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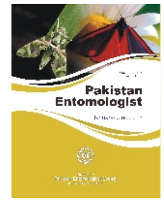

VISUAL AND OLFACTORY STIMULI AFFECTING THE RESPONSE OF *RHAGOLETIS CINGULATA* (LOEW) AND *R. FAUSTA* (OSTEN SACKEN) (DIPTERA: TEPHRITIDAE)

Jessica L. Kostarides[1] and [*]Oscar E. Liburd[2]

[1]Department of Entomology, Center for Integrated Plant Systems B-9, Michigan State University, East Lansing, MI 48824
[2]Entomology and Nematology Department, Natural Area Drive, University of Florida, Gainesville, FL 32611

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***Corresponding Author**:
Oscar E. Liburd
Email: oeliburd@ufl.edu

ABSTRACT

During 2000 and 2001, we investigated modifications of the Rebell trap to improve monitoring efficiency and to gain insights into visual and olfactory differences between *Rhagoletis cingulata* (Loew) and *R. fausta* (Osten Sacken). Additional studies were conducted to evaluate species-specific response to host fruit and foliage. Significantly more *R. cingulata* were caught on ammonium-acetate baited yellow Rebell traps, compared with other trap models tested. On an average, ammonium-acetate baited yellow Rebell traps captured 1.8, 8.6 and 18.8 times as many *R. cingulata* as the unbaited yellow Rebell (standard), baited transparent Rebell and unbaited transparent Rebell traps, respectively. The results for *R. fausta* varied from those of *R. cingulata*. There was no significant difference in the number of *R. fausta* captured on ammonium-acetate baited and unbaited yellow Rebell (standard) traps. However, both yellow Rebell traps (baited and unbaited) captured significantly more flies than transparent (baited and unbaited) Rebell traps. Overall, yellow Rebell traps (baited and unbaited) captured significantly more *R. cingulata* and *R. fausta* females than males compared with transparent traps. In experiments to investigate *R. fausta* response to host fruit and foliage, we found that traps placed in sour cherry trees, *Prunus cerasus* L., with adequate fruit and foliage attracted significantly more *R. fausta* flies compared with traps placed in trees that had fruit, but no leaves, or trees without fruit but with leaves. Our results indicate that the ammonium acetate baited yellow Rebell trap is superior to previous models including the standard unbaited yellow Rebell trap for monitoring *R. cingulata*. However, the ammonium acetate baited yellow Rebell trap has no advantage over the standard unbaited yellow Rebell for monitoring *R. fausta* populations. The results also indicate that host trees with an abundant supply of fruit and foliage provide optimum resources for *R. fausta* diurnal activities.

Keywords: *Rhagoletis cingulata, R. fausta*, flies, Rebell traps, host fruit

INTRODUCTION

The passage of the 1996 Food Quality Protection Act (FQPA) and environmental awareness have provided an impetus for producers as well as other agricultural personnel to reduce the amount of pesticide on farms throughout the United States. One of the ways to accomplish this reduction in pesticide usage is to improve monitoring protocols to detect the presence of key pests. Improved monitoring programs may allow pesticides to be used judiciously when pests are present and alternatives are not available.

The eastern cherry fruit fly, *Rhagoletis cingulata* (Loew), and black cherry fruit fly, *R. fausta* (Osten Sacken), are key late-season pests of cultivated cherries, *Prunus* spp. in the eastern and mid-western United States. Their larvae develop inside the fruit causing major tissue damage and entire shipments of cherries can be rejected if one or more maggots are found in the load (Liburd *et al.*, 2001). In order to ensure maggot-free fruit, growers generally apply broad-spectrum prophylactic insecticide sprays every 7-10 days after the flies emerge until harvest (Jubb and Cox, 1974). These insecticides are generally effective but they could potentially affect non-target organisms, particularly invertebrates, in the immediate and surrounding habitats.

