Trap Designs for Monitoring *Drosophila suzukii* (Diptera: Drosophilidae)

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ABSTRACT *Drosophila suzukii* (Matsumura), an invasive pest of small and stone fruits, has been recently detected in 39 states of the United States, Canada, Mexico, and Europe. This pest attacks ripening fruit, causing economic losses including increased management costs and crop rejection. Ongoing research aims to improve the efficacy of monitoring traps. Studies were conducted to evaluate how physical trap features affect captures of *D. suzukii*. We evaluated five colors, two bait surface areas, and a top and side position for the fly entry point. Studies were conducted at 16 sites spanning seven states and provinces of North America and nine crop types. Apple cider vinegar was the standard bait in all trap types. In the overall analysis, yellow-colored traps caught significantly more flies than clear, white, and black traps; and red traps caught more than clear traps. Results by color may be influenced by crop type. Overall, the trap with a greater bait surface area caught slightly more *D. suzukii* than the trap with smaller area (90 vs. 40 cm^2). Overall, the two traps with a side-mesh entry, with or without a protective rain tent, caught more *D. suzukii* than the trap with a top-mesh entry and tent.

RESUMEN *Drosophila suzukii* (Matsumura), es una plaga que ataca frutas pequeñas así como “frutas con hueso” o drupas. Esta especie ha sido recientemente reportada en 39 Estados de EEUU, así como en Canadá, México y Europa. Esta plaga ataca frutas en estado de maduración, causando pérdidas económicas incluyendo el aumento en los costos de manejo y rechazo del cultivo. La actual investigación tiene por objetivo el mejorar la eficiencia de las trampas utilizadas para el monitoreo de la especie. Se llevaron a cabo estudios para evaluar como las características físicas de la trampa afectan la captura de *D. suzukii*. Fueron evaluados el color, superficie de exposición del cebo y posición del punto de entrada para las moscas. Los estudios fueron conducidos en nueve cultivos, distribuidos en 16 sitios localizados en siete Estados y Provincias de America del Norte. Se utilizó vinagre de cidra de manzana como cebo estándar en todas las trampas. En análisis general, las trampas de color amarillo capturaron significativamente mas moscas que las trampas transparentes, blancas y negras, y las trampas rojas capturaron mas que las trampas transparentes. Resultados por color pueden estar influenciados por el tipo de cultivo. En general, las trampas con mayor área de exposición del

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cebo capturaron ligeramente más *D. suzukii* que aquellas con menor área (90 vs. 40 cm^2). En general, las dos trampas con entradas laterales cubiertas por malla (con o sin techo protector de lluvia) capturaron más *D. suzukii* que las que poseían una entrada en la parte superior de la trampa.

KEY WORDS color, monitoring, spotted wing drosophila, trap design, vinegar fly

Drosophila suzukii (Matsumura) (Diptera: Drosophilidae), commonly called spotted wing drosophila, was first detected on the mainland of the United States in 2008 (Hauser 2011). In a short amount of time, this invasive pest has been detected in 39 states (Lee et al. 2011, National Agricultural Pest Information System [NAPIS] 2013, H.J. Burrack, personal communication). This pest is of concern to small and stone fruit industries, and growers may need multiple insecticide applications to manage infestations (Beers et al. 2011, Bruck et al. 2011). Furthermore, growers risk rejection of their harvested fruit at the processing plant and export terminal if an infestation is found. Rejection of exported fruit may also occur when residual pesticide levels exceed the maximum residue limits (Haviland and Beers 2012). These potentially devastating economic consequences have led to many products to monitor *D. suzukii* in the field. A variety of trap prototypes made by researchers (Lee et al. 2012) and commercial traps are available to monitor adult *D. suzukii.* Commercial traps include the CAPtiva (Marginal Designs, Oakland, CA), Spotted wing drosophila trap (Contech Enterprises Inc., Victoria, Canada), Victor fly trap (Woodstream Corp., Lititz, PA), and various plastic McPhail-type traps such as the Trappitt trap (Agrisense Ltd., Pontypridd, United Kingdom), multi-lure trap (Better World Manufacturing Inc. Fresno, CA), and Droso-trap (Biobest, Belgium). Some of these traps are adaptations of existing designs and were not designed originally for *D. suzukii* detection.

