Mortality of *Rhagoletis* Species Encountering Pesticide-Treated Spheres (Diptera: Tephritidae)

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ABSTRACT Baited pesticide-treated biodegradable spheres were evaluated for their efficacy to control and monitor apple maggot, *Rhagoletis pomonella* (Walsh), and blueberry maggot, *R. mendax* Curran, flies. A Plexiglas pane treated with sprayable Tangle-Trap was found to be an effective technique for assessing the fate of *Rhagoletis* flies encountering treated spheres. Significantly more *R. pomonella* and *R. mendax* flies were captured on Plexiglas panes below pesticide-treated spheres compared with panes below nonpesticide-treated spheres. The mean time spent on pesticide-treated spheres was also significantly longer compared with nonpesticide-treated spheres. Monitoring traps (consisting of unbaited 9-cm-diameter red sticky spheres) placed within a 2-m radius of pesticide-treated spheres captured significantly fewer flies compared with traps placed at the same distance from nonpesticide-treated spheres. The results support the potential for using pesticide-treated spheres for control of *R. pomonella* and other *Rhagoletis* species.

KEY WORDS *Rhagoletis pomonella, Rhagoletis mendax,* flies, pesticide-treated spheres

THE GENUS *RHAGOLETIS* is widely distributed over the Holarctic and Neotropical regions and it includes species that are major economic pests of fruits, including apples and blueberries (Bush 1966). A prominent characteristic of the genus is the frequent occurrence of morphologically indistinguishable species that are ecologically independent. Two important species in the genus include the apple maggot fly, *Rhagoletis pomonella* (Walsh), a major pest of apples, *Malus domestica* Borkhausen, and the blueberry maggot fly, *R. mendax* Curran, a key pest in highbush, *Vaccinium corymbosum* L., and lowbush, *V. angustifolium* Aiton, blueberries. Each fly species restricts its attack to plant species within a few closely related genera. Larvae develop inside host fruits causing major destruction of tissues, rendering the fruit unmarketable (Liburd et al. 1998a).

Federal (USDA) regulations, phytosanitary restrictions and consumer demands have resulted in a zero tolerance for maggot infested fruits, including apples and blueberries. Processing plants may reject entire shipments of fruits if only a few maggots are detected. To avert losses in areas prone to maggot infestation, growers generally apply at least 3 insecticide treatments regardless of whether flies are present (Stanley et al. 1987, Liburd et al. 1998b).

Several researchers have reported on the use of sticky traps in the management of *Rhagoletis* species (Prokopy and Coli 1978, Prokopy and Hauschild 1979, Johnson 1983, Neilson et al. 1984, Liburd et al. 1998b). However, after 2 wk of deployment both sticky boards and spheres frequently are inundated with insects, resulting in a decline in their effectiveness. The preparation, placement, and maintenance of various trapping systems is time consuming and labor intensive (Prokopy et al. 1990, Liburd 1997). Duan and Prokopy (1993) indicated that the effectiveness of **Tangle-Trap** for capturing *Rhagoletis* species in large-scale operations aimed at direct control is a major impediment to the implementation of trapping programs for control in commercial orchards. The difficulties in using sticky boards and spheres necessitate the need to seek alternative management tactics for *Rhagoletis* species.

An alternative tactic being developed for *R. pomonella* control is the deployment of nonsticky biodegradable spheres coated with a pesticide (Duan and Prokopy 1993, Duan and Prokopy 1995a, Duan and Prokopy 1995b, Hu et al. 1998). In cage studies using spheres treated with a combination of a pesticide, feeding stimulant and a residue-extending agent, Duan and Prokopy (1995a) found that dimethoate and malathion were the only insecticides tested that did not reduce fly visitation or feeding. Spheres treated with combinations of an insecticide, corn syrup, and

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latex paint were effective in killing >50% of alighting flies.

In a related study, Duan and Prokopy (1995b) compared the effectiveness of pesticide-treated spheres with conventional sticky spheres for apple maggot control. They reported that in field cage studies, a fresh baited pesticide-treated sphere was as effective as a fresh baited sticky sphere in killing released flies as well as reducing oviposition. Similarly, under field conditions, they sighted approximately equal numbers of *R. pomonella* flies visiting apple trees containing pesticide-treated spheres and sticky red spheres and found that a pesticide-treated sphere hung in a fruiting tree was as attractive to wild *R. pomonella* flies as a sticky sphere.

