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DIFFERENTIAL CAPTURES OF *RHAGOLETIS POMONELLA* (DIPTERA: TEPHRITIDAE) ON FOUR FLUORESCENT YELLOW RECTANGLE TRAPS

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ABSTRACT

Four commercial sticky fluorescent yellow rectangle traps differing in shades of yellow, fluorescence, and other features were compared for capturing apple maggot fly, *Rhagoletis pomonella* (Walsh). Traps were the Alpha Scents Yellow Card (Alpha Scents), Pherocon® AM (Pherocon), Multigard® AM (Multigard), and the Stiky™ Strips Insect Trap (Olson, small and large sizes), all baited with the same ammonium bicarbonate lure. L*, a*, and b* color space values indicated that the Alpha Scents trap was whiter (higher L*) and greener (lower a*) than the other traps, less yellow than the Pherocon trap, and more yellow (higher b*) than Multigard and Olson traps. The Pherocon trap had the highest relative fluorescence and was the brightest trap, followed in order by Multigard, Olson, and Alpha Scents traps. Various modified forms of the Alpha Scents trap captured significantly (1.5-6.4 times) more *R. pomonella* in choice tests than the Pherocon trap. The Alpha Scents trap captured 1.3-3.6 times more *R. pomonella* in paired choice tests than Pherocon, Multigard, and small and large Olson traps, and the Pherocon trap caught 1.4 times more *R. pomonella* than the Multigard trap (the Olson traps were not compared with these two traps). A combination of color and fluorescence features in the Alpha Scents trap could have contributed to its superior performance. These results suggest the Alpha Scents trap could be an alternative to the other traps tested for monitoring *R. pomonella*.

Key Words: Apple maggot fly, Alpha Scents trap, Pherocon trap, ammonium bicarbonate, Washington state

RESUMEN

Cuatro trampas comerciales pegajosas rectángulares de color amarillo fluorescente con tonos diferentes de amarillo y fluorescencia y con otras características fueron comparadas para la captura de la mosca de la manzana, *Rhagoletis pomenella* (Walsh). Las trampas fueron de las siguientes clases: Tarjetas Amarillas de Aroma Alfa (Aromas Alfa), Pherocon® AM (Pherocon), Multigard® AM (Multigard), y Stiky™ (Cintas pegajosas para atrapar insectos) (Olson, tamaños pequeños y grandes). Cebo con el señuelo de bicarbonato de amonio fue puesto en todas las trampas. Los valores del espacio de color L*, a* y b* indicaron que la trampa de Alfa Aroma fue más blanca (mayor L*) y mas verde (menor a*) que las otras trampas, menos amarillo que la trampa Pherocon y más amarillo (mayor b*) que la Multigard y las trampas Olson. La trampa Pherocon tuvo la mayor fluorescencia relativa y fue la trampa más brillante, seguida en orden por las trampas Multigard, Olson, y de Aroma Alfa. En las pruebas de selección, las diversas formas modificadas de la trampa de Aroma Alfa capturaron de forma significativa (1.5 a 6.4 veces) un mayor cantidad de *R. pomonella* que la trampa Pherocon. La trampa de Aroma Alfa capturó 1.3-3.6 veces más *R. pomonella* en las pruebas de selección de pares que las trampas de Pherocon, Multigard y las trampas pequeñas y grandes de Olson, y la trampa Pherocon capturó 1.4 veces más *R. pomonella* que la trampa Multigard (las trampas Olson no fueron comparadas con estas dos trampas). Una combinación de color y características de fluorescencia en las trampas de Aroma Alfa podría haber contribuido a su excelente exito. Estos resultados sugieren que la trampa de Aroma Alfa podría ser una alternativa a las trampas de ostras pruebas de control de *R. pomonella*.

Washington state is the leading producer of apples, *Malus domestica* (Borkh.) Borkh., in the USA. Apples in Washington in 2009 were worth US$1.47 billion, with an estimated per ha value of $23,791 over 61,918 harvested ha (USDA 2010). To keep apple production costs down and to retain export, insect detection and pest management are vital. The apple maggot fly, *Rhagoletis pomonella* (Walsh), is a quarantine pest of apples in Washington and other states in the US Pacific Northwest. It is abundant in western Washington and is found in low numbers in central Washington (Yee 2008), where the vast majority of commercial apple orchards is found. In this region, the fly potentially impacts ~18,211 ha of apples (Klaus 2011). To date no commercial apples in this region have been found to be infested with *R. pomonella* (Washington State Department of Agriculture 2010) possibly, in part, because extensive surveys have detected flies before they could move into orchards. However, *R. pomonella* appears to be expanding its range and is a constant threat to the apple industry (Klaus 2011).

The Washington State Department of Agriculture (WSDA) has monitored for *R. pomonella* since 1981 using sticky yellow rectangle traps baited with ammonium carbonate or ammonium bicarbonate lures, which are more effective than fruit volatile lures in Washington (Yee et al. 2005). Yellow rectangles capture more *R. pomonella* than rectangles of other colors (Prokopy 1968, 1972). Red spheres can capture more flies than yellow rectangles (Prokopy & Hauschild 1979; Agnello et al. 1990; Bostanian et al. 1993; Yee & Landolt 2004) although not in all cases (Jones & Davis 1989). However, red spheres are not used on a large scale in Washington because they are less convenient to handle (e.g., adhesive needs to be applied by the user), take more space, and flies are more difficult to find on them than on flat yellow rectangles.