Monitoring traps are used to delimit the distribution of *D. suzukii* and record seasonal activity. However, growers consider current traps of limited value until they can predict fly populations and risk of infestation, that is, until a threshold is developed. This is based on a meeting that requested stakeholder feedback on a grant-funded spotted wing drosophila project (J. Brunner, personal communication). Researchers have been working steadily to improve the attractiveness of the bait formulation and physical design of the trap. Currently, apple cider vinegar is a common bait because it is easily found, inexpensive, and transparent to see captured flies, but it is not the most attractive bait. The combination of wine and apple cider vinegar has caught more *D. suzukii* in the field compared with apple cider vinegar alone (Landolt et al. 2011), as has a combination of wine, molasses, and vinegar (E.H.B., unpublished data), blends of wine and vinegar volatiles (Cha et al. 2012), and a yeast–sugar–water solution when warm temperatures are present (A.J.D., unpublished data, R.I., unpublished data). Commercialized dispenser lures are also being evaluated, and is a key step toward making trapping a more viable monitoring tool, given its convenience of use.

Before the launch of this study, limited information was available on physical features of traps that improve capture of *D. suzukii.* Traps with narrow entry points were considered better than those with wide openings because the narrow openings slowed the evaporation of the bait and prevented entry of insects larger than *D. suzukii* (Kanzawa 1939), but this was not explicitly tested. In 2011, six commonly used trap types were compared across 16 sites in nine states/province of North America (Lee et al. 2012). The number of *D. suzukii* captured increased consistently in traps with greater entry areas, but the proportion of nontarget drosophilids captured remained the same. Some trap designs clearly caught more *D. suzukii* than others, and the role of color, surface area of the bait–air interface, container shape, tent coverings, and position of entry points was highlighted for testing. The visual abilities and cues preferred by *Drosophila melanogaster* Meigen may provide insight on *D. suzukii,* given their phylogenetic relatedness (Yang et al. 2004). Tall 31-cm vertical posts are attractive to flying *D. melanogaster* compared with short 1.3-cm posts (Malmon et al. 2008). These results might suggest traps with a taller opaque shape might be attractive stimuli for *D. suzukii.*

The goal of this study was to identify physical features of traps that increase the catch of *D. suzukii.* Specific objectives tested how 1) five colors, 2) two bait surface areas, and 3) top- vs. side-entry position affected captures. These objectives were tested broadly across North America in multiple crop types. A subset of sites were tested for variation in catch among traps between four crop types, between in-season and postharvest periods, and the selectivity of traps for *D. suzukii* vs. other drosophilids.

Materials and Methods

Sites and Protocols. Research was conducted across 16 sites within nine crop types and seven states or provinces in North America. Traps were set up in three or four blocks at each site with 52 replicated blocks in the color study and 51 blocks in the bait surface area and fly entry position studies (Table 2). Blocks were set up in one or multiple varieties with similar ripening times. All blocks were separated by a minimum of 40 m from other blocks or were in separate fields. Within a block, the locations of the five trap types pertaining to the color study were randomized, as were the locations of the five traps pertaining to the bait surface area and entry position study. Traps within a block and randomization group were placed

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

Study	Trap	Container, volume, source	Point of entry	Tent[a]
Color	Black Red Yellow White	Colored cups, 473 ml, Creative Converting, Clintonville, WI, and Clear lid, Solo Cup Co. Lake Forest, IL, specific names are 'white,' 'black velvet,' 'classic red,' and 'school bus yellow'	All have 12, 0.5-cm holes arranged in a 15.2-cm zigzag band on upper side	No
	Clear	Clear cup, 473 ml, Walmart, Bentonville, AR and same lid as above		No
Bait surface area	90 cm^2	Clear plastic bowl with 10.7 cm diameter with red lid, 760 ml, Rubbermaid, Huntersville, NC	All have a lid with 8.3-cm-diameter opening with 5,410-cm^2 plastic mesh with 0.32-cm grid, Darice, Strongsville, OH	Yes
	40 cm^2	Bowl (as above) with clear cup cut embedded at bottom with 7.1 cm diameter[b], 532 ml before cut, Solo Cup Co.		Yes
Entry position	Top	All are a clear deli cup and lid, 946 ml, Solo Cup Co.	Mesh placed on top opening (as above)	Yes
	Side		Two sides plastic mesh panels 6.7 by 4 cm rectangles with 5410 cm^2	Yes
	Side-tentless		Two sides plastic mesh panels 6.7 by 4 cm rectangles with 5410 cm^2	No

[a] A protective tent prevents rain or irrigation water from entering trap, tent is an inverted white bowl, 591 ml, Kroger Co., Cincinnati, OH, held 5–8 cm above the trap.
[b] Distance between the bait surface and lid is 5 cm in both traps of the bait surface area study.