To date, published research using pesticide-treated spheres has been directed toward *R. pomonella.* Most of the results and conclusions from these studies have been based on visual observations and fruit injury data. The practice of tracking movement of flies visually after they have departed a particular treated sphere is time consuming and demanding (Duan and Prokopy 1995b). Growers who adopt the tactic of using pesticide-treated spheres need information on fly mortality to evaluate effectiveness of spheres.

The objective of this study was to demonstrate mortality of *R. pomonella* and *R. mendax* flies in the field after contact with pesticide-treated spheres. Our primary hypothesis was that pesticide-treated spheres baited with an appropriate lure and feeding stimulant will attract and kill *Rhagoletis* flies. In addition, fly mortality could be assessed by placing a sticky coated Plexiglas pane beneath each biodegradable sphere.

Materials and Methods

Biodegradable spheres (9 cm diameter) obtained from the United States Department of Agriculture (USDA) laboratory in Peoria, IL, were used in the apple and blueberry experiments at 4 sites in southwestern Michigan.

Biodegradable Sphere Preparation. Spheres were prepared with an extrusion process that made them hard and durable to withstand adverse weather conditions during the summer. Extruder feed consisted of a mixture of water (150 g), table sugar (360 g), high fructose corn syrup (330 g) (A. E. Staley, Decatur, IL), pregelatinized corn flour, (630 g) (designated 961 Illinois Cereal Mills, Paris, IL), cayenne pepper (14.7 g) (90,000 heat units), and sorbic acid (1.5 g) (Sigma, St. Louis, IL). The ingredients were mixed together in a KSM50P Kitchen Aid Mixer (St. Joseph, MI) and allowed to equilibrate for 4–24 h. A Brabender PL2000 (C. W. Brabender, South Hackensack, NJ) 1.9-cm laboratory extruder, with a 30:1 L:D and 3/1 compression ratio, was run at 150 rpm. Barrel temperatures were 40, 120, and 90°C. The soft extrudate was expelled through a 1-cm-diameter stainless steel pipe into an 8-cm-diameter hollow plastic sphere. The filled ball was allowed to cool for 3 min on an air cooling belt and then the ball was scored with a knife and the solidified sphere was removed. After cooling at room temperature, spheres were painted with a mixture of red enamel paint (90% wt:wt) and sugar (10% wt:wt) and placed in an oven at 90°C for ≈1 h. Each sphere weighed ≈400 g when dry.

Before field deployment, pesticide-treated spheres were brush-painted with a mixture containing 70% enamel paint, 2% (AI) imidacloprid (Provado 1.6 F [flowable], Bayer, Kansas City, MO), 20% sucrose solution (wt:vol) and 8% water (Wright et al. 1997). Spheres without pesticide were given identical treatment (70% enamel paint, 20% sucrose solution, and 10% water) without imidacloprid. Spheres were painted with red (Glidden Red Latex Gloss) or green (Shamrock green 197A111) enamel paint. The red spheres were used in both apple and blueberry experiments, and green spheres (Liburd et al. 1998a, b) were only used in blueberry experiments. The choice of pesticide, imidacloprid, was based on the positive results from laboratory assays with *R. pomonella* (Wright et al. 1997, Hu and Prokopy 1998) and the low mammalian toxicity of this chemical (Jones et al. 1998). All spheres were allowed to dry for 48 h before used in field experiments.

Apple Maggot. The effectiveness of 9-cm-diameter biodegradable red spheres treated with pesticide for control of apple maggot flies was evaluated at 2 southwest Michigan locations: The Trevor Nichols Research Complex (TNRC) and Fox Orchards. The specific objective of the experiment was to demonstrate adult mortality of *R. pomonella* flies using pesticide-treated spheres. The experimental design was a randomized block (blocked by variety) with 2 treatments replicated 5 times. The treatments were a biodegradable sphere treated with imidacloprid (2% [AI]) and an identical sphere without imidacloprid.