Sticky yellow rectangles from various manufacturers have been used by WSDA during the last 30 years. However, no research has focused on comparing numbers of *R. pomonella* caught by different commercial yellow rectangles. Most trapping studies have focused on comparing vastly different trap types (sometimes with different attractants) such as red spheres, yellow cards, sectar traps, Rebell traps, and BioLure Jackson traps (Reissig 1975; Prokopy & Hauschild 1979; Neilson et al. 1981; AliNiazee et al. 1987; Jones & Davis 1989; Bostanian et al. 1993).

The main objectives of this study were (i) to document differences in shades of yellow and in relative fluorescence of 4 commercial sticky fluorescent yellow rectangle traps, (ii) to identify through choice tests the trap that captures the most *R. pomonella* flies, and (iii) to elucidate and discuss relationships among trap color, fluorescence differences and fly captures.

Materials and Methods

Traps Tested

The Alpha Scents Yellow Card (Alpha Scents, West Linn, Oregon), Pherocon® AM (Pherocon; Trece, Inc., Adair, Oklahoma), Multigard AM (apple maggot) (Scentry Biologicals Inc., Billings, Montana) (Multigard), and the Stiky™ Strips Insect Trap (Olson Products, Medina, Ohio) (Olson) (Fig. 1) were compared. Two sizes of Olson traps were tested; the smaller one (Fig. 1D) resulted from trimming the original size trap (Fig. 1E) so that it matched the size of the Alpha Scents Yellow Card trap (Fig. 1A). Key features and dimensions of the traps are shown in Table 1. The Alpha Scents and Olson traps were covered with silicone release paper that had to be peeled off to expose the sticky surfaces. The sticky surface of the Alpha Scents Yellow Card trap was an hot melt pressure sensitive adhesive (HMPSA). The sticky surface of the Olson trap was a proprietary adhesive. The Pherocon and Multigard traps were coated with sticky gel (SG) and had to be unfolded to expose the sticky surfaces. In all experiments, traps were baited with a white plastic pouch lure (PL) (Fig. 1F) containing 27 g of ammonium bicarbonate (AgBio Inc., Westminster, Colorado). The pouch was 7.7 × 10.0 cm and had four 5-mm diam holes covered with thin membrane on each side.

Comparisons of Trap Colors and Effects of Field Exposure

Colors of traps were quantified by L*a*b* color space values (Hanbury & Serra 2001): the range of L* is 0-100, with 0 = black and 100 = diffuse white; -a* = greener; +a* = redder; -b* = bluer; and +b* = yellower. Colors were determined with a Chroma Meter CR-400/410 (Konica Minolta Sensing, Inc. Japan). Before measurements were made, the meter measuring head was calibrated using a white calibration plate. Absolute color values were measured at a distance of 6 mm directly above the sticky material covering the traps. Five randomly chosen traps of each type taken directly out of the box from the distributor were measured. In addition, 5 measurements of Pherocon traps were made over variable thickness SG and uniformly thick (smooth) SG sections of the traps to determine if the thickness and/or irregular surface of the SG caused by pulling apart the 2 sticky sides of the closed trap had an impact on color measurements. With respect to the other traps, the sticky material appeared to cover the surfaces more uniformly, even when sides had been pulled apart in the case of the Multigard trap; therefore color measurements of these traps were made only over their smooth surfaces.

In a separate evaluation, L*a*b* color space values of new Alpha Scents, Pherocon, and Multigard traps (5 each) were compared with those of Alpha Scents, Pherocon, and Multigard traps (16 each) that had been exposed in hawthorn trees in the field for 2 wk (20 Aug to 3 Sep 2010) at Wenas in Yakima County (46.50°N, 120.43°W) (Olson traps were not included). For these comparisons, measurements from new and field-exposed traps were taken from the non-sticky border areas of traps because many nontarget insects had been