Since the 1980s, cherry fruit fly IPM programs in Michigan have relied on visual and olfactory traps for monitoring the

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presence of adult cherry fruit flies in commercial orchards. Until recently, the standard trap used by most growers has been the Pherocon AM yellow board (Great Lakes IPM, Vestaburg, MI, USA) deployed in a vertical orientation (Reissig, 1976). However, Liburd *et al.* (2001) showed that an unbaited three-dimensional Rebell trap (Swiss Federal Research Station, Wadswill, Switzerland) was two times better than Pherocon AM yellow boards in detecting *R. fausta* populations in commercial fields. Unbaited Rebell traps used in their study were more selective for both eastern and black cherry fruit flies. In addition, unbaited Rebell traps captured cherry fruit flies 1-2 week earlier in the season compared with other traps evaluated.

In previous studies, Reissig (1976) found that ammonium baited yellow panel traps were more effective than unbaited yellow panels for monitoring *R. cingulata* but not *R. fausta*. Earlier, Prokopy (1975) showed that baited, yellow sticky-coated traps hung in a 45^{o} angle, were as good and more selective than vertically-hanging yellow rectangle traps for monitoring *R. cingulata* flies. In another study with the related European cherry fruit fly, *Rhagoletis cerasi* (L.), Russ *et al.* (1973) found that a three-dimensional trap was superior to the two-dimensional Pherocon AM or rectangular boards. Additional investigations found that daylight fluorescent yellow was also highly attractive to *R. cerasi*.

Rhagoletis cingulata and *R. fausta* appear to respond differently to host stimuli (Liburd *et al.,* 2001). Howitt (1993) found that *R. cingulata* prefer to forage and oviposit in sweet cherries *P. avium* (L) whereas *R. fausta* favors sour cherries *P. cerasus* L. Thornton and Liburd (1999) noted that in addition to host preferences, other habitat-associated factors including the abundance of wild hosts and rainfall affected populations of cherry fruit fly species in commercial orchards in northwestern Michigan. Among the tephritids, several factors affect oviposition and infestation levels in commercial orchards. Messina and Jones (1990) found that the ripening phenology and degree of hardness affected the oviposition rate of *R. pomonella* flies in commercial orchards. Earlier, Roitberg *et al.* (1982) and Averill *et al.* (1996) found that the presence or absence of host marking pheromones influenced *R. pomonella* decision to oviposit into apples. In blueberries, the developmental state of the fruit affected *R. mendax* Curran ability oviposit into the fruit (Liburd *et al.*, 1998).

The overall objective of present research was to study the visual and olfactory responses of *R. cingulata* and *R. fausta* using baited and unbaited Rebell traps. The goal the research was to improve monitoring efficiency and determine the effects of host characteristics on the abundance of cherry fruit flies in commercial orchards. The specific objectives were 1) to determine whether baiting Rebell traps would increase the captures of cherry fruit flies and 2) to investigate the roles of fruit and foliage in attracting cherry fruit flies to commercial orchards.

MATERIALS AND METHODS

Baited Rebell traps versus unbaited traps

Experiments to evaluate baited versus unbaited Rebell traps were conducted at the Michigan State UniversityNorthwest Horticultural Research Station (NWHRS), in Traverse City, Michigan and at an abandoned sour cherry, *P. cerasus,* orchard in southwestern Michigan. At the NWHRS, the experiment was conducted from 1 July to 25 August, 2000. In southwest Michigan, the experiment was conducted from 29 May to 2 July 2001. Each experimental site consisted of a 3-hectare block of un-sprayed cherries. The NWHRS site has a dominant residential population of *R. cingulata* flies, whereas the southwestern site has a high population of *R. fausta* (Liburd *et al.*, 2001).

Prior to deploying Rebell traps (Swiss Federal Research Station, Wadswill, Switzerland) in the field, all traps were initially washed with Histo-Clear (National Diagnostics, Atlanta, GA) to remove tangle-trap, rinsed twice with distilled water and allowed to air dry. All traps were then sprayed with a thin layer of insect tangle-trap (aerosol formula) [Tanglefoot Company, Grand Rapids, MI]. Baited traps had a green polycon dispenser (Great Lakes IPM) containing 5 g of ammonium acetate attached to the top surface of the trap. Ammonium acetate crystals were used as the lure because an appropriate host volatile attractant has not been identified. In addition, Prokopy (1975) demonstrated increased attraction of *R. cingulata* flies using ammonium acetate crystals.