Biodegradable spheres were hung ≈25 m apart within tree canopies, and with 30 m between blocks of 'Red Delicious' at the TNRC (experiment 1) or Red and 'Golden Delicious' at Fox Orchard (experiment 2). An apple maggot BioLure dispenser (Consep, Bend, OR) containing the apple maggot attractant butyl hexanoate (1.8-g load rate) was stapled to a branch adjacent to each biodegradable sphere. Two methods were used to evaluate treatment effects. An innovative trapping system was designed to capture flies exposed to pesticide-treated or untreated spheres. This consisted of a horizontal Plexiglas pane (60 by 45 cm) lightly coated on the upper surface with insect Tangle-Trap aerosol formula (Tanglefoot, Grand Rapids, MI). Panes were placed ≈30 cm below each sphere and supported by 'tie' wire. At the TNRC site, an unbaited 9-cm-diameter red sphere (Great Lakes integrated pest management [IPM], Vestaburg, MI) coated with 13 g of insect Tangle-Trap (Tanglefoot) was also placed within a 2-m radius of a biodegradable sphere to monitor apple maggot densities. Sphere positions were switched every 5 d at TNRC, and 3 d at Fox Orchard. During this study, biodegradable spheres and pane traps were left in the field from 10 July to 14 August. In other field studies, we observed the activities of 54 *R. pomonella* flies visiting pesticide-treated and untreated biodegradable spheres over a 24-h period.

Blueberry Maggot. Red and green biodegradable spheres (9 cm diameter) treated with pesticide or untreated were evaluated for their effectiveness in controlling blueberry maggot flies. Both red and green spheres were included in our blueberry experiments because Liburd et al. (1998a, b) demonstrated their effectiveness for monitoring the blueberry maggot fly. Two experiments were conducted at an organic blueberry farm in Fennville, MI. Red spheres were used in experiment 3 and green spheres were used in experiment 4. Experiment 3 was located in an area with a moderate blueberry maggot population based on trap data from previous years (≈10 flies per trap captured over 2 wk). Experiment 4 was located in an area within the same blueberry plantation known to have fairly low population (<5 flies per trap captured over 2 wk) of *R. mendax* flies.

The experimental design was a randomized block (blocked by variety) with 2 treatments replicated 4 times. Treatment 1 was a 9-cm-diameter biodegradable sphere treated with imidacloprid (2% [AI]) and treatment 2 consisted of an identical sphere without imidacloprid. Spheres were hung within blueberry bushes ≈15 m apart (20 m between blocks) in plantings of 'Jersey', 'Rubel', and 'Bluecrop'. Sphere positions were switched every 4 d. A scintillation vial (National Diagnostics, Atlanta, GA) containing 1 g of ammonium acetate (Aldrich, Milwaukee, WI) dissolved in 4 ml of water was affixed (using masking tape) to a branch adjacent to each biodegradable sphere. Each vial was plugged with cotton, which became damp whenever branch movement occurred. Treatment effects were measured by placing a Plexiglas pane beneath each sphere as previously described.

Sampling. *R. pomonella* and *R. mendax* flies captured on spheres and Plexiglas panes were counted and removed twice per week, with flies sexed weekly for 5 wk. A 30-min visual observation of flies (chosen randomly) that landed on biodegradable spheres was performed weekly and direct measurements were taken between 1000 and 1500 hours of the mean time each species spent on biodegradable spheres.

Statistical Analysis. The data from biodegradable sphere experiments were analyzed by analysis of variance (ANOVA) followed by mean separation using the least significant difference (LSD) test (SAS Institute 1989).

Results

Apple Maggot. In experiments 1 and 2, *R. pomonella* flies responded in a consistent manner to pesticide-treated spheres. At the TNRC site (experiment 1), significantly ($F = 52.4$; df = 1, 4; $P < 0.01$) more *R. pomonella* flies were captured on Plexiglas panes beneath pesticide-treated spheres than on panes below spheres without pesticide (Table 1). Panes placed below pesticide-treated spheres caught ≈25 times as many flies as panes under nonpesticide-treated spheres (Table 1). The mean time (in minutes) that *R. pomonella* flies spent on pesticide-treated spheres was also significantly longer ($F = 12.7$; df = 1, 4; $P = 0.02$) than on nonpesticide-treated spheres (Table 2). On average, flies remained ≈4 times longer on pesticide-treated spheres compared with spheres without pesticide (Table 2).

Monitoring traps consisting of unbaited sticky spheres placed within a 2-m radius of pesticide-treated spheres captured significantly fewer ($F = 7.2$; df = 1, 4; $P = 0.05$) *R. pomonella* flies than unbaited sticky spheres placed at the same distance from nonpesticide-treated spheres (Fig 1). The mean number of flies caught on sticky spheres within a 2-m radius of pesticide-treated spheres was only one-third the number flies caught on sticky spheres placed within 2 m of nonpesticide-treated spheres (Fig. 1).