2–3 m apart in shady spots of crops, adjacent to hanging fruit. Traps within a block from different randomization groups were spaced ≥10 m apart. All traps were baited with 150 ml of apple cider vinegar with 5% acidity. Approximately 4 ml of unscented Ultra Pure + Clear dish soap (Colgate–Palmolive Co., NY, NY) was added per 3.78 liters of vinegar to break the surface tension. At weekly intervals, fly captures were recorded, vinegar replaced, and traps randomly reassigned to a new position. The numbers of male and female *D. suzukii* were recorded with the aid of a stereomicroscope, and other nontarget drosophilids were recorded at five sites.

Color. Five colors were selected to test the effect on fly captures. Red and black caught more *D. suzukii* than other colors in greenhouse and field trials (J.C.L., unpublished data). Other colors were selected for their ubiquity; bright yellow is a common color among insect traps; and white and clear are common in traps currently used for *D. suzukii.* A small 473-ml cup was used because various bright colors were commercially available (Table 1; Fig. 1a). Cups were characterized by a colorimeter (Konica Minolta CR-400, Ramsey, NJ) in Wapato, WA. The yellow cup had an L*a*b* value of −74.23, −2.21, and 64.01; red had 38.03, 35.15, and 19.06; black had 28.57, 0.09, and −0.08; and white had 81.82, −1.14, and −3.81. The L* value is 0 for black and 100 for white, a* is negative for green and positive for magenta, and b* is negative for blue and positive for yellow (Hanbury and Serra 2001). While certain colors such as yellow are known to be attractive, the specific hue of the color can influence attraction to a trap, as shown for tephritid flies (Yee 2012). Hues refer to a gradation within a color. A secondary study compared the capture of *D. suzukii* to traps of various red and yellow hues with choice cage (Supp. 1 [online only]) and field tests (Supp. 2 [online only]). Field tests revealed that the commercially available red and yellow cups caught similar or more *D. suzukii* than various red- or yellow-hued painted cups.

Bait Surface Area. Bait surface area was tested by using a clear 760-ml plastic bowl (Fig. 1b, Table 1) because the surface area could be manipulated, and this trap type performed well in the study by Lee et al. (2012).

Entry Position. Entry position (top- and side-mesh) was tested by using a clear 946-ml deli cup (Fig. 1c; Table 1) because its height prevented bait from spilling out of traps with a side entry, and it performed well in the study by Lee et al. (2012). In addition, the side-entry traps were tested, with and without protective tents, to determine the effect on captures. The trap with a top-entry point requires a tent to prevent bait dilution from rain or irrigation water.

Statistical Analyses. For analyses, the capture of adult *D. suzukii* from each trap of each block was averaged on a weekly basis. Data were analyzed with males and females combined together because there were no significant trap × gender interactions in preliminary analyses. Data were $Log_{10}(x + 1)$-transformed to homogenize variances or improve the fit of the model. First, to test the effect of color, bait surface area, or trap entry position, data from all 16 sites were analyzed by using generalized linear mixed models in Proc Glimmix (SAS 9.2, Cary, NC). The main model had trap, crop, and trap × crop as fixed effects and site(crop) [site nested within crop] and block (site) as random effects. Degrees of freedom were calculated with a Kenward Rogers adjustment, and trap means separated by lsmeans and Tukey honestly significant difference tests. Second, to test trap variation by crop type, data were sliced by crop type when trap × crop interactions were significant ($P < 0.05$) in the main model. Slicing by crop type occurred when testing occurred at two or more sites: blueberry, sweet cherry, grapes, and raspberry. The effect of trap type

