Response of blueberry maggot fly (Diptera: Tephritidae) to imidacloprid-treated spheres and selected insecticides

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Abstract—Imidacloprid-treated spheres and several classes of insecticides were evaluated in field and laboratory experiments to determine their effects on *Rhagoletis mendax* Curran adult behavioural activity and larval infestation in highbush blueberries, *Vaccinium corymbosum* L. (Ericaceae). In field tests, three treatments representing an attract-and-kill system (imidacloprid-treated spheres) and two classes of insecticides, including a naturalyte spinosad (SpinTor 2 SC) and organophosphates (Imidan®/Malathion), were evaluated against an untreated control. Significantly more blueberry maggot puparia were collected from untreated (control) plots than from other treatments evaluated. There were no significant differences in larval infestation of berries collected from plots treated with imidacloprid-treated spheres, SpinTor 2 SC, and Imidan®/Malathion. Less than 1% of the berries collected from imidacloprid-treated sphere plots and SpinTor 2 SC treated plots contained blueberry maggot larvae. In toxicity and fruit-injury studies, SpinTor 2 SC as well as additional compounds from various classes were evaluated, including a botanical [azadiractin (Ecozin 3%)], a particle film [kaolin clay (Surround™ WP)], and three neonicotinoids [imidacloprid (Provado 1.6 F), thiocloprid (Calypso 480 SC), and thiamethoxam (Platinum™ 2 SC and Actara™ 25 WG)]. SpinTor 2 SC exhibited a time lag (18 h) in reducing *R. mendax* activity. Ecozin 3% and Surround™ WP were ineffective in suppressing *R. mendax* adult activity, but numbers of larvae in Surround™ WP treated fruit were significantly reduced. The effectiveness of neonicotinoid insecticides varied initially but resulted in equivalent levels of mortality after 48 h compared with our conventional organophosphate treatment of Guthion 50 WP. Oviposition scars on Provado 1.6 F treated plots were significantly more numerous than on plots treated with SpinTor 2 SC, Calypso 480 SC, Actara 25 WG, and Guthion 50 WP.

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Résumé—Des sphères traitées à l’imidaclopride et plusieurs classes d’insecticides ont été évaluées au cours d’expériences en nature et en laboratoire pour déterminer leurs effets sur le comportement des adultes de *Rhagoletis mendax* Curran et sur les infestations de larves dans les plants d’airelles en corymbe, *Vaccinium corymbosum* L. (Ericaceae). Au cours d’essais sur le terrain, trois traitements représentant un système attraction–destruction (des sphères traitées à l’imidaclopride) et deux classes d’insecticides, dont un naturalyte spinosad (SpinTor 2 SC) et des

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organophosphorés (Imidan^{MD}/Malathion), ont été évalués par comparaison à un témoin non traité. Les pupariums de la mouche des airelles ont été récoltés en nombres significativement plus grands dans les parcelles non traitées (témoins) que dans les parcelles traitées. Il n'y avait pas de différences significatives entre les parcelles où il y avait des sphères traitées à l'imidaclopride, du SpinTor 2 SC et de l'Imidan^{MD}/Malathion. Moins de 1 % des airelles récoltées dans les parcelles contenant des sphères traitées à l'imidaclopride ou dans les parcelles traitées au SpinTor 2 SC contenaient des larves de mouches. Dans les évaluations de la toxicité et des dommages aux fruits, le SpinTor 2 SC de même que d'autres composés de classes diverses ont été testés, dont un composé botanique [l'azadiractine (écozine 3 %)], un film de particules [du kaolin (Surround^{MD} WP)] et trois nicotinoïdes [l'imidaclopride (Povado 1,6 F), le thioclopride (Calypso 480 SC) et le thiométhoxam (Platinum^{MD} 2 SC et Actara^{MD} 25 WG)]. Le SpinTor 2 SC met 18 h avant de réduire l'activité de *R. mendax*. L'écozine 3 % et Surround^{MD} WP sont inefficaces contre les adultes de *R. mendax*, mais le nombre de larves dans les fruits traités au Surround^{MD} WP avait diminué considérablement. L'efficacité des insecticides néonicotinoïdes est variable au début, mais après 48 h, donne les mêmes taux de mortalité que le traitement conventionnel à un organophosphoré, le Guthion 50 WP. Les cicatrices de ponte dans les parcelles traitées au Provado 1,6 F sont significativement plus nombreuses que dans celles traitées au Spin Tor 2 SC, au Calypso 480 C, à l'Actara 25 WG et au Guthion 50 WP.