The experimental design was a completely randomized block with four replicates. Traps were hung within the center of the tree canopy and spaced 20 m apart within rows and approximately 30 m between blocks. The foliage immediately (~15 cm) surrounding the traps was cleared to prevent any interference between the hung traps and the tree canopy (Drummond *et al.*, 1984). All traps were rotated on a weekly basis. Four treatments (baited yellow Rebell; unbaited yellow Rebell; unbaited transparent (lab made from plexiglas) Rebell; and baited transparent Rebell) consisting of the three-dimensional Rebell trap (Fig. 1) type were evaluated.

Fig. 1
Unbaited Rebell trap deployed within the canopy of sweet cherry trees *Prunus avium* (L).

Roles of fruit and foliage in attracting cherry fruit flies

Experiments to investigate the relationship between host plant characteristics and the abundance of black cherry fruit flies were conducted in a 1-hectare block of unsprayed cherry, *P. cerasus*, in southwestern, Michigan. The experimental design was a completely randomized block design with four replications. Experimental blocks were spaced ~ 20 m apart with four test trees per replicate (16 trees per treatment). Three treatments evaluated were: 1) cherry trees with fruit and foliage, 2) cherry trees with fruit and without foliage and 3) cherry trees without fruit and with foliage. Cherry trees without leaves and with fruit used in our study were defoliated manually prior to the start of the experiment. Our defoliation process continued on a weekly basis to ensure that there was absolutely no leaf growth. Trees with leaves and without fruit were de-fruited manually (in a similar fashion to our leaf defoliation process). An unbaited Rebell trap was hung in the center of the each test tree to monitor *R. fausta* and *R. cingulata* population. For data collection, *R. cingulata* and *R. fausta* caught on traps were counted by sex two times per week and trapped flies were removed.

Statistical analysis

Data from all experiments were square root transformed (x + 0.5) and then subjected to an analysis of variance (ANOVA). Least significant difference (LSD) test was used to determine differences in treatment means (P < 0.05) (SAS Institute, 1989). The untransformed mean values are presented in the tables and figures.

RESULTS

Performance of baited Rebell traps versus unbaited traps in 2000

In experiments to investigate the visual and olfactory responses of *R. cingulata*, significantly (F = 77.2; df = 3/9; P < 0.01) more cherry fruit flies were caught on the baited Rebell traps compared with all other traps tested (Fig. 2). Baited Rebell traps captured 1.8, 8.6 and 18.8 times as many *R. cingulata* as the unbaited Rebell, baited transparent and unbaited transparent Rebell traps, respectively (Fig. 2). The unbaited Rebell trap (standard) caught significantly more *R. cingulata* than the baited or unbaited transparent traps. On average, unbaited Rebell traps captured at least 4.9 times as many flies as any of the baited or unbaited transparent traps (Fig. 2).

During field-season of 2000, first *R. cingulata* was captured on June 30 and peak activity was recorded on July 14 (Fig. 3). After July 14, *R. cingulata* activity declined rapidly and no flies were caught after August 25 (Fig. 3). Yellow Rebell traps (baited and unbaited) captured significantly (F = 42.9; df = 1/3; P < 0.01) more *R. cingulata* females than males (Table 1). Baited and unbaited yellow Rebell traps caught 2.6 and 3.7 times as many females as males, respectively (Table 1). There were no significant differences for females or males between baited and unbaited transparent Rebell traps (Table 1).

Performance of baited Rebell traps versus unbaited traps in 2001

The responses of *R. fausta* to baited and unbaited Rebell traps differed from those observed for *R. cingulata*. There was no significant difference between baited and unbaited (standard) yellow Rebell trap captures (Fig. 4). However, these two traps (baited and unbaited yellow Rebell) captured significantly (F = 12.5; df = 3,9; P < 0.01) more flies than transparent traps (Fig. 4). On average, baited and unbaited yellow traps caught 13.8 times as many flies as transparent Rebell traps. There were no significant differences between baited and unbaited transparent traps (Fig. 4).