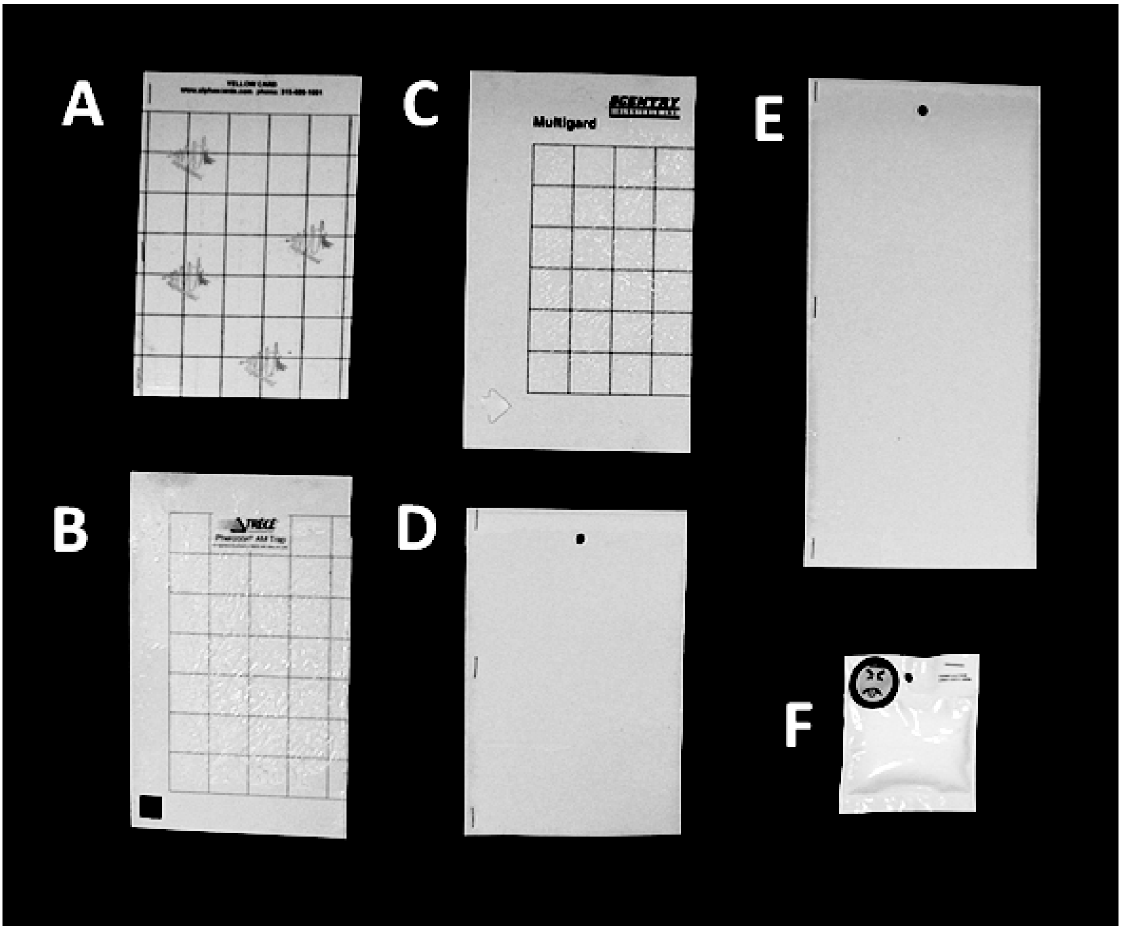

Fig.1. (A) Alpha Scents Yellow Card, (B) Pherocon® AM, (C) Multigard, (D) small Olson trap, (E) large Olson trap, and (F) ammonium bicarbonate lure used in *Rhagoletis pomonella* trapping studies, all to scale.

caught on the sticky material of the field-exposed traps. During the 2 wk, most days were sunny, the mean temp was 20.3 °C, and there was a total of 1.3 mm precipitation during 2 of the days (National Climatic Data Center 2011).

Delta E (color difference) values between pairs of different traps were calculated using the square root of $[(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2]$ (Sharma 2003). Mean values were used in calculations. Delta Es were calculated between (1) all pairs of the 4 types of traps when new, (2) between all pairings of Alpha Scents, Pherocon, and Multigard traps that had been exposed 2 wk in the field, and (3) within trap types when new and exposed 2 wk in the field.

Fluorescence of Traps

Relative fluorescence values of traps were measured over the sticky material with a Jobin Yvon Horiba Fluorolog-3 Spectrofluoremeter (Edison, New Jersey), and analyses were made by PhytoPhotonics, Gloucester, Virginia. Only 1 trap of each of the 4 types was measured because the high cost of fluorescence analyses prevented multiple measurements of each type of trap and measurements of field-aged traps.

Field Sites

Trapping experiments were conducted at 4 sites in western Washington. Sites were Vancouver, Clark County (45.63 °N, 122.60 °W) (Experiment 1); Saint Cloud, Skamania County (45.60 °N, 122.11 °W) (Experiments 1, 2, and 3); Woodland, Cowlitz County (45.88 °N, 122.75 °W) (Experiment 2); and Puyallup, Pierce County (46.11 °N, 122.17 °W) (Experiment 3). The Vancouver site was in a public park (Burnt Bridge Greenway) with about 40 black hawthorn trees (*Crataegus douglasii* Lindl.), planted along a path. The Saint Cloud site was a homestead converted into

TABLE 1. KEY FEATURES AND DIMENSIONS OF FLUORESCENT YELLOW RECTANGLE TRAPS EVALUATED FOR CAPTURE OF *RHAGOLETIS POMONELLA* FLIES.

	Trap Type				
Feature	Alpha Scents	Pherocon[1]	Multigard[1]	Olson-small	Olson-large
Designed to Fold	No	Yes	Yes	No	No
Sticky Surface Material[2]	HMPSA	SG	SG	Proprietary	
Trap Dimensions (cm)	20.3 × 14	22.8 × 13.9	23.5 × 14.0	20.3 × 14	30.5 × 14.6
Total Area (cm^2)	568.4	633.84	658	568.4	890.6
Sticky Area (cm per side)	17.5 × 14	17.8 × 11.4	15.3 × 10.2	20.3 × 14	30.5 × 14.6
Total Sticky Area (cm^2)	490	405.8	312.1	568.4	890.6
Non-Sticky Edge (cm):					
Top	2.8	2.5	4.8	None	None
Bottom	None	2.5	3.4	None	None
Sides	None	2.5	3.8	None	None
Number of Grids[3]	70	59	48	None	None
Grid Line Thickness (mm)	0.46	0.23	0.39	None	None
Grid Line Color	black	green	green	None	None

[1]Dimensions when folded;
[2]Hot melt pressure sensitive adhesive (HMPSA), sticky gel (SG) or proprietary;
[3]Grids were 2.5 * 2.5 cm on all traps with grids.

a recreational park along the Columbia River with a mix of old variety apples, black hawthorn, Suksdorf's hawthorn [*Crataegus suksdorfii* (Sarg.) Kruschke], ornamental hawthorn (*Crataegus monogyna* Jacq.), pears (*Pyrus pyrifolia* (Burm. f.) Nakai), and plums [*Prunus domestica* L. var. *insititia* (L.) Fiori & Paoletti]. The Woodland site was a yard with 15 apple trees near a housing complex along the edge of woods. The Puyallup site was an unmanaged apple orchard.