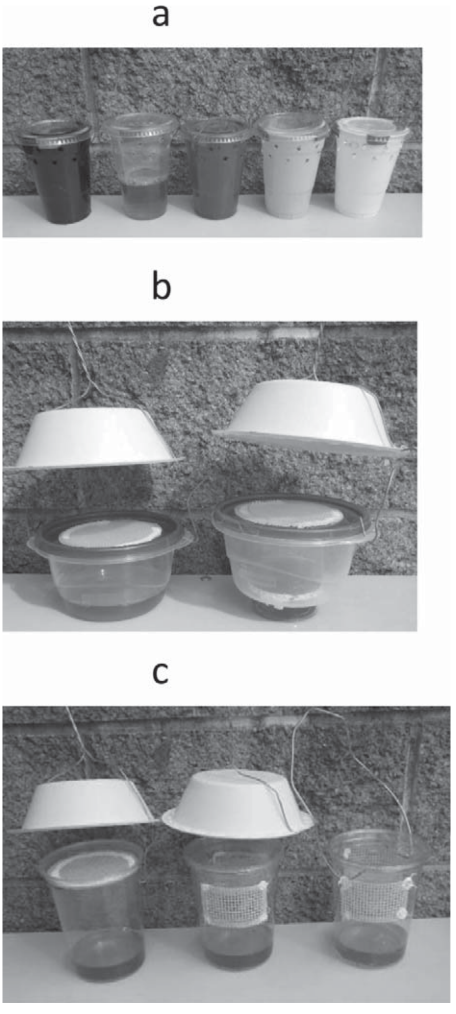

Fig. 1. Photos of traps tested including the (a) black, clear, red, yellow, and white traps in the color study; (b) 90 and 40-cm^2 area traps in the bait surface area study; (c) and the top, side, and side-tentless traps in the entry position study.

was compared with site and block(site) as random effects. Third, to further explore variation by crops, post hoc analyses were conducted for red, black, and orange fruit colors where two or more crop types shared the same color. The variable color was not tested in the main model because crop and fruit color were not independent variables. Fourth, to test variation by period, the "in season" (preharvest and harvest combined) and "postharvest" periods were analyzed among five sites: Blackberry WA, Blueberry OR, Cherry CA, Cherry WA, and Grape OR. Analyses were performed with trap, period, trap × period as fixed effects and site and block(site) as random effects. Fifth, to test species selectivity, analyses were conducted on proportions, the number of *D. suzukii* divided by the total drosophilids caught in a trap. This was done at five sites: Blueberry NC, Blueberry OR, Cherry WA, Grape OR, and Raspberry NC. Untransformed proportions were analyzed with trap as a fixed effect and site and block(site) as random effects.

Results

Total number of *D. suzukii* caught among sites varied from 109 at Blueberry NC with 4 wk of collection to 23,452 at Blueberry MI with 7 wk of collection. Females comprised 29% of the catch at Cherry OR to 83% at Blueberry NC (Table 2). Although total fly counts were low at Blueberry NC and Blackberry WA, these sites provided trap comparisons under low-capture conditions. Traps placed in the early season often catch fewer flies, but early season detection is an important monitoring period, as growers make management decisions. Trends regarding trap × crop interactions, fruit colors, trap × period interactions, and species selectivity suggest potential points to investigate further. These results should be interpreted with caution, given the unbalanced experimental design and testing with a subset of sites.

Color. Overall, the yellow trap caught more *D. suzukii* than black, clear, and white traps, and the red trap caught more than the clear trap, and there were no differences between red and yellow (Tables 3 and 4). There was a significant trap × crop interaction (Tables 3 and 4). The high capture of *D. suzukii* in yellow or red traps was not consistent across crops. In blueberry, there were no significant trends (Table 4). In sweet cherry, the black, red, and white traps caught more than the clear trap, and the yellow trap was not different from any trap (Table 4). In grape, the clear trap caught fewer flies than the other four colors (Table 4). In raspberry, the red trap caught more than clear and white traps, and black and yellow traps were not different from any trap (Table 4).

Next, when data from all red-colored fruits were analyzed together, more flies were caught in red traps than white or clear traps (Table 4). When data from all black/purple fruit were grouped together, more flies were caught in yellow than clear or white traps, and more flies were caught in red or black than clear traps (Table 4). No trends appeared among the orange-colored fruit. When analyzing the data for seasonal trends, there was no interaction between trap and period (Table 3). Finally, trap color had no effect on the selectivity; *D. suzukii* comprised 62.9 ± 8.9–71.3 ± 7.4% of the total number of drosophilids caught (Table 3).