At the Fox Orchard site (experiment 2) the results were similar to those observed at TNRC. Significantly more ($F = 34.2$; df = 1, 4; $P < 0.01$) *R. pomonella* flies were caught on Plexiglas panes beneath pesticide-treated spheres than on panes below spheres without pesticide (Table 1). Panes placed below pesticide-treated spheres caught 17 times as many flies as those under nonpesticide-treated spheres (Table 1). Female and male response to spheres was consistent. There were no significant ($P > 0.05$) differences between sexes of *R. pomonella* flies caught on Plexiglas panes, either for pesticide-treated or nonpesticide-treated spheres (Table 3). However, significantly more fe-

Table 1. Total captures of apple maggot and blueberry maggot flies on sticky panes placed beneath biodegradable spheres in southwest Michigan

Experiment	Mean ± SEM no. flies per trap (10 July–14 Aug.)	
	Pesticide-treated spheres	Non pesticide-treated spheres
	Apple maggot	
1 TNRC Orchard	20.0 ± 3.0a	0.8 ± 0.6b
2 Fox Orchard	17.4 ± 2.6a	1.0 ± 0.5b
	Blueberry maggot	
Fennville		
3 (Red spheres)	10.8 ± 2.9a	3.0 ± 0.7b
4 (Green spheres)	4.0 ± 0.4a	0.8 ± 0.5b

Means within each experiment followed by the same letter are not significantly different ($P = 0.05$, LSD test).

Table 2. Duration (mean ± SEM) in minutes of apple maggot and blueberry maggot flies on biodegradable spheres in southwest Michigan

Spheres	Duration of flies on spheres (mean ± SEM)	
	Experiment 1 (apple maggot)	
Pesticide-treated	8.8 ± 1.9a	$n = 56$
Nonpesticide-treated	2.0 ± 0.6b	
	Experiment 3 (blueberry maggot)	
Pesticide-treated	7.4 ± 1.9a	$n = 54$
Nonpesticide-treated	1.9 ± 0.6b	

Means within each experiment followed by the same letter are not significantly different ($P = 0.05$, LSD test).

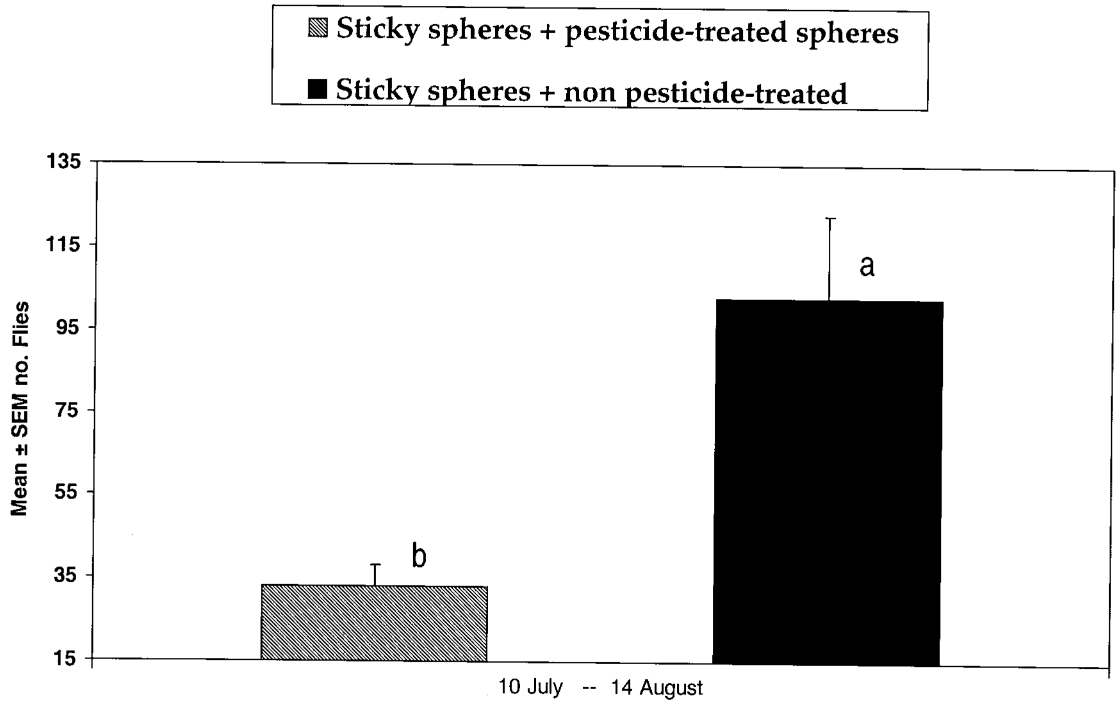

Fig. 1. Total captures of *R. pomonella* flies on sticky spheres placed within 2-m radius of biodegradable spheres in southwest Michigan.

males ($P = 0.02$) and males ($P < 0.01$) were caught on Plexiglas panes beneath pesticide-treated spheres compared with nonpesticide-treated spheres (Table 3). Throughout the trapping period we caught an average of 13.5 and 17.0 times as many females and males, respectively, on Plexiglas panes beneath pesticide-treated spheres compared with nonpesticide-treated spheres (Table 3).