Experiment 1. Comparison of Alpha Scents Yellow Card and Pherocon AM Traps

Choice tests to compare captures of *R. pomonella* on Alpha Scents Yellow Card and Pherocon AM traps and to determine effect of HMPSA- and SG-coatings were conducted at the sites in Vancouver and Saint Cloud. The PL on the Alpha Scents Yellow Card trap was either exposed (on the front of each Alpha Scents trap) or concealed (between two Alpha Scents traps that were stapled back to back to create a space). The trapping surface area of 1 Alpha Scents trap was the same as that of 2 stapled Alpha Scents traps. The PL on the Pherocon trap was concealed by placing the pouch in the fold of each Pherocon trap. Lure pouches are concealed by WSDA to make them safer to use in homeowners' yards. In addition, SG was applied over the HMPSA for 2 Alpha Scents trap treatments. By visual inspection, we established that the SG covered the HMPSA without mixing with it. There were 5 treatments: (1) Alpha Scents + SG, exposed PL; (2) Alpha Scents + SG, concealed PL; (3) Alpha Scents, exposed PL; (4) Alpha Scents, concealed PL; and (5) Pherocon, concealed PL. The trapping design was a randomized complete block. Each of 3 hawthorn (Vancouver) or apple trees (Saint Cloud) was considered a replicate block with the above 5 traps installed. Each trap treatment was randomly spaced ~1-1.5 m apart within a tree, and ~1.5-2 m above the ground. Hawthorn and apple trees (var. 'Newtown' and 'Spitzenberg') with traps were spaced ~3-7 m and ~5-10 m from one another, respectively. Traps were inspected every 4-14 d, at which time they were rotated or removed (end of test), and flies were removed using forceps and counted. Flies were not sexed. Flies were confirmed to be *R. pomonella* based on Wescott (1982) (also in Experiments 2 and 3). At Vancouver, traps were set up in trees on 7 Jun and inspected on 21 and 28 Jun and on 2 and 10 Jul. At Saint Cloud, traps were set up in trees on 28 Jun and checked on 5, 12, and 19 Jul and on 2 August. Traps were not replaced.

Experiment 2. Paired Choice Tests of Alpha Scents, Pherocon, and Multigard Traps

A paired choice experiment was conducted to determine *R. pomonella* trap preference. Captures of flies with paired Alpha Scents and Pherocon, paired Alpha Scents and Multigard, and paired Pherocon and Multigard traps were compared by placing each trap within a pair 30-90 cm apart. Each trap was baited with a PL concealed in between folds of the traps (two stapled sheets in the case of Alpha Scents trap). Each trap pair was hung ~1.5-2 m above the ground in a separate tree. At Woodland, 5 sets of paired Alpha Scents and Pherocon traps were placed in feral apple trees (varieties unknown) spaced ~3-10 m from one another on 20 Jun and checked on 27 Jun and 4 and 14 Jul. At Saint Cloud, 5 sets of each pair comparison were set up in apple trees (var. 'Newtown' and 'Spitzenberg') spaced ~5-10 m from one another on 3 Aug and inspected 10, 16, 23, and 28 Aug. At both sites, trap positions were switched at each check date and flies removed using forceps. Flies were stored in vials with 70% ethanol and were later identified and counted. Traps were not replaced.

Experiment 3. Paired Choice Tests of Alpha Scents and Olson Traps

A second paired choice experiment was set up to compare *R. pomonella* captures by Alpha Scents and Olson traps. The three comparisons were Alpha Scents and small Olson, Alpha Scents and large Olson, and small Olson and large Olson traps. PL lures were concealed, there was one pair per tree and 5 replicates of each comparison. Flies were removed and trap positions within each pair were switched every 3-7 d, and traps were not replaced. At Saint Cloud, traps were set up in apple trees (var. 'Newtown' and 'Spitzenberg') spaced ~5-10 m from one another on 31 Aug and checked on 7, 14, 28 Sep and 5 Oct. At Puyallup, traps were set up in apple trees (var. 'Gravenstein' and 'Chief') spaced ~6-9 m from one another on 3 Sep, and checked on 6, 9, 13, 16, 20, and 24 Sep.

Statistical Analyses

For L*a*b* color space data, analysis of variance (ANOVA) was performed when data were normal and their variances were homogenous based on the Shapiro-Wilk and the Brown and Forsythe's tests, respectively. When data did not meet assumptions of ANOVA, a Kruskal-Wallis test (4 trap types) followed by multiple comparisons using Fisher's least significant difference (LSD) procedure (Conover 1980) or a Mann-Whitney U test (2 treatments: new and field-exposed traps) was conducted. For Experiment 1, fly numbers were square root transformed and data confirmed to be normal and their variances homogeneous before ANOVA was performed, followed by the Fisher LSD test ($\alpha = 0.05$). Counts over the season were combined to generate higher numbers for analysis and to take into account position differences within trees. In Experiments 2 and 3, count data within each inspection date and total counts over entire trapping periods were square-root transformed and data confirmed to be normal and their variances homogenous before being analyzed using paired *t*-tests (SAS Institute 1999). Otherwise, a Wilcoxon paired sample test (Zar 1999) was used to analyze the data.

RESULTS

Comparisons of Trap Colors and Effects of Field Exposure

L*, a*, and b* color space values indicated the Alpha Scents trap was whiter (higher L*) and greener (lower a*) than the other traps, less yellow than the Pherocon trap, and more yellow (higher b*) than Multigard and Olson traps. All L*, a*, and b* values of the 4 trap types differed significantly, except for the L* values between Multigard and Olson traps (Table 2). There were no significant differences in L*, a*, or b* values between the Pherocon variable SG and Pherocon smooth SG traps. Individual L*, a*, and b* values of new traps and traps exposed in the field (Table 3) differed in 5 of 9 cases. However, the b* values of exposed and unexposed Alpha Scents traps did not differ. Also, the L* and a*values of new vs. exposed Pherocon traps did not differ, nor did L*

TABLE 2. MEAN L*A*B* COLOR SPACE VALUES ± SE OF NEW UNUSED YELLOW RECTANGLE TRAPS USED IN THIS STUDY.