Bait Surface Area. Overall, the trap with a bait surface area of 90 cm^2 caught 12% more *D. suzukii* than the trap with an area of 40 cm^2 (Tables 3 and 4). No trends occurred when comparing traps during the in-season and postharvest periods (Table 3). Bait surface area had no effect on selectivity; *D. suzukii* comprised 58.7 ± 9.1–61.9 ± 8.9% of total drosophilids (Table 3).

Entry Position. Overall, the side-entry traps, with and without a tent (side, side-tentless), caught more *D. suzukii* than the trap with a top entry and tent (top) (Tables 3 and 4). There was a significant trap × crop interaction (Table 3). In blueberry, there were no sig-

Table 2. Trapping information for *D. suzukii* in North America in 2012

Site	Cultivar (blocks)	County	Dates	Wk	Harvest period	In-season or postharvest period	Harvest occurred	♀:♂	Total
Blackberry WA	Wild Himalayan (3)	Benton Co.	26 June–11 Sept.	11	14–21 Aug.	In-season 26 June 21 Aug. Postharvest 21 Aug.–11 Sept.	No	73:27	399
Blueberry MI	'Jersey' (3)	Allegan Co.	31 Aug.–19 Oct.	7	Until 16 Aug.	Postharvest	Yes	48:52	23,452
Blueberry NC	Mixed cultivars (4)	Rowan Co.	9 Aug.–7 Sept.	4	Continuous	In-season	No	83:17	109
Blueberry NJ	'Bluecrop' (2), 'Duke' (1)	Atlantic Co.	20 Aug.–24 Sept.	5	Until 30 July	Postharvest	Yes	57:43	4,372
Blueberry OR	'Jersey' (3)	Benton Co.	30 June–28 Sept.	13	20 July–9 Sept.	In-season 30 June–7 Sept. Postharvest 7–28 Sept.	Yes	47:53	8,485
Cherry CA	Mixed cultivars (3)	Yolo Co.	9 May–18 July	10	9 May–27 June	In-season 9 May–27 June Postharvest 27 June–18 July	No	67:33	7,750
Cherry OR	'Regina' (3)	Hood River Co.	2 Aug.–24 Oct.	12	20–30 July	Postharvest	No	29:71	10,840
Cherry WA	'Sweetheart' (1), 'Chelan' & 'Bing' (1), 'Bing' & 'Rainer' (1)	Douglas Co., Okanogan Co.	5 June–1 Nov.	21	9 July, 5 July, and 23 June−6 July, respectively	In-season 5 June–17 July Postharvest 17 July–1 Nov.	Yes	38:62	8,763
Tart cherry MI	'Mortmorency' (3, 4 for color study)	Berrien Co.	8 Aug.–3 Oct.	8		Postharvest	No	55:45	1,656
Grape BC	'Pinot noir' (2), 'Cabernet franc' (1)	Cawston and Oliver	5 Sept.–10 Oct.	7	3–10 Oct.	In-season	Yes	57:43	4,950
Grape OR	'Pinot noir' (3)	Yamhill Co.	17 Aug.–9 Nov.	12	9–11 Oct.	In-season 17 Aug.–11 Oct. Postharvest 11 Oct.–9 Nov.	Yes	65:35	10,122
Orange CA	Navel (3)	Kern Co.	30 Oct.–19 Dec.	7	19 Dec.	In-season	Yes	50:50	1,755
Peach NJ	'Harrow Beauty' (3)	Cumberland Co.	20 June–16 Aug.	8	27 July16 Aug.	In-season	No	57:43	1,477
Raspberry NC	Mixed cultivars (4)	Rowan Co.	12 July–9 Aug.	4	Continuous	In-season	No	52:48	4,372
Raspberry OR	Mixed cultivars (3)	Linn Co.	3 July–5 Sept.	9	Continuous	In-season	No	53:47	4,509
Strawberry OR	Mixed cultivars (4)	Linn Co.	4 June–6 Aug.	8	Continuous	In-season	No	45:55	368

nificant trends. In sweet cherry and grape, the side-tentless trap caught more flies than the top trap, but the side trap was not different from other traps (Table 4). In raspberry, the side and side-tentless traps caught more flies than top traps (Table 4).