[Traduit par la Rédaction]

Introduction

Within the last decade significant progress has been made towards the development of integrated pest management (IPM) programs, including the use of traps in refining monitoring strategies for blueberry maggot, *Rhagoletis mendax* Curran (Diptera: Tephritidae) (Gaul *et al.* 1995; Liburd *et al.* 1998*a*, 1998*b*, 2000*a*; Liburd and Stelinski 1999). In the past, several applications of broad-spectrum organophosphates (OPs), primarily malathion (Aqua Malathion) and phosmet (Imidan®), have been applied for control of blueberry maggot in highbush blueberry, *Vaccinium corymbosum* L. (Ericaceae) (Liburd *et al.* 1998*b*). Such rigorous control schedules arose from consumers' demand for larvae-free fruit and export restrictions on infested berries. Broad-spectrum contact insecticides are generally effective against key pests (Liburd *et al.* 2000*b*), but they threaten nontarget organisms, particularly invertebrates in the immediate and surrounding habitats. Thus, increased public concern and environmental awareness have heightened interest in finding more environmentally benign insecticides to be used in *R. mendax* management programs.

The use of ammonium-baited, 9 cm diameter, green, insecticide-impregnated spheres may offer the greatest potential as an alternative to conventional broad-spectrum organophosphates for blueberry maggot management (Liburd *et al.* 1999; Ayyappath *et al.* 2000; Stelinski and Liburd 2001). This technology for managing *R. mendax* addresses the 1996 United States of America Food Quality Protection Act (FQPA), which discussed regulations for reducing organophosphate residues on fruits and vegetables. The value of using insecticide-treated spheres is dependent on many factors, including their ability to reduce blueberry fruit injury to levels similar to those obtained using conventional insecticide treatments. Nevertheless, until insecticide-treated sphere technology is ready for commercialization, there is a need to identify reduced-risk or environmentally safe insecticides (Hu and Prokopy 1998) that allow growers to meet the stringent zero (maggot-free) tolerance policy demanded by consumers while improving environmental safety.

Several insecticide chemistries (such as spinosad, neem, and kaolin clay) are classified as either reduced-risk or OP replacements by the United States Environmental

Protection Agency, and have shown promise for control of key pests in commercial orchards (Adan *et al.* 1996; VanRanden and Roitberg 1998; Glenn *et al.* 1999). These newer chemistries have different modes of action than conventional broad-spectrum toxicants and, in many cases, are more selective, therefore posing less threat to the environment and to nontarget organisms.

Spinosad (SpinTor 2 SC), a reduced-risk insecticide, belongs to a new class of compounds called naturalytes. Spinosad is derived from the actinomycete *Saccharopolyspora spinosa* and acts in conjunction with the neurotransmitter acetylcholine to prolong insect neural responses, which are often witnessed as twitching and paralysis (Salgado 1997). In studies to determine the effect of spinosad on the Mediterranean fruit fly, *Ceratitis capitata* Wied (Diptera: Tephritidae), Adan *et al.* (1996) found that direct applications induced mortality and reduced fecundity in adults exposed to oral treatments. Similarly, Wood and Hardin (2000) reported that in laboratory tests a small concentration (0.2 ppm) of spinosad in Solbait proved to be lethal to 50% of Mexican fruit flies *Anastrepha ludens* (Loew) (Diptera: Tephritidae) 72 h post application.

Two additional classes of reduced-risk compounds that may have potential for inclusion in blueberry IPM programs are the botanical neem-based, *Azadirachta indica* A. Juss (Meliaceae), compound Ecozin 3% and a particle film, kaolin clay (Surround™ WP). Extracts from the neem tree have been found to deter oviposition in the western cherry fruit fly, *Rhagoletis indifferens* Curran (Diptera: Tephritidae) (VanRanden and Roitberg 1998). Kaolin clay has also been found to deter oviposition in some insects (Glenn *et al.* 1999; Knight *et al.* 2000). In choice tests, Knight *et al.* (2000) found that female obliquebanded leafrollers, *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae), avoided ovipositing on leaves treated with the particle film. A similar response may be observed for other tree/bush dwelling insects such as those belonging to the genus *Rhagoletis*.

The neonicotinoids are a class of compounds showing promise against the apple maggot, *Rhagoletis pomonella* Walsh (Diptera: Tephritidae), species complex. In laboratory studies, Hu and Prokopy (1998) found that the neonicotinoid compound imidacloprid (nonreduced-risk) demonstrated high lethal and sublethal effects against apple maggot flies. Thiamethoxam and thiocloprid are two additional and relatively new neonicotinoids that have not been rigorously tested on blueberry maggot.