In our field observation studies, 54 *R. pomonella* flies were seen landing on biodegradable spheres. Eighteen flies landed on spheres without imidacloprid, and 36 landed on spheres treated with imidacloprid. All 18 flies that landed on untreated biodegradable spheres flew away after feeding for >1 min. Twenty-five of the total 36 flies that landed on imidacloprid-treated spheres either died within a few seconds or fell to the ground and died later. Eleven (of the 36 imidacloprid-fed) flies flew away and 6 were recaptured. All 6 of the flies that were recaptured died within 24 h.

Blueberry Maggot. In the area naturally infested with a moderate *R. mendax* population (experiment 3, Table 1), sticky Plexiglas panes placed under red pesticide-treated spheres captured significantly more ($F = 10.4$; df = 1, 3; $P = 0.05$) *R. mendax* flies than panes placed under nonpesticide-treated spheres (Table 1). Plexiglas panes captured an average of 3.6 times as many *R. mendax* flies under red pesticide-treated spheres compared with nonpesticide-treated spheres (Table 1). The response of *R. mendax* females and males was similar to that observed for *R. pomonella.* There were no significant differences ($P > 0.05$) between the number of females and males caught on pane traps below treated and untreated spheres (Table 3). However, significantly more females ($P = 0.03$) and males ($P = 0.05$) were caught on panes beneath pesticide-treated spheres compared with nonpesticide-treated spheres (Table 3).

Similar results were obtained using green biodegradable spheres where *R. mendax* population was low (Table 1, experiment 4). We recorded highly significant ($P < 0.001$) differences between flies captured on Plexiglas panes beneath pesticide-treated spheres compared with panes below nonpesticide-treated spheres (Table 1). There was a 5-fold increase in fly captures on panes beneath green pesticide-treated

Table 3. Capture of male and female apple maggot and blueberry maggot flies on sticky panes placed beneath biodegradable spheres in southwest Michigan

Spheres	No. flies per trap (mean ± SEM)		
	Female	Male	
Apple maggot (Fox Orchards)			
Pesticide-treated	10.8 ± 1.6a	6.8 ± 2.2a	$n = 92$
Nonpesticide-treated	0.8 ± 0.2b	0.4 ± 2.2b	
Blueberry maggot (red spheres)			
Pesticide-treated	7.0 ± 1.6a	5.8 ± 0.9a	$n = 64$
Nonpesticide-treated	1.5 ± 0.6b	1.8 ± 0.3b	

Means within each experiment followed by the same letter are not significantly different ($P = 0.05$, LSD test).

spheres compared with nonpesticide-treated spheres (Table 1).

Response of *R. mendax* alighting on spheres was similar to those observed for *R. pomonella.* We recorded a significant difference ($F = 7.0$; df = 1, 3; $P = 0.02$) in the average time *R. mendax* flies spent on pesticide-treated spheres compared with nonpesticide-treated spheres (Table 2). The duration of time spent on pesticide-treated spheres was 3.8 times that on nonpesticide-treated spheres (Table 2). More than 60% of the flies caught on Plexiglas panes were positioned directly under pesticide-treated spheres. The few flies caught on Plexiglas panes under nonpesticide-treated spheres were randomly distributed across the panes.

Discussion

A passive trapping system was developed and successfully used to measure field mortality of *Rhagoletis* species encountering pesticide-treated spheres. This study also demonstrated the use of pesticide-treated spheres for control of *R. mendax.* Other researchers (Duan and Prokopy 1993; Duan and Prokopy 1995a, b; Hu et al. 1998) have previously documented the lethal effects of pesticide-treated spheres on *R. pomonella,* but their conclusions have been based on visual observations and differences in fruit injury between treated and untreated orchards.

