas, are preferable for trapping *D. suzukii*, but no traps were selective. Selectivity will likely require a more specific bait than apple cider vinegar. Future studies examining physical design should test one trap feature while keeping other trap features equal, exploring features such as shape, methods to prevent fly escape, entry type (holes versus mesh), as well as consider the cost and ease of use of the trap. In 2012, three studies are underway to test colors (black, red, yellow, white, and clear), volatilization area of the bait, and orientation of the entry points (top or side of trap).

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