Bioassays to evaluate these newer compounds are necessary to understand how *R. mendax* flies respond to them and to potentially expand the range of insecticides available for management of key *Rhagoletis* species. Our objectives were to compare imidacloprid-treated spheres with reduced-risk insecticides and other OP replacements, as well as with conventional insecticides to determine sphere effectiveness in relation to insecticides. In addition, we used toxicity and fruit-injury studies to investigate the response of blueberry maggot to several classes of insecticides.

Materials and methods

Field trials

Field trials were designed to compare imidacloprid-treated spheres with SpinTor 2 SC and a conventional treatment of the organophosphates Imidan® and Malathion. Experiments were conducted at a commercial highbush blueberry planting cv Jersey located in Covert, Michigan, United States of America. Experimental design was a randomized complete block and consisted of 2-ha plots with four replicates per treatment. The treatments evaluated were (*i*) spheres treated with 2% AI Provado 1.6 F, an imidacloprid (Liburd *et al.* 1999); (*ii*) two applications (10 and 25 July 2000) of SpinTor 2 SC (Dow AgroSciences, Carmel, Indiana, United States of America) at a rate of 0.1 L formulated product/ha; (*iii*) a conventional application on 18 June of the organophosphate phosmet (Imidan®) (Gowan, Yuma, Arizona, United States of America) at a rate of 1.5 kg/ha, followed by four biweekly treatments of another organophosphate, Malathion (Gowan, Yuma, Arizona, United States of America), at a rate of 2.8 kg/ha beginning on 1 July 2000 and ending on 8 August 2000; and (*iv*) an untreated control.

Insecticide applications were made with a 3-point hitch-mounted sprayer (AgTec Crop Sprayer Model 3004) fitted with a 16-nozzle orchard head (AgTec Crop Sprayer, Minnetonka, Minnesota, United States of America). Imidacloprid-treated spheres were placed within the canopy of blueberry bushes approximately 15 cm from the uppermost branch, according to the recommendations specified by Liburd *et al.* (2000*a*). Spheres were spaced 15 m apart (every fifth bush) and baited with slow-release ammonium acetate polycon dispenser lures (Liburd *et al.* 1998*b*). Sugar–starch imidacloprid-treated spheres were prepared according to the methodology described by Liburd *et al.* (1999) and Stelinski and Liburd (2001). To monitor blueberry maggot activity, 10 baited Pherocon® AM yellow sticky traps (Great Lakes IPM, Vestaburg, Michigan, United States of America) were hung in a V-shaped orientation (Prokopy and Coli 1978) within each treatment. Traps were attached to outer blueberry bush foliage, approximately 1.5 m from ground level, and replaced every 3 weeks. Traps were sampled on 26 July, 3 August, 10 August, and 18 August 2000.

Sampling

Blueberry fruit samples (100 berries per replicate, totaling 400 berries per treatment) were randomly selected for harvest on 5 and 10 August 2000 and placed over 0.5-cm hardware cloth and left for 3 weeks suspended above vermiculite (Liburd *et al.* 1998*a*). A total of 800 berries per treatment were sampled over the two harvesting dates. The vermiculite was then sifted and the number of larvae and puparia that exited the berries were collected and recorded on a weekly basis.

Toxicity and fruit-injury studies

Bioassays were conducted at our research laboratory in the Center for Integrated Plant Systems at Michigan State University in East Lansing, Michigan, United States of America. Two different assay techniques were used for studying various responses of *R. mendax* to selected insecticides. Toxicity assays were designed to assess lethal and sublethal effects of selected insecticides on *R. mendax* encountering treated fruit and foliage, whereas fruit-injury studies were initiated to investigate the relationship between *R. mendax* oviposition behaviour and fruit (berry) infestation after exposure to field-aged insecticide residues from various classes.

Preparation of flies

Infested blueberries were collected from unsprayed farms in western Michigan during the summer of 1999 and placed on 0.5 cm mesh hardware cloth (Ace Hardware Corporation, Oak Brook, Illinois, United States of America) for 21 d over collecting trays containing vermiculite to allow maggots to exit the berries (Liburd *et al.* 1998*a*). Puparia were collected from trays twice a week during the 21-d period and maintained at 5°C for approximately 4 months. Approximately 50 d prior to the start of each bioassay, puparia were placed in 60 × 60 × 60 cm stainless steel collapsible insect cages (BioQuip, Gardena, California, United States of America) in 2 cm deep plastic containers with moist vermiculite. Puparia were maintained at 24°C and exposed to 16L:8D and 70% RH. After approximately 35 d, blueberry maggot flies began to emerge. Upon

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eclosion, newly emerged flies were provided with water and a food mixture consisting of yeast hydrolysate (enzymatic autolyzed brewers yeast) (ICN Biomedicals Inc, Costa Mesa, California, United States of America), honey, and water. All flies used in our assays were tested when they were 10 d old because they were mated and reproductively mature (Hu and Prokopy 1998; Liburd and Stelinski 1999). Just prior to the start of each assay, flies were subjected to a 60-s cold treatment (5°C) to facilitate transport into bioassay chambers.