Our data from Plexiglas panes strongly indicated that baited red and green biodegradable spheres coated with paint containing 2% (**AI**) imidacloprid were effective in attracting and killing *R. pomonella* and *R. mendax* flies compared with nonpesticide-treated spheres. On several occasions, flies were observed to fly from pesticide-treated spheres after having fed on them, suggesting that mortality caused by pesticide-treated spheres may have been greater than that indicated by captures on pane traps. Previous work by Wright et al. (1997) and Hu and Prokopy (1998) showed that imidacloprid causes high lethal and sublethal effects on *R. pomonella* flies after oral ingestion. In their study, flies that only consumed moderate amounts of imidacloprid frequently regurgitated, ceased feeding, and eventually succumbed to the pesticide. In this study, *R. pomonella* flies alighted on pesticide-treated spheres for an average of 8.8 ± 1.9 min, giving them ample time to have ingested a toxic dose of the insecticide. Flies that landed on pesticide-treated spheres for <5 min appeared to show signs of poisoning such as a loss of motor skills (lack of coordination and difficulty in walking). This may have been caused by the sublethal effects of imidacloprid observed by Hu and Prokopy (1998).

In our field observation studies, it is presumed that the mortality of the 6 recaptured flies was caused by the toxicity of the imidacloprid. This supports the idea that earlier-mentioned *Rhagoletis* adults that were observed feeding then flying away from pesticide-treated spheres may have died at sites away from spheres (and away from panes beneath spheres).

The effectiveness of pesticide-treated spheres was further demonstrated by the results obtained from monitoring traps (unbaited sticky spheres). The data suggest that there was suppression of *R. pomonella* flies within the vicinity of pesticide-treated spheres. The level of control within an orchard is likely to depend on the number of spheres used per hectare, frequency and duration of fly visitation, the potency of insecticide used, and the type of bait and feeding stimulant used on the traps (Reissig et al. 1985, Duan and Prokopy 1993, Duan and Prokopy 1995a). The bait used in our apple orchard study was apple maggot BioLure. The primary attractant in this bait is butyl hexanoate, which is a fruit volatile known to attract sexually mature *R. pomonella* flies within an apple orchard (Reynolds and Prokopy 1997).

Duan and Prokopy (1995b) indicated that a nearly acceptable level of control (based on data from fruit injury) was obtained with pesticide-treated wooden spheres in commercial orchards. However, in their study, a reapplication of sucrose was necessary after each rainfall to maintain sphere effectiveness. Spheres were also retreated with pesticide as the season progressed. The effectiveness of biodegradable spheres used in our study did not appear to be affected by normal rainfall or heavy dew.

Current versions of pesticide-treated spheres and pane trapping systems may lose their effectiveness during severe weather conditions. After a heavy rainstorm or wind speed in excess of 55-mph, leaf drop can interfere with effectiveness of pane traps in terms of their ability to record mortality data or to potentially monitor fly population (unpublished data). Furthermore, a severe storm that occurred during the course of our studies reduced the effectiveness of some spheres. Rain and high winds caused some of the spheres to crack and allowed for water penetration. Research focusing on the durability of biodegradable spheres is needed to improve their reliability for monitoring and controlling *Rhagolets* species.

The higher percentage (60%) of flies found on Plexiglas panes directly below pesticide-treated spheres compared with untreated spheres was probably caused by the toxic effects of imidacloprid, which may have caused flies to lose motor skills and fall directly below the sphere. This distribution on the Plexiglas was noticeably different from the uniform distribution under the nontreated spheres. Imidacloprid is a relatively new systemic nitroguanidine insecticide with relatively low mammalian toxicity (Jones et al. 1998). Our rate of application of imidacloprid was higher than field application rates. However, because fruits were not sprayed with imidacloprid, the potential risk to fruits as a result of insecticide residues was undoubtedly greatly reduced.

As a control strategy, pesticide-treated spheres would be used without Plexiglas panes. Pesticide-treated spheres offer additional advantages over conventional and contemporary systems of using insecticides, sticky yellow boards and colored spheres. For instance, insects that are killed from feeding on pesticide-treated spheres do not accumulate on spheres.

Consequently, there is no interference between the odor of decomposing insects and the odor of baits used to attract flies to pesticide-treated spheres.

Our research has led to the development of a durable biodegradable pesticide-treated sphere for controlling *Rhagoletis* flies. Furthermore, the results have shown that a sticky (lightly coated) Plexiglas pane can be used with pesticide-treated spheres to document field mortality of *Rhagoletis* flies. These results support previous studies proposing the use of biodegradable pesticide-treated spheres for the control of *R. pomonella* and further indicate that *R. mendax* may also be effectively controlled using pesticide-treated spheres.

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