Trap	L* (mean rank)	a* (mean rank)	b*
Alpha Scents	93.34 ± 0.09 (23 a)	-15.49 ± 0.05 (5 d)	81.84 ± 0.44 b
Pherocon, variable SG[1]	87.56 ± 0.41 (5.2 c)	-6.42 ± 0.23 (19.2 a)	87.76 ± 1.72 a
Pherocon, smooth SG[2]	87.85 ± 0.45 (5.8 c)	-6.01 ± 0.10 (21.8 a)	86.51 ± 0.73 a
Multigard	92.35 ± 0.26 (17 b)	-13.90 ± 0.07 (8 c)	79.04 ± 0.23 c
Olson	91.34 ± 0.39 (14 b)	-11.24 ± 0.26 (13 b)	71.57 ± 0.84 d

Measurements of 5 traps of each type were taken with a Chroma Meter CR-400/410 held directly above the sticky material. Numbers inside parentheses are mean ranks.

[1]Over sticky gel that was variable in thickness.

[2]Over sticky gel that was uniformly thick.

L*: data not normal; Kruskal Wallis test: T = 21.200; df = 4; critical T = 9.488, ∞ = 0.05; multiple comparison critical value = 3.633.

a*: data not normal, variance not homogenous; Kruskal-Wallis test: T = 22.24; df = 4; critical T = 9.488, ∞ = 0.05; multiple comparison critical value = 2.880.

b*: data normal, homogenous variance: ANOVA: $F = 50.64$; df = 4, 20; $P < 0.0001$.

Ranks or means within columns followed by same letters are not significantly different ($P > 0.05$).

TABLE 3. MEAN ± SE AND MEAN RANK COLOR SPACE VALUES OF NEW YELLOW RECTANGLE TRAPS (*N* = 5) AND TRAPS THAT HAD BEEN EXPOSED IN THE FIELD (N = 16) FROM 20 AUG TO 3 SEP 2010 AT WENAS, WASHINGTON. MEASUREMENTS ON NEW TRAPS WERE MADE OVER STICKY MATERIAL, BUT MEASUREMENTS ON EXPOSED TRAPS WERE MADE OVER NON-STICKY BORDER AREAS.

	Alpha Scents			Pherocon			Multigard		
	L*	a*	b* (mean rank)	L* (mean rank)	a*	b*	L*	a* (mean rank)	b*
New	93.86 ± 0.21 b	-15.25 ± 0.18 b	79.69 ± 0.79 (12.4 a)	91.33 ± 0.08 (13.0a)	-8.76 ± 0.14 a	85.85 ± 0.23 a	93.88 ± 0.05 a	-13.98 ± 0.01 (8.5 b)	78.33 ± 1.18 a
Exposed In Field	95.15 ± 0.29 a	-14.74 ± 0.08 a	77.25 ± 1.09 (6.6a)	90.62 ± 0.13 (4.6 a)	-8.66 ± 0.17 a	84.78 ± 0.23 b	93.81 ± 0.10 a	-13.59 ± 0.04 (19.0a)	69.67 ± 0.72 b

Means or ranks followed by the same letter within columns are not significantly different ($P > 0.05$). ANOVA was conducted when data were normal and the variances were homogenous. Mann-Whitney U test was conducted on ranks when data were not normal and/or variances were not homogenous

values of Multigard traps (new and exposed: Alpha Scents: L*: $F = 5.81$; df = 1, 19; $P = 0.0262$; a*: $F = 9.11$; df = 1, 19; $P = 0.0071$; b*: U = 18; critical $U_{(0.05)\,16,\,5} = 61$; Pherocon: L*: U = 8; critical $U_{(0.05)\,16,\,5} = 61$; a*: $F = 0.10$; df = 1, 19; $P = 0.7578$; b*: $F = 6.02$; df = 1, 19; $P = 0.0239$; Multigard: L*: $F = 0.15$; df = 1, 19: $P = 0.7017$; a*: $U = 80$; critical $U_{(0.05)\,16,\,5} = 61$; b*: $F = 35.91$; df = 1, 19; $P < 0.0001$).

Within new trap comparisons [(1) of Table 4], the Delta E between Pherocon and Olson traps was the largest, and that between the Alpha Scents and Multigard traps was the smallest. In comparisons of field-exposed and new traps [(2) vs. (1) in Table 4], the Delta E values between field-exposed Alpha Scents and Pherocon traps were similar to those measured when traps were new. The Delta E between field-exposed Alpha Scents and Multigard traps was larger than when these traps were new, and that between field-exposed Pherocon and Multigard traps was much larger than when these traps were new. In new and field-exposed traps of the same types [(3) in Table 4], the Delta E was largest in Multigard traps (Table 4).

Fluorescence of Traps

The Pherocon trap had the highest relative fluorescence and was the brightest trap, followed in order by Multigard, Olson, and Alpha Scents traps (Table 5). With respect to mean relative and maximum fluorescence, the Alpha Scents trap differed the most from the Pherocon trap and resembled most closely the Olson trap. With respect to peak excitation, the Alpha Scents trap was the most different from the Multigard trap and most similar to the Olson trap. With respect to peak emission, the Alpha Scents trap was most different from the Olson trap and most similar to the Pherocon trap.