Toxicity study

Blueberry shoots from the southern highbush *Vaccinium* spp. 'O'Neal' plants with blue (mature) and green (immature) berries were obtained from North Carolina State University, Horticultural Crops Research Station, Castle Hayne, North Carolina, United States of America. Blueberry shoots selected randomly for assays were homogeneous with respect to berry ripeness and foliage density among replicates. Treatments (described below) were applied to both fruit and foliage with a hand-atomizer until all surfaces were moist. Treated shoots containing 10 berries each were placed in transparent food containers (946 mL) with lids (SOLO CUP Company, Urbana, Illinois, United States of America) and held turgid with moistened Oasis Floral Foam (Hyacinth House Greenery, Lansing, Michigan, United States of America). These delicatessen containers served as individual bioassay chambers for our study. Holes were punctured into the lids of each container using a pushpin to allow free circulation of air in and out of bioassay chambers. Food (yeast hydrolysate and honey) and water were provided as previously described. Twenty sexually mature female (Liburd and Stelinski 1999) flies per treatment (five flies per replicate) were introduced into the bioassay chambers.

In our toxicity studies, eight treatments were evaluated: (1) SpinTor 2 SC at a rate of 100 µL in 200 mL water; (2) the neem-based insecticide Ecozin 3% (Amvac, Los Angeles, California, United States of America) at a rate of 100 µL in 130 mL water; (3) the kaolin clay Surround™ WP (Engelhard Corporation, Iselin, New Jersey, United States of America) at a rate of 6 g in 100 mL water; (4) the imidacloprid Provado 1.6 F (Bayer, Kansas City, Missouri, United States of America) at a rate of 100 µL in 160 mL water; (5) the thiocloprid Calypso 480 SC (Bayer Corp) at a rate of 100 µL in 400 mL water; (6) the thiamethoxam Platinum™ 2 SC (Novartis Crop Protection Inc, Greensboro, North Carolina, United States of America) at a rate of 100 µL in 200 mL water; (7) the azinphos-methyl Guthion 50 WP (Bayer Corp) at a rate of 1.0 g in 400 mL water; and (8) an untreated control (water). All treatments were prepared with Sun ultra fine oil surfactant (Sun Refining and Marketing Company, Philadelphia, Pennsylvania, United States of America) at 1% v/v (surfactant/water) and administered at rates equivalent to those recommended for field application by proportionate scaling of large quantity recipes. Rates of liquid-form insecticides refer to volume of formulated product.

Sampling

Rhagoletis mendax activity was recorded at 1, 2, 18, 24, and 48 h post introduction into the bioassay chamber to allow inferences regarding the level and rate of response to the various classes of insecticides. Mean fly activity was evaluated for 60 s in each of the bioassay chambers. Flies were given a score from 0 to 3 based upon average activity in each bioassay chamber. A score of 3 indicated uninhibited mobility and responsiveness to light (the status of the fly in nature). A score of 2 indicated decreased mobility (limited flying and increased sitting and grooming) and decreased responsiveness to light. A score of 1 indicated no responsiveness to light, movement stimulated only by touch, and often onset of twitching in an inverted position. A score of 0 indicated fly death. Responsiveness to light was evaluated based on fly orientation with respect to an overhead light source.

Fruit-injury study

To measure the relationship between *R. mendax* oviposition behaviour and fruit (berry) infestation post exposure to field-aged insecticide residues, we applied treatments to plots of previously unsprayed highbush blueberry 'Jersey' plants, which contained mature and immature fruit in Fennville, Michigan, United States of America. Individual plot size consisted of 13-m rows of 11 bushes arranged in a completely randomized block design with four replicates per treatment. Eight treatments were evaluated with applications made at a rate of 467 L water/ha with a Friend Airblast Sprayer (Air-O-Fan, Reedley, California, United States of America). Treatments were applied on 6 July 2000 and included (*i*) SpinTor 2 SC at a rate of 0.4 L/ha; (*ii*) Ecozin 3% at a rate of 0.7 L/ha; (*iii*) Surround™ WP at a rate of 28 kg/ha; (*iv*) Provado 1.6 F at a rate of 0.6 L/ha, (*v*) Calypso 480 SC at a rate of 0.2 L/ha; (*vi*) the thiamethoxam Actara 25 WG (Novartis Crop Protection Inc) at a rate of 0.3 L/ha; (*vii*) Guthion 50 WP at a rate of 1.7 kg/ha; and (*viii*) an untreated control. The organosilicant adjuvant Sylgard 309 (Diatect International Inc, Smith Center, Kansas, United States of America) was added to SpinTor 2 SC at a rate of 0.4 L/ha and to Ecozin 3% at a rate of 0.3 L/ha to achieve a more uniform distribution of spray droplets on blueberry bushes and fruit. Treatments were applied in a randomized complete block fashion with four replicates each.