As for seasonal trends, there was a trap × period effect among the five sites (Table 3). There was no difference between trap designs in the season, but during postharvest, side and side-tentless traps caught more flies than top traps (Table 4). Entry position had no effect on selectivity; *D. suzukii* comprised 61.2 ± 9.5–68.9 ± 9.1% of the total drosophilids (Table 3).

Finally, the five traps tested for bait surface area and entry position were randomized and analyzed together (Table 3). Overall, the side and side-tentless trap caught significantly more flies than the top and 40-cm^2 trap. The 90-cm^2 trap was not significantly different from any trap.

Discussion

Yellow and red traps caught more *D. suzukii* than clear traps in overall results spanning 16 sites. Black traps captured less than yellow traps overall, but more than clear traps within sweet cherry and grape sites. Basoalto et al. (2013) also studied color preference of *D. suzukii*, and attraction to red and black was evident in several cage tests. More *D. suzukii* were caught in clear traps with red or black caps than white caps placed in choice cages. More *D. suzukii* landed on red, burgundy, and black cards compared with white, yellow, and light blue cards placed in choice-cage studies. Finally, CAPtiva traps (also called "Zorro") with red-black-red banding pattern caught more *D. suzukii* than all-red or all-black traps in cages with two choices. However, field trials with CAPtiva traps indicated that they were no more effective than some clear traps baited with apple cider vinegar or a yeast–sugar solution (Basoalto et al. 2013, A.J.D., unpublished data, R.I., unpublished data).

To our knowledge, this study is the first to demonstrate higher captures of *D. suzukii* with yellow. In contrast, Basoalto et al. (2013) observed just as many *D. suzukii* landing on yellow cards as white, which was fewer than on red or black cards. Such differences could be because of differences among hues. The yellow cup used in our study had L*a*b* values of 74.23, −2.21, and 64.01, whereas these values were 89.96, −10.99, and 90.31, respectively, in the study by Basoalto et al. (2013). The yellow used in their study was lighter, as indicated by the greater L* value, where 0 is black and 100 is white. Reasons as to why some

Table 3. Statistical analyses of the effect of different trap designs on the captures of *D. suzukii*

Study	Response	Effect	df	*F*	*P*
Color	Count[a]	Trap	4, 172	8.9	< 0.001
		Crop	8, 7	0.80	0.62
		Trap × crop	32, 172	3.26	< 0.001
Bait surface area	Count	Trap	1, 42	5.02	0.030
		Crop	8, 7	1.10	0.46
		Trap × crop	8, 42	1.13	0.37
Entry position	Count	Trap	2, 84	15.9	< 0.001
		Crop	8, 7	0.75	0.65
		Trap × crop	16, 84	1.97	0.024
Bait surface area and entry position combined (5 traps)	Count	Trap	4, 165	8.9	< 0.001
		Crop	8, 7	0.87	0.58
		Trap × crop	32, 168	1.7	0.017
Color (in-season and postharvest comparison)	Count	Trap	4, 112	5.4	< 0.001
		Period	1, 24	3.3	0.08
		Trap × period	4, 112	1.3	0.28
Bait surface area (in-season and postharvest comparison)	Count	Trap	1, 28	2.0	0.17
		Period	1, 24	1.0	0.32
		Trap × period	1, 28	0.17	0.68
Entry position (in-season and postharvest comparison)	Count	Trap	2, 56	13.8	< 0.001
		Period	1, 24	2.0	0.17
		Trap × period	2, 56	10.0	< 0.001
Color	Proportion[b]	Trap	4, 63.5	0.81	0.52
Bait surface area	Proportion	Trap	1, 12.4	0.26	0.62
Entry position	Proportion	Trap	2, 36	1.6	0.22

[a] Weekly average count of male and female *D. suzukii*.
[b] Proportion of drosophilids that were *D. suzukii*.

hues are more attractive than others are not known; in outdoor choice cages, the yellow hues that trapped more *D. suzukii* had L* values ranging from 76 to 93 (Supp. 1 [online only]).