Experiment 1. Comparison of Alpha Scents and Pherocon Traps

At Vancouver, there was a trap effect but no block effect (trap: $F = 13.03$; df = 4, 8; $P = 0.0014$; block: $F = 0.32$; df = 2, 8; $P = 0.7368$). Alpha Scents traps caught 1.5-2.2 times more *R. pomonella* than Pherocon traps except for the One Alpha Scents + SG, exposed PL trap, which did not differ from the Pherocon trap (Table 6). The Two Alpha Scents + SG, concealed PL and Two Alpha Scents, concealed PL traps caught 1.1-1.7 times more flies than the two types of Alpha Scents, exposed PL traps. At Saint Cloud, there was also a trap effect but no block effect (trap: $F = 4.04$; df = 4, 8; $P = 0.0505$; block: $F = 2.61$; df = 2, 8; $P = 0.1338$). Four of the 5 Alpha Scents traps (Table 6) caught 4.6-6.4 times more flies than the Pherocon trap, but trap catch in the OneAlpha Scents trap with an exposed PL did not differ from that of the

TABLE 4. DELTA E VALUES (COLOR DIFFERENCES) AMONG YELLOW RECTANGLE TRAPS. DELTA E OF ~2.3 INDICATES A JUST NOTICEABLE DIFFERENCE TO A HUMAN OBSERVER (SHARMA 2003).

	(1)New Unused Traps[1]			
Trap	Alpha Scents	Pherocon, variable	Pherocon, smooth	Multigard
Pherocon, variable SG[2]	12.28	—	—	—
Pherocon, smooth SG[3]	11.91	1.30	—	—
Multigard[4]	3.37	12.46	11.34	—
Olson[4]	11.30	17.31	16.21	8.00

	(2) All Traps Exposed for Two Weeks in Field[5]	
Trap	Alpha Scents	Pherocon
Pherocon	10.69	—
Multigard	7.78	16.21

	(3) New Traps[4] versus Traps Exposed Two Weeks in Field[5]		
	Alpha Scents	Pherocon	Multigard
Within Trap Types	2.80	1.28	8.67

[1]n = 5.
[2]Over sticky gel (SG) that was variable in thickness.
[3]Over SG that was uniformly thick.
[4]Over adhesive.
[5]n = 16, values from non-sticky border areas; in field 20 Aug to 3 Sep 2010 at Wenas site.

Pherocon trap. The Two Alpha Scents concealed PL trap caught 3.3 times more flies than the One Alpha Scents exposed PL trap. The Two Alpha Scents + SG concealed PL trap caught numerically more flies than the One Alpha Scents + SG exposed PL trap and the One Alpha Scents exposed PL trap.

Experiment 2. Paired Choice Tests of Alpha Scents, Pherocon, and Multigard Traps

At Woodland, the Alpha Scents trap caught more *R. pomonella* than the Pherocon trap on each of 3 dates, and overall captured 3.6 fold more flies (Table 7). At Saint Cloud, the Alpha Scents trap also caught more flies than the Pherocon trap on each of 4 dates, even though these differences were not significant statistically due to highly variable fly numbers among the various trees. However, the total flies caught on the Alpha Scents trap was 1.3 times greater than on the Pherocon trap (Table 7). The Alpha Scents trap captured more *R. pomonella* than the Multigard trap on all 4 dates and overall captured 3.1 fold more flies (Table 7). The Pherocon trap caught more flies than the Multigard trap on 4 of the 5 dates, although differences were not significant statistically. However, the total flies caught by the Pherocon trap was 1.4 fold greater than by the Multigard trap (Table 7).

TABLE 5. FLUORESCENCE (RELATIVE UNITS), PEAK EXCITATION AND PEAK EMISSION OF EACH OF THE FOUR YELLOW RECTANGLE TRAPS USED IN THIS STUDY.

Measure	Alpha Scents	Pherocon	Multigard	Olson
Fluorescence, Mean Relative[1]	45,819.00	179,392.37	130,301.05	47,985.56
Fluorescence, Maximum	707,600	1,965,000	1,049,000	539,200
Fluorescence, Excitation Peak	485 nm	420 nm	380 nm	465 nm
Fluorescence, Emission Peak	530 nm	540 nm	515 nm	505 nm

[1]Relative fluorescence here has no absolute units. Measurements were made over the sticky material.

TABLE 6. MEAN TOTAL NUMBERS ± SE OF *RHAGOLETIS POMONELLA* CAUGHT PER TRAP IN FIELD TESTS CONDUCTED AT TWO SITES IN WASHINGTON (N = 3 PER SITE).

Treatment	Vancouver (7 Jun to 10 Jul)	Saint Cloud (28 Jun to 2 Aug)
One Alpha Scents + SG, exposed PL	109.7 ± 1.8 bc	47.0 ± 13.9 ab
Two Alpha Scents + SG, concealed PL	136.0 ± 9.2 a	52.7 ± 22.0 ab
One Alpha Scents, exposed PL	125.7 ± 17.9 b	20.3 ± 3.7 bc
Two Alpha Scents, concealed PL	186.0 ± 5.5 a	66.3 ± 26.9 a
Pherocon, concealed PL	83.3 ± 1.8 c	0.3 ± 5.8 c

SG, sticky gel. PL, pouch lure. Two Alpha Scents: two Alpha Scents traps that were stapled back to back to create a space for sandwiching the PL. Means within columns followed the same letters are not significantly different (P > 0.05).

Experiment 3. Paired Choice Tests of Alpha Scents and Olson Traps

At Saint Cloud, the Alpha Scents trap caught numerically more flies than the small Olson trap on each of the 5 dates, although the differences were significant for only 2 of them (Table 8). However, the total fly capture on the Alpha Scents trap was 2.2 times greater than on the small Olson trap. The Alpha Scents trap caught numerically more flies than the large Olson trap on 4 of 5 dates with differences significant

TABLE 7. MEAN NUMBERS OF *RHAGOLETIS POMONELLA* ± SE FLIES CAUGHT PER TRAP PER SAMPLE PERIOD OR SUMMED OVER THE ENTIRE SAMPLING PERIOD (TOTAL) IN PAIRED FIELD TESTS CONDUCTED IN WASHINGTON (N = 5).