Sprayed shoots were collected 24 h post treatment application and trimmed to provide 10 berries per replicate (40 berries per treatment). Shoots were then placed into transparent food containers (bioassay chambers) as previously described. Five sexually mature blueberry maggot flies were placed into each chamber (20 per treatment). Flies were provided with food and water as previously described and lids were punctured with a pushpin to allow airflow in and out of each bioassay chamber as previously described. All flies remained in chambers for 72 h.

Sampling

All 40 berries per treatment (10 berries per replicate) were examined for oviposition scars under a light-powered 10× magnifying lens. Later, all of the berries were dissected to measure larval infestation. Infestation was reported as the percentage of blueberries that contained blueberry maggot larvae.

Statistical analysis

Data collected from field trials and toxicity and fruit-injury studies were subjected to an ANOVA followed by mean separation with least significant difference (LSD) tests. Differences among treatments were considered significant when $P \leq 0.05$ (SAS Institute Inc 2001). Data are reported as the mean ± standard errors of the mean (SEM).

Results

Field trials

There were more blueberry maggot puparia collected from untreated control plots (3.0 ± 0.4) than from the three treated plots ($F_{3,9} = 13.7$, $P < 0.01$, $n = 400$). The three treatments gave similar results with respect to the reduction in *R. mendax* infestation levels, with 0.5 ± 0.3, 0.5 ± 0.3, and 1.0 ± 0.3% infestation for imidacloprid-treated spheres, SpinTor 2 SC, and Imidan®/Malathion, respectively. Our trapping data suggest that fly activity was very low in all of the treatments. Across sampling dates, trap counts were generally higher among control (2.8 ± 1.6) and Imidan®/Malathion plots (1.8 ± 1.6), followed by SpinTor 2 SC and imidacloprid-treated sphere plots, which had 0.8 ± 0.6 and 0.8 ± 0.9 flies, respectively.

Toxicity study

At 1 h, only the neonicotinoid treatment Platinum™ 2 SC significantly reduced *R. mendax* activity relative to the control. The results at 2 h were similar to those reported at 1 h, with the exception of Guthion 50 WP and Platinum™ 2 SC, which reduced *R. mendax* activity compared with the control ($F_{7,21}$ = 16.1, P < 0.01, n = 20; Table 1).

At 18 h, a similar degree of reduction in *R. mendax* responsiveness was recorded for treatments of SpinTor 2 SC, Provado 1.6 F, and Guthion 50 WP, whereas no significant effect was measured for the other insecticide treatments (Table 1).

At 24 h, all flies exposed to shoots treated with SpinTor 2 SC and Guthion 50 WP had died. Among the other treatments assessed, only Provado 1.6 F and Platinum™ 2 SC significantly reduced fly activity; flies in these treatments only moved when touched with a probe (Table 1).

At 48 h, the mean fly activity for most treatments was similar to that reported at 24 h, with the exception of Calypso 480 SC, which had significantly reduced *R. mendax* activity compared with the control (Table 1).

Fruit-injury study

There were more larvae (approximately 1.5 times) collected from untreated (control) than treated berries at 1 d post treatment, except for berries sprayed with Ecozin 3% ($F_{7,28}$ = 4.2, P < 0.01, n = 20; Fig. 1). There were no significant differences in larval infestation levels among the SpinTor 2 SC, Ecozin 3%, Surround™ WP, and Calypso 480 SC treatments. Infestation levels among all four treatments ranged from 1.8% for Surround™ WP to 4.4% for Ecozin 3% (Fig. 1). SpinTor 2 SC, Surround™ WP, Provado 1.6 F, and Actara 25 WG were all as effective as our standard Guthion 50 WP treatment in reducing infestation levels (Fig. 1). However, berries treated with Guthion 50 WP contained fewer maggots than Calypso 480 SC treated berries.

Oviposition scars inflicted by *R. mendax* females were more numerous for berries treated with Provado 1.6 F than berries treated with SpinTor 2 SC, Calypso 480 SC, Actara 25 WG, and Guthion 50 WP ($F_{7,28}$ = 2.0, P = 0.01, n = 20; Fig. 2). There were no significant differences in the number of oviposition scars among berries treated with Ecozin 3%, Surround™ WP, and Provado 1.6 F, and untreated berries (Fig. 2).