Rhagoletis fausta began emerging on May 24 when three flies were caught on baited Rebell traps (Fig. 5). Trap captures quickly increased and peaked within three weeks on June 14 (Fig. 5). An average of 145 and 160 flies was captured on baited and unbaited Rebell traps, respectively (Fig. 5). After June 14, *R. fausta* captures declined and no flies were captured after July 4 (Fig. 5). Both baited and unbaited yellow Rebell traps captured significantly (F = 19.2; df = 1,3; P < 0.01) more females compared with males (Table 2). There was no significant difference in the ratio of female to male captures of *R. fausta* with baited and unbaited transparent Rebell traps (Table 2).

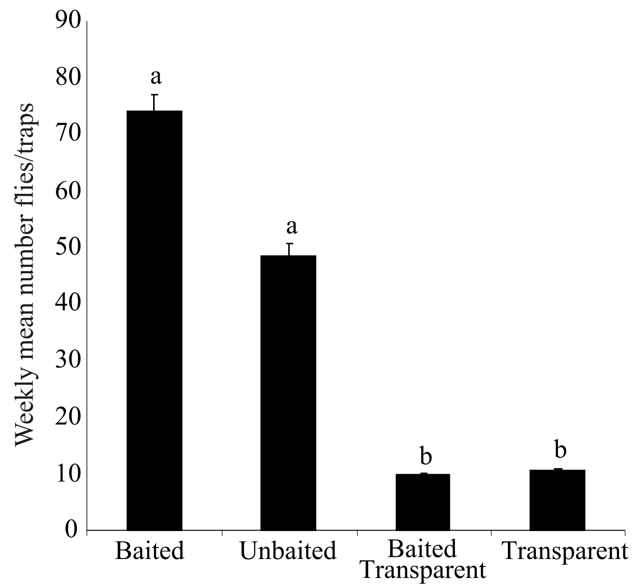

Fig. 2
Captures of *R. cingulata* 1 July 25 Aug. on modified Rebell traps in Traverse city, Michigan, 2000.

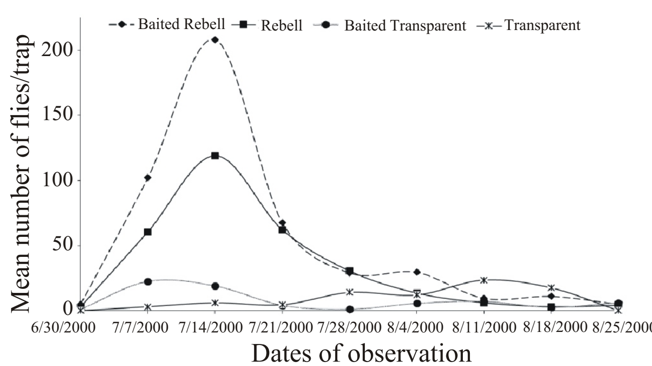

Fig. 3
Weekly capture of *Rhagoletis cingulate* on modified Rebell trap in Traverse city MI, 2000.

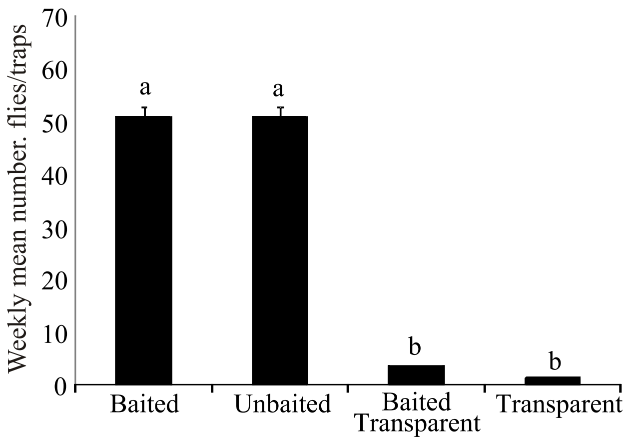

Fig. 4
Captures of *Rhagoletis fausta* 24 May 4 July on modified Rebell traps Paw Paw, MI, 2001.