The attractiveness of different colors may also be influenced by crop type. Red traps caught more flies in crops with red fruits based on combined data from two raspberry sites, three sweet cherry sites, and seven red-colored fruit sites. Attractiveness of traps that share the same color as the fruit host has been observed with tephritid flies. The apple maggot, *Rhagoletis pomonella* (Walsh), was attracted to red traps in apple orchards (Kring 1970); the western cherry fruit fly, *Rhagoletis indifferens* Curran, was attracted to red traps in cherry orchards (Mayer et al. 2000); and walnut fly, *Rhagoletis juglandis* Cresson, was attracted to green traps in walnut orchards when oviposition occurs on green fruit (Henneman and Papaj 1999). However, the color of the fruit changes over time and other colors associated with food sources and mate location may also be attractive. In the combined data for wine grapes or black/purple fruit, more flies were caught in yellow than clear traps. This preference for yellow may be based on attraction to foliage-like hues (Prokopy and Owens 1983). In the case of *D. suzukii*, which has a large host range, attraction to colors may not be fully explained by host association. A combination of volatile cues or physical contrast with the environment may also affect their attraction to colors.

The attractiveness of colors might vary with the time of the year depending on crop maturity and senescence. For example, the walnut husk fly, *Rhagoletis completa* Cresson, preferred yellow during the early season when reproduction was low, and then preferred green as the season progressed, when green walnuts were present as their ovipositional host (Riedl and Hislop 1985). Similarly, the apple maggot were caught in high numbers in traps with red spheres and yellow panels, but the attraction to yellow decreased as the season advanced and the apples ripened (Kring 1970). However, seasonal trends for *D. suzukii* in the current color study could not be clearly examined from the 16 sites sampled at different times of the year. In this study, responses of *D. suzukii* to colors were consistent both in-season and postharvest periods among the five sites sampled. Moreover, red caught more than other colors at sites tested during the season (Raspberry NC) or postharvest (Blueberry MI, Cherry OR) where the effect of trap color was significant within a site (data not shown). Further balanced studies are needed to determine the influence of crop type and maturity on captures of *D. suzukii* in traps.

More *D. suzukii* were caught overall when the bait surface area was greater in a comparison between two traps with equal distances from the bait to the top-entry point. This was expected because a larger surface area between the bait and air would encourage volatilization. Because captures increased by only 12% when the bait surface area increased 225% from 40 to 90 cm^2, this may not be a substantial difference to warrant using a trap with a much larger bait surface areas, as practical issues arise. A larger surface area requires a broader container, which may be more bulky and vulnerable to spilling.

The captures of flies in the 40- and 90-cm^2 traps may have been confounded by headspace, the volume of space between the bait and entry point into the trap. With other trap designs, more *D. suzukii* were caught with a smaller headspace when bait surface areas were

Table 4. Weekly captures of *D. suzukii* in traps (mean ± SE) when comparing traps: 1) overall, 2) by period when trap × period was significant, 3) by crop type when trap × crop was significant, and 4) by fruit colors

Trap	Overall	Period		Crop				Fruit color		
		In-season	Postharvest	Blueberry	Cherry (sweet)	Grape	Raspberry	Black/purple	Orange	Red
Black	27.3 ± 6.5bc[a]			57.5 ± 23.2	29.9 ± 4.8a	34.3 ± 9.6a	19.6 ± 4.0ab	23.3 ± 8.3ab	6.6 ± 1.5	17.5 ± 3.2abc
Clear	20.2 ± 4.7c			44.6 ± 16.3	16.6 ± 1.5b	20.6 ± 5.4b	19.0 ± 4.0b	14.0 ± 4.8c	7.6 ± 1.3	12.4 ± 3.0c
Red	33.6 ± 7.6ab			54.1 ± 21.5	34.9 ± 6.8a	38.0 ± 11.1a	62.0 ± 33.8a	25.7 ± 9.5ab	7.3 ± 1.1	32.0 ± 10.8a
White	22.4 ± 4.0bc			38.4 ± 12.6	28.1 ± 3.9a	31.8 ± 7.2a	22.0 ± 10.4b	21.5 ± 6.9bc	7.8 ± 1.1	17.8 ± 4.0bc
Yellow	30.3 ± 6.4a			26.6 ± 21.0	26.6 ± 4.1ab	49.9 ± 18.5a	31.2 ± 12.6ab	33.8 ± 14.4a	9.4 ± 1.2	20.0 ± 4.6ab
P value	< 0.001			0.079	0.005	< 0.001	0.002	< 0.001	0.29	< 0.001
40 cm^2	13.4 ± 1.8b									
90 cm^2	15.0 ± 2.1a									
P value	0.030									
Top	15.0 ± 2.4b	17.8 ± 5.0	14.3 ± 4.6b	27.5 ± 6.8	18.5 ± 4.8b	21.4 ± 2.1b	6.4 ± 2.5b			
Side	21.7 ± 3.5a	18.7 ± 5.0	27.8 ± 10.9a	39.1 ± 10.6	20.7 ± 3.3ab	31.1 ± 5.6ab	18.2 ± 6.6a			
Side-tentless	18.6 ± 2.3a	20.1 ± 5.2	25.1 ± 6.5a	28.1 ± 6.1	24.6 ± 4.1a	31.6 ± 3.4a	11.3 ± 2.4a			
P value	< 0.001	0.37	< 0.001	0.078	0.023	0.022	0.014			
Blocks	51, 52 (color)	12	12	13	9	6	7	9	6	24
States or crops	All states and crops	Blackberry WA, Blueberry OR, Cherry OR and WA, Grape OR		MI, NC, NJ, OR	CA, OR, WA	BC, OR	NC, OR	Grape, Blackberry	Orange, Peach	Cherry (all), Raspbery, Straw.