Discussion

Field trials

This study demonstrated that the use of imidacloprid-treated spheres or selected reduced-risk insecticides can achieve results similar to those obtained with conventional broad-spectrum organophosphates for *R. mendax* management. In our field experiments, there were no significant differences between our imidacloprid-treated spheres, reduced-risk insecticide, SpinTor 2 SC, and the conventional organophosphates Imidan®/Malathion. Infestation levels were below 0.5% in fruit collected from imidacloprid-treated spheres and SpinTor 2 SC treated plots, similar to that observed in Imidan®/Malathion treated plots (1% fruit injury); current US regulations require 0% infestation, which was

TABLE 1. Response of *Rhagoletis mendax* flies to various classes of insecticides during a 48-h observational period.

Time (h)	Naturalyte (SpinTor 2 SC)	Botanical (Ecozin 3%)	Particle film (Surround™ WP)	Neonicotinoids: Provado 1.6 F	Neonicotinoids: Calypso 480 SC	Neonicotinoids: Platinum™ 2 SC	Organophosphate (Guthion 50 WP)	Control
1	2.0±0.0*a*	2.0±0.0*a*	2.0±0.0*a*	2.0±0.0*a*	2.0±0.0*a*	1.5±0.3*b*	1.8±0.3*ab*	2.0±0.0*a*
2	2.0±0.0*a*	2.0±0.0*a*	2.0±0.0*a*	1.8±0.3*a*	2.0±0.0*a*	1.0±0.0*b*	0.8±0.3*b*	2.0±0.0*a*
18	0.5±0.3*bc*	2.0±0.0*a*	2.0±0.0*a*	0.8±0.5*bc*	1.8±0.3*a*	1.3±0.5*ab*	0.0±0.0*c*	2.0±0.0*a*
24	0.0±0.0*c*	2.0±0.0*a*	2.0±0.0*a*	0.5±0.5*b*	1.8±0.3*a*	0.3±0.3*b*	0.0±0.0*c*	2.0±0.0*a*
48	0.0±0.0*c*	2.0±0.0*a*	2.0±0.0*a*	0.3±0.3*c*	0.8±0.3*b*	0.0±0.0*c*	0.0±0.0*c*	2.0±0.0*a*

NOTE: Insecticide treatments were applied to fruit and foliage of blueberry shoots, and exposed to five sexually mature *R. mendax* females. The mean fly response was based on a scale from 0 to 3, with "0" indicating death and "3" indicating uninhibited activity. Our overall results showed a lower-than-expected activity of *R. mendax* in our control treatments (*i.e.*, none of the flies were given an activity score of 3). We presume that the refrigeration process employed to subdue flies for easier handling may have reduced their metabolic activity. Mean values across rows delineated by hourly time periods and followed by the same letter are not different (LSD test, $P > 0.05$).