Woodland (20 Jun to 14 Jul)					
Dates	Alpha Scents	Pherocon	t	df	P
20-27 Jun	5.6 ± 2.2	0.6 ± 0.2	2.67	4	0.0560
27 Jun-4 Jul	5.8 ± 2.3	1.8 ± 0.9	3.56	4	0.0236
4-14 Jul	28.6 ± 6.1	8.6 ± 3.8	2.77	4	0.0503
Total	40.0 ± 7.7	11.0 ± 4.6	3.92	4	0.0173
Saint Cloud (3 to 28 Aug)					
Dates	Alpha Scents	Pherocon	t	df	P
3-10 Aug	26.2 ± 5.8	22.0 ± 4.5	-2.38	4	0.0763
10-16 Aug	55.6 ± 9.8	42.2 ± 10.2	-2.42	4	0.0724
16-23 Aug	7.8 ± 2.5	7.6 ± 1.9	0.05	4	0.9652
23-28 Aug	26.6 ± 6.1	16.8 ± 7.2	-2.19	4	0.0935
Total	116.2 ± 20.7	88.6 ± 19.1	-5.51	4	0.0053
Dates	Alpha Scents	Multigard	t	df	P
3-10 Aug	52.6 ± 27.0	13.4 ± 5.7	-2.84	4	0.0467
10-16 Aug	108.8 ± 32.9	33.2 ± 9.2	-5.48	4	0.0054
16-23 Aug	21.0 ± 8.7	10.8 ± 7.3	-2.91	4	0.0438
23-28 Aug	46.4 ± 12.9	16.6 ± 8.5	-3.12	4	0.0357
Total	228.8 ± 63.9	74.0 ± 21.6	-5.15	4	0.0067
Dates	Alpha Scents	Multigard	t	df	P
3-10 Aug	19.6 ± 9.2	10.8 ± 2.3	0.94	4	0.4027
10-16 Aug	35.6 ± 3.9	25.4 ± 5.7	2.23	4	0.0900
16-23 Aug	5.2 ± 1.7	6.2 ± 2.4	0.05	4	0.9606
23-28 Aug	20.2 ± 6.2	14.2 ± 4.3	2.04	4	0.1104
Total	80.6 ± 17.1	56.6 ± 10.4	4.62	4	0.0099

TABLE 8. MEAN NUMBERS OF *RHAGOLETIS POMONELLA* ± SE FLIES PER PAIRED ALPHA SCENTS TRAP AND OLSON TRAP AT SAINT CLOUD AND PUYALLUP IN 2010.

Saint Cloud					
Date	Alpha Scents	Small Olson	*t*	df	*P*
31 Aug to 7 Sep	35.4 ± 10.4	22.0 ± 5.6	1.28	4	0.2705
7-14 Sep	27.8 ± 11.0	13.2 ± 3.7	1.80	4	0.1468
14-21 Sep	14.8 ± 3.5	4.8 ± 0.9	2.78	4	0.0498
21-28 Sep	10.4 ± 1.1	1.8 ± 0.7	4.38	4	0.0119
28 Sep to 5 Oct	7.4 ± 2.1	1.6 ± 0.4	1.85	4	0.1385
Total	95.4 ± 14.0	44.2 ± 7.7	7.39	4	0.0018
Date	Alpha Scents	Large Olson	*t*	df	*P*
31 Aug to 7 Sep	62.4 ± 16.8	63.8 ± 21.3	0.20	4	0.8513
7-14 Sep	53.6 ± 20.0	33.6 ± 9.0	0.97	4	0.3866
14-21 Sep	40.0 ± 12.2	19.0 ± 8.1	7.05	4	0.0021
21-28 Sep	22.8 ± 5.9	7.6 ± 2.3	6.44	4	0.0030
28 Sep to 5 Oct	14.8 ± 5.6	2.6 ± 1.1	2.80	4	0.0487
Total	193.6 ± 31.3	126.6 ± 12.0	2.94	4	0.0424
Date	Small Olson	Large Olson	*t*	df	*P*
31 Aug to 7 Sep	30.6 ± 6.4	30.6 ± 7.8	0.13	4	0.8994
7-14 Sep	17.8 ± 2.9	16.4 ± 4.7	0.59	4	0.5862
14-21 Sep	16.4 ± 4.5	7.8 ± 3.2	3.56	4	0.0237
21-28 Sep	8.6 ± 2.4	6.8 ± 2.2	0.70	4	0.5212
28 Sep to 5 Oct	2.4 ± 1.3	2.2 ± 0.6	-0.29	4	0.7865
Total	75.8 ± 10.7	63.8 ± 15.6	1.57	4	0.1907
Puyallup (3 to 24 Sep)[1]					
	Alpha Scents	Small Olson	*t*	df	*P*
	15.4 ± 8.5	6.4 ± 4.2	4.73	4	0.0091
	Alpha Scents	Large Olson	*t*	df	*P*
	19.8 ± 4.0	6.2 ± 1.6	5.21	4	0.0065
	Small Olson	Large Olson	*t*	df	*P*
	7.6 ± 4.0	8.2 ± 2.8	-0.91	4	0.4148

Five pairs of traps compared at each site.
[1]Data from all dates were combined, because there were few or no flies captured on some individual dates.

for 3 of them. The total capture on the Alpha Scents trap was 1.5 times greater than on the large Olson trap. The small Olson trap captured more flies than the large Olson trap on 1 of 5 dates, but the totals on the 2 kinds of traps did not differ. At Puyallup, the Alpha Scents trap caught 2.4 fold more *R. pomonella* than the small Olson trap and 3.2 fold more than the large Olson trap, but there was no significant difference in capture between the small and large Olson traps.