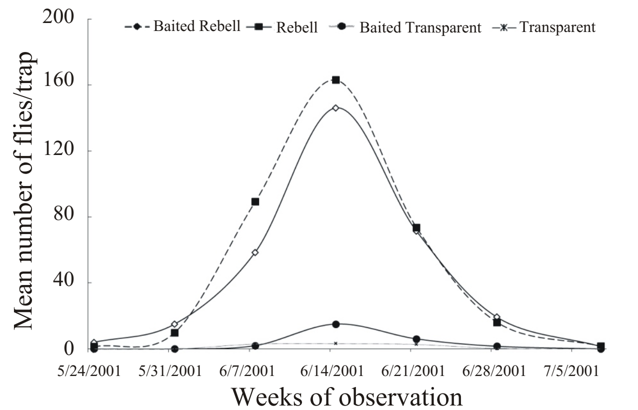

Fig. 5
Weekly capture of *Rhagoletis fausta* on modified Rebell trap in Paw Paw, MI, 2001.

Table 1
Captures of male and female *Rhagoletis cingulata* on modified Rebell traps in Traverse City, MI during 2000.

	Mean number of *Rhagoletis cingulata* captured (SEM per traps)			
	Baited Rebell	Rebell	Baited Transparent	Transparent
Male	17.6 ± 1.0b	7.8 ± 1.6b	3.2 ± 0.2a	1.8 ± 0.8a
Female	45.6 ± 4.9a	28.8 ± 4.9a	5.1 ± 1.0a	3.4 ± 1.9a

Means across rows followed by the same letter are not significantly different (P = 0.05, LSD test, [SAS Institute Inc. 2001]) for male versus female (F = 42.9; df =1, 3; P < 0.01).

Table 2
Captures of male and female *Rhagoletis fausta* on modified Rebell traps, Traverse City, MI (2001).

	Mean number of *Rhagoletis fausta* captured (SEM per traps)			
	Baited Rebell	Rebell	Baited Transparent	Transparent
Male	22.6 ± 4.0b	25.2 ± 5.4b	1.5 ± 0.6a	1.1 ± 0.6a
Female	125.8 ± 13.8a	146.8 ± 4.7a	10.3 ± 3.2a	3.5 ± 0.7a

Means within rows followed by the same letter are not significantly different (P = 0.05, LSD test, [SAS Institute Inc. 2001]) for males versus females (F = 19.2; df =1, 3; P < 0.01).

Roles of fruit and foliage in attracting cherry fruit flies

Our results show that unbaited yellow Rebell traps positioned in sour cherry trees *P. cerasus* with adequate fruit and foliage captured significantly (F = 12.0; df = 2/6; P < 0.01) more *R. fausta* compared with trees that had fruit but no leaves or trees with no fruit but with leaves (Fig. 6). Unbaited yellow Rebell monitoring traps placed within cherry trees with adequate fruit and foliage caught 1.5 and 31.5 times as many flies as traps placed in trees with fruit but no leaves and no fruit but with leaves, respectively (Fig. 6). Trap captures were also significantly (F = 16.2; df = 2/6; P < 0.01) greater for *R. fausta* in cherry trees that had fruit but no leaves compared with trees with no fruit but with leaves (Fig. 6). Unbaited yellow Rebell traps placed in sour cherry trees deprived of leaves (with an abundant fruit supply) captured 16.5 times as many *R. fausta* as traps placed in trees deprived of fruit but with leaves.

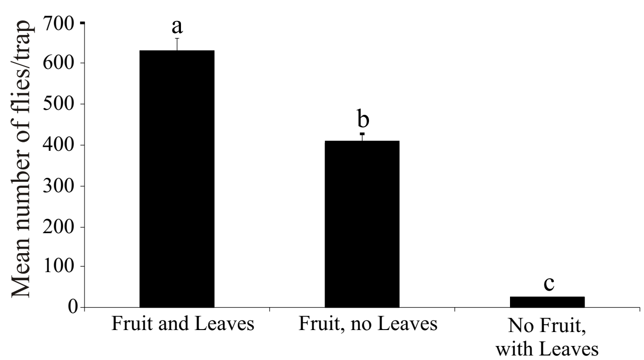

Fig. 6
Capture of cherry fruit flies effected by fruit and foliage.