[a] Letters denote significant difference by Tukey HSD on lsmeans of log-transformed counts. In the overall comparison of color traps, the lsmeans estimate of yellow is 1.00, and red is 0.967.

kept equal (A.J.D., unpublished data, Van Steenwyk et al. 2013). The 40-cm^2 trap had a smaller headspace than the 90-cm^2 trap because it had a smaller-diameter cup embedded that reached the mesh opening to prevent the bait from spilling into the outer bowl. The smaller headspace may have elevated captures to some extent and counteract the presence of a smaller surface area in reducing captures.

More *D. suzukii* were caught overall and within sweet cherry, grape, and raspberry crops when the entry point was on the side rather than on the top in a comparison of deli cup traps. Potential reasons include 1) the volatiles emanating from the side may be more perceptible to flies that are present in the canopy of the plant, and 2) the headspace is smaller when the entry is positioned on the side rather than the top of the trap. The fact that side-entry traps had higher catches brings practical advantages. Traps with a top entry require a rain tent, which can be cumbersome when servicing traps; otherwise, rain or irrigation water can enter and dilute the bait. Given that the two side-entry traps often performed similarly with or without a tent, the side-entry trap without a tent should be used. It requires less handling time and fits more easily within a bushy plant canopy.

Finally, the deli-container trap with mesh sides ("side-tentless") and the bowl trap with a mesh lid ("90 cm^2") caught a similar number of flies. These two trap designs, adapted from the previous "Dreves" and "Haviland" traps, respectively, caught most flies in the study by Lee et al. (2012). In the previous study, no direct comparisons were made between these two traps because one trap had a greater entry area than the other (64 cm^2 and 56.8 cm^2, respectively). In this study, both traps had an entry area of 54.1 cm^2 and were tested at all 16 sites. A smaller entry area was used here to accommodate all five traps in the bait surface area and entry position studies: specifically the "top" trap had a smaller diameter lid to fit a circular mesh opening.

Considering the results of these three experiments, traps with yellow or red color in certain crop types, a larger bait surface area (90 vs. 40 cm^2), and a side vs. top entrance can increase fly captures. These features were tested separately, and how these features would perform in combination needs to be determined. The fact that some traps caught more flies than others is advantageous if higher catches translate to greater sensitivity for capturing flies early in the season (Lee et al. 2012). An ideal trap design or bait should also be selective for *D. suzukii* to ease sorting. The current study revealed no differences in species selectivity by trap design, and *D. suzukii* comprised 58.7–71.3% of the total drosophilid catch at five sites. Previous studies with other trap designs found *D. suzukii* to comprise 10–33% (Basoalto et al. 2013) and 26–31% (Lee et al. 2012) of the total drosophilid catch. All traps tested in these experiments, and all those currently available, are constructed assuming that liquid lures will be used. Future research should include traps with improved physical characteristics, with an emphasis on lure improvement for early detection of flies. This will enable growers to predict crop risk and optimize timely management decisions.

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