DISCUSSION

The standard yellow rectangle trap for *R. pomonella* is the Pherocon trap, which has been in continuous use over the last 35 years (Reissig 1976; Prokopy & Hauschild 1979; Neilson et al. 1981, Bostanian et al. 1993). The current version of the Pherocon trap was introduced in 1987. However, this study shows the Pherocon trap is not the optimal yellow rectangle trap. Alpha Scents, Pherocon, Multigard, and Olson yellow rectangle traps differ significantly in various features, including their colors, changes in colors caused by field exposure, and fluorescence, so the higher overall captures of flies on Alpha Scents than on other traps cannot be explained by 1 specific feature. However, based on the literature on *R. pomonella* and other tephritids (Prokopy & Boller 1971; Prokopy 1972; Russ et al. 1973; Remund & Boller 1974: Prokopy et al. 1975; Prokopy & Economopoulos 1975, 1976; Greany et al. 1977), differential fly captures in large part may be related to differences in trap color.

Changes in trap color after exposure to the sun could affect fly captures. The fluorescent yellow pigments or sticky materials on the different traps may be affected differently by UV radiation. Moreover the adhesive on the Alpha Scents trap may have had UV stable ingredients that prevented changes in the yellow pigments under the conditions at our test sites. The sticky material on the Multigard trap may not have UV protectants or protectants of a different type than on Alpha Scents traps. In any case, the Multigard trap sustained damage to its appearance from the sun and became less yellow and possibly less attractive.

Fluorescence among the various new traps also differed and these differences may have the potential to affect fly capture. The Alpha Scents trap had the lowest relative fluorescence, which may have contributed to its high attractiveness. Fluorescent paint was more attractive than non-fluorescent paint for *R. pomonella* and other tephritids (Prokopy 1972; Prokopy et al. 1975; Greany et al. 1978), but effects of different degrees of fluorescence on fly captures have not been reported. It seems possible that differences in trap fluorescence in our study were caused by different compositions of fluorescent yellow pigments or by the sticky materials.

In Experiment 1, the Alpha Scents traps, whether covered with HMPSA or with SG, usually caught more *R. pomonella* than the Pherocon traps with SG. This suggests the HMPSA was not responsible for the higher fly captures on the Alpha Scents traps, a conclusion supported by previous work on *R. indifferens* (Yee 2011). The Alpha Scents traps were 10.3% smaller than the Pherocon trap but had 20.7% greater sticky surface area. Possibly this factor interacted with yellow colors and/or fluorescence to increase captures. Interestingly, the Alpha Scents traps with concealed PLs caught more flies than Alpha Scents traps with exposed PLs. Exposed PLs possibly lost much of their ammonia early in the trapping period and then had relatively low release and suboptimal rates during the later and longer period of trapping. Another possibility is that the exposed PLs interfered visually with attraction.

Experiment 2 suggested that *R. pomonella* flies directly chose particular traps. The fact that differences in numbers caught were detected in this experiment suggests the set up successfully allowed the flies to make a choice, because there is no other apparent reason why one trap within a pair caught more flies than the other except that the flies exercised a preference. The data suggest that flies preferred Alpha Scents traps over Pherocon and Multigard traps, and Pherocon traps over Multigard traps. Unbaited Multigard traps (assumed to be the same trap as in the current study) captured only one-tenth as many *R. cerasi* as unbaited Pherocon traps (Katsoyannos et al. 2000).

In Experiment 3, *R. pomonella* seemed to choose the Alpha Scents trap over both the small and large Olson traps. The difference in size of small and large Olson traps (56.7% greater surface area) had no differential effect on fly captures. In contrast, the numbers of *R. pomonella* caught on Lemon Yellow rectangle traps increased with larger trap size (Moericke et al 1975), perhaps in part because these traps were not baited with odors.

Although trap color differences can be postulated as one cause for differential fly captures in Experiments 2 and 3, closeness in similarity of colors alone was not a reliable predictor of which trap a fly would choose. The Alpha Scents and Pherocon traps differed greatly in color (Delta E was 12.28 or 11.91), and 1.3 times more flies were caught on the Alpha Scents trap; however, colors of the Alpha Scents and Multigard traps differed less (Delta E was 3.37), but 3.1 times more flies were caught on the Alpha Scents trap. Also, the Pherocon and Multigard traps differed greatly in color (Delta E was 12.46 or 11.34), but only 1.4 times more flies were caught on the Pherocon trap. Finally, the Alpha Scents and Olson traps differed greatly in color (Delta E was 11.30), but there were only 2.2 times more flies caught on the Alpha Scents trap.

Trap fluorescence differences could affect fly captures, but in Experiments 2 and 3, closeness in fluorescence alone was also not a reliable predictor of which trap a fly would choose. For example, the Alpha Scents and Pherocon traps differed greatly in fluorescence, but only 1.3 times more flies were caught on the Alpha Scents trap. However, the Alpha Scents and Multigard traps differed less in fluorescence, but 3.1 times more flies were caught on the Alpha Scents trap.

Results suggest a combination of color and fluorescence features in the Alpha Scents trap could have contributed to its superior performance in capturing *R. pomonella*, and that the Alpha Scents trap could be an alternative to the other traps tested for monitoring this fly. This assumes traps that catch the most flies in areas with high fly populations also are the most effective at detecting very low fly populations. The Alpha Scents trap can be compared with rectangles of additional shades of yellow and a range fluorescence characteristics and also to various three-dimensional traps to provide clues to whether Alpha Scents trap is the optimal two-dimensional trap for capturing *R. pomonella*.

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