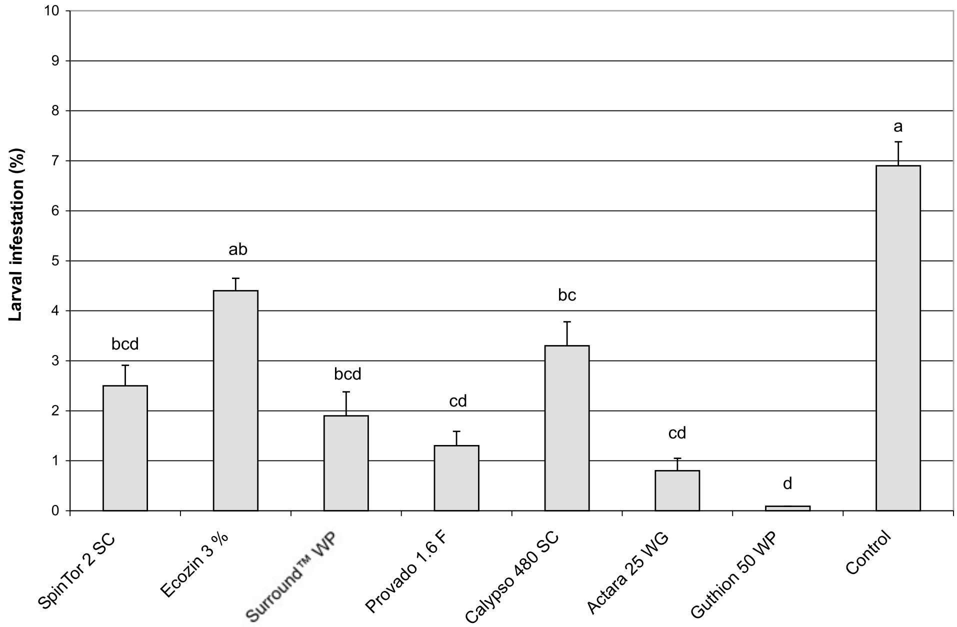

FIGURE 1. Effect of selected insecticides on larval infestation (%) of *Rhagoletis mendax* in highbush blueberries 1 d post treatment (fruit-injury study, 2000). Insecticide treatments were applied to blueberry plants in the field 24 h before samples (10 berries per shoot) were placed in individual bioassay chambers. Five sexually mature female *Rhagoletis mendax* flies were introduced into each of four treatment replicates. Fruit in each bioassay chamber were dissected for the presence of larvae. Values are means + SE. Means with the same letter are not different (LSD test, $P > 0.05$).

not achieved in any of the three treatments. In the case of SpinTor 2 SC, improved performance may be accomplished by increasing the rate or frequency of application. In addition, SpinTor recently (*i.e.*, in 2002) received registration for blueberry maggot in the United States. In plots treated with imidacloprid-treated spheres, decreasing the spacing (<15 m apart) or using stronger attractants may lower infestation levels. The effectiveness of imidacloprid-treated spheres has previously been demonstrated (Liburd *et al.* 1999; Ayyappath *et al.* 2000; Stelinski and Liburd 2001); however, these studies did not compare imidacloprid-treated spheres with reduced-risk and conventional insecticides and no studies were conducted on large blocks. One of the major problems with the sugar–starch imidacloprid-treated spheres identified by Stelinski and Liburd (2001) was their susceptibility to feeding by deer and rodents. Newer prototypes of insecticide-treated spheres, made from plastic, have a wire-protected sucrose cap to serve as a feeding stimulant and appear to be more resistant to deer and rodent feeding and may function well in a blueberry maggot IPM program. Nevertheless, the economics of using sphere or reduced-risk tactics need to be studied before such recommendations are made (Stelinski and Liburd 2001).

Toxicity and fruit-injury studies

Naturalyte

In our toxicity studies, SpinTor 2 SC was initially ineffective (1–2 h) and appeared to have no activity on flies; however, at 18 h and beyond, *R. mendax* activity was totally subdued. Flies exposed to SpinTor 2 SC may be capable of laying viable eggs up to 18 h post treatment. The lag-time between treatment and mortality explains why

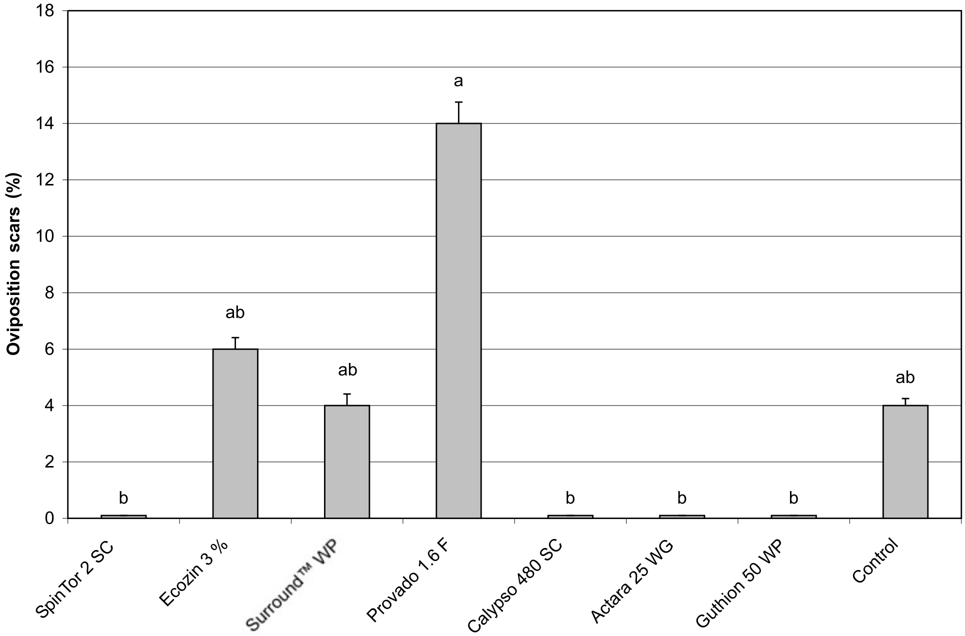

FIGURE 2. Effect of selected insecticides on ovipositional scars resulting from *Rhagoletis mendax* infestation in highbush blueberries 1 d post treatment (fruit-injury study, 2000). Insecticide treatments were applied to blueberry plants in the field 24 h before samples (10 berries per shoot) were placed in individual bioassay chambers. Five sexually mature female *Rhagoletis mendax* flies were introduced into each of four treatment replicates. Fruit in each bioassay chamber were viewed under a 10× magnifying lens to examine for oviposition scars. Values are means + SE. Means with the same letter are not different (LSD test, $P > 0.05$).