DISCUSSION

Response of cherry fruit flies to Rebell traps

Our findings indicate that ammonium acetate baited yellow Rebell traps were considerably more effective in detecting the presence of *R. cingulata* compared with other modified Rebell traps evaluated in the study. A major concern regarding ammonium-baited traps is that they attract non-target organisms (Liburd *et al.,* 2000; Drummond *et al.,* 1984). Although there was low attraction of *R. cingulata* to baited transparent Rebell traps, adding a visual (yellow color) stimulus significantly increased trap captures above the standard unbaited yellow Rebell. This suggests that both visual (yellow) and olfactory (bait) stimuli are responsible for the increased attraction of *R. cingulata* to baited yellow Rebell traps. Previous work by Liburd *et al.* (2001) investigated the potential for using unbaited yellow Rebell traps for monitoring *R. cingulata* and *R. fausta* populations.

In this study, *R. fausta* responses were different from those of *R. cingulata*. Both baited and unbaited yellow Rebell traps were considerably more attractive to *R. fausta* than transparent (baited and unbaited) traps. No differences were found between baited and unbaited yellow Rebell traps, indicating that yellow color was the principal attractant for *R. fausta*. Earlier work by Reissig (1976) indicated that the relative effectiveness of different lures for monitoring *R. cingulata* and *R. fausta* varied with trap types. Yellow panel traps baited with ammonium acetate solution were found to be more effective than unbaited yellow panels for monitoring *R. cingulata* but not *R. fausta* (Reissig, 1976).

Evidence for behavioral differences between *R. cingulata* and *R. fausta* has been reported earlier by Liburd *et al.* (2001). In their studies, *R. fausta* trap captures by unbaited yellow Rebell traps were higher for several types of baited and unbaited commercial traps including Pherocon AM boards, red spheres and modified Ladd traps. When the same study was repeated with *R. cingulata*, captures on unbaited yellow Rebell traps were not significantly different to baited yellow boards or red spheres demonstrating clear behavioral differences between the species. Approximately 2.8 times as many females compared with males were caught throughout the season. We presume that more sexually mature females were caught on yellow Rebell traps because mature females are moving into commercial cherry orchards where abundant resources are available for oviposition and larval development. Sexually mature females are probably moving into commercial orchards from adjacent woodlands where wild hosts may be limited (Reynolds and Prokopy, 1997).

Response of cherry fruit flies to fruit and foliage

In studies investigating the presence and absence of fruit and leaves, we found that more flies were captured in sour cherry trees that had an abundant supply of fruit and foliage. Host fruit provides adequate resources for egg deposition and larval development for *Rhagoletis* species and leaves provide sites for feeding and shelter (Prokopy *et al.,* 1976). When both fruit and leaves are in abundant supply, they provide optimum resources for *R. fausta* diurnal activities. This was evident in our studies since host trees without fruit and with an abundant supply of leaves had significantly fewer flies on Rebell traps. Previous studies have indicated that *R. fausta* visit leaves more frequently than fruit (Prokopy *et al.,* 1976). However, our work suggests that fruit is more important than leaves, perhaps for mature *R. fausta* flies. Fruit maturity, fly maturity, temperature and rainfall can also affect the number of flies foraging in cherry orchards (Thornton and Liburd, 1999).

Our results have important implications with respect to monitoring cherry fruit fly populations. When researchers, growers and agricultural extension personnel are developing monitoring protocols for *R. cingulata* in cultivated cherries, they should consider using an ammonium acetate baited trap (until an appropriate host volatile is identified) to improve early detection of *R. cingulata*. In Michigan, ammonium-acetate baited yellow Rebell traps should be deployed in mid-June prior to *R. cingulata* emergence. However, since there is no response of *R. fausta* to baited yellow Rebell traps, growers should use the standard unbaited yellow Rebell traps for monitoring *R. fausta* populations. In Michigan, unbaited yellow Rebell traps should be deployed in cherry orchards during mid-May before *R. fausta* emerges. The number of traps to be deployed per hectare will be dependant on tree size and the amount of fruit and foliage on host plant.

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