larval infestation in SpinTor 2 SC treated chambers was relatively high in our fruit-injury studies, exceeding 2%. These results suggest that applications of SpinTor 2 SC must be timed such that initial applications are made before the flies reach sexual maturity and begin laying eggs. The major concern for SpinTor 2 SC with respect to *R. mendax* management is its relatively short residual toxicity, lasting approximately 8–10 d (OE Liburd, personal observation). This drawback may necessitate frequent reapplication, and thus limit its usefulness in blueberry IPM programs. Nevertheless, the benefit of using SpinTor 2 SC is its reduced-risk impact on nontarget organisms and the potential for integration with other management tactics.

Botanical

Ecozin 3% is a neem-based insect growth regulator that interferes with the metabolism of ecdysone, thereby preventing or slowing down larval and pupal development. In our study, Ecozin 3% was ineffective in suppressing adult activity and preventing larval infestation. However, VanRanden and Roitberg (1998) found that neem-based products decrease survival of *R. indifferens* eggs, larvae, and adults. Further study is required to determine if Ecozin 3% has any value in blueberry maggot IPM programs.

Particle film

Surround™ WP did not suppress adult *R. mendax* activity, but it provided some protection from larval infestation when compared with control treatments. Flies appeared to prefer untreated (control) berries for oviposition than berries treated with

Surround™ WP (OE Liburd, personal observation). The reason for this type of response by *R. mendax* is unknown; however, Surround™ WP treated plants are known to have repellency effects on insects and may interfere with feeding and ovipositing behaviour (Glenn *et al.* 1999). Similarly, in our fruit-injury studies, larval infestation with Surround™ WP treated berries was significantly reduced compared with the control; however, infestation levels were still much higher than consumers' tolerance levels. Surround™ WP may work well in blueberry IPM programs when integrated with other management tactics. A note of concern is that the effectiveness of Surround™ WP appears to be hindered by excessive rainfall and may require additional applications (OE Liburd, personal observation).

Neonicotinoids

In the toxicity study, all three neonicotinoids were successful in suppressing normal fly activity 48 h post exposure. The activity of Platinum™ 2 SC was the most rapid, followed by Provado 1.6 F, and Calypso 480 SC. In our fruit-injury studies, both Provado 1.6 F and Actara 25 WG provided a level of protection equivalent to that of Guthion 50 WP. Berries treated with Provado 1.6 F had a high percentage of oviposition scars, whereas berries treated with Actara 25 WG and Calypso 480 SC did not. The reason for the large numbers of oviposition scars is unknown but may be linked to the lethal and sublethal effects reported by Hu and Prokopy (1998). These authors observed that mortality of *Rhagoletis pomonella* Walsh peaked 4 d post exposure to Provado 1.6 F residues, pointing to its relatively slow activity. The 24- to 48-h period between initial exposure and fly death is theoretically enough time for *R. mendax* adults to oviposit into fruit. In general, neonicotinoids produce lethal effects in insects by mimicking acetylcholine and interfering with postsynaptic nicotinergic acetylcholine receptors. This process usually results in pronounced disturbance of the nervous system, eventually causing insect death (Salgado 1997). In the case of Platinum™ 2 SC and Calypso 480 SC, the sublethal activities of the compounds appear to serve as an oviposition deterrent, as no oviposition scars were detected.

Our overall results showed a lower-than-expected activity of *R. mendax* in our control treatments (*i.e.*, none of the flies were given an activity score of 3). We presume that this decreased activity was due to the short-term (60 s) refrigeration process that we employed to subdue flies for easier handling. Cold treatment may have reduced the metabolic activity of *R. mendax* in our bioassay studies.

Our study demonstrated that equivalent levels of *R. mendax* larval suppression could be accomplished in blueberry plantings by using imidacloprid-treated spheres as well as reduced-risk insecticides instead of broad-spectrum organophosphate toxicants. The naturalyte SpinTor 2 SC has minimal effects on *R. mendax* during the first 2 h of application, but adult activity can be subdued beyond 18 h post application. The decision to include Ecozin 3% into the blueberry cropping systems to suppress *R. mendax* activity does not appear fully justified at this time. In addition, the study indicated that the use of the neonicotinoid compounds (potential OP replacements) Provado 1.6 F, Calypso 480 SC, and Actara 25 WG vary with respect to their initial effects on *R. mendax* activity, but beyond 48 h their effects are strikingly similar.

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