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The efficacy of spinosad against the western flower thrips, *Frankliniella occidentalis*, and its impact on associated biological control agents on greenhouse cucumbers in southern Ontario

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Abstract: Insecticides are the most commonly used tactic to control western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), on greenhouse cucumber. However, WFT has developed resistance to several of the insecticides presently in use. In addition, some of these insecticides adversely affect greenhouse biological control agents used to control WFT, resulting in subsequent pest resurgence. Therefore, there is a need to identify novel insecticides with unique modes of action for use in integrated pest management (IPM) programs to effectively control WFT with minimal impact on associated biological control agents. In laboratory bioassays conducted in 2001, immature and adult WFT and three associated greenhouse biological control agents: *Amblyseius cucumeris* Oudemans (Acarina: Phytoseiidae), *Orius insidiosus* Say (Hemiptera: Anthocoridae) and *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) were exposed to direct, direct/residual, and residual contact applications of the novel biopesticide, spinosad (Conserve® 120 SC), and the industry standard for whitefly control, endosulfan (Thiodan® 50 WP). In all three types of assay, spinosad was effective against immature and adult WFT life stages. It showed low toxicity to *A cucumeris,* moderate toxicity to *O insidiosus* and high toxicity to *E formosa*. Greenhouse studies involving exposure of immature and adult WFT and adult biological control agents to cucumber leaves sprayed previously with spinosad supported the laboratory data. Spinosad showed low toxicity to *A cucumeris* exposed to leaves 1 day after treatment (DAT), moderate toxicity to *O insidiosus* 1 and 8 DAT, and high toxicity to *E formosa* up to 28 DAT. These data, along with spinosad's unique mode of action, suggest it would be a valuable reduced-risk control agent for greenhouse cucumber IPM programs.
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Keywords: *Frankliniella occidentalis*; *Amblyseius cucumeris*; *Orius insidiosus*; *Encarsia formosa*; biological control agents; greenhouse; cucumbers; integrated pest management; spinosad; impact; efficacy

1 INTRODUCTION

Western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), is an economic pest of greenhouse cucumber world-wide.[1,2] It causes direct (eg scarring and deformation of fruit) and indirect (eg feeding and oviposition on leaves and flowers) damage to cucurbits, resulting in yield loss and decreased market value.[3] In addition, WFT is the major vector of tomato spotted wilt virus, a devastating polyphagous tospsvirus on tomatoes. Insecticides are commonly used to control WFT.[4] However, the pest's high reproductive potential and short generation time, and the improper use of pesticides, have resulted in the development of insecticide resistance to several major classes of chemical.[5] In addition, some of these insecticides have adverse effects, either directly (eg mortality) or indirectly (eg affecting oviposition, longevity and predation), on greenhouse biological control agents, resulting in pest resurgence in the greenhouse.[6]

Therefore, it is important to use resistance management strategies and to develop new reduced-risk insecticides with unique modes of action that can be used in integrated pest management (IPM)

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programs with minimal impact on biological control agents. Spinosad (Dow AgroSciences Canada Inc, Calgary, AB) is a macrocyclic lactone bioinsecticide that has shown promise against WFT.[7,8] It is a naturally occurring mixture of spinosyns A and D, which is produced by an actinomycete, *Saccharopolyspora spinosa* Mertz and Yao, under aerobic fermentation conditions. Spinosad has a unique mode of action and low to moderate toxicity to common greenhouse biological control agents, including *Amblyseius cucumeris* Oudemans (Acarina: Phytoseiidae) and *Orius insidiosus* Say (Hymenoptera: Aphelinidae),[8,9] suggesting it has potential in an IPM program for WFT on greenhouse cucumbers in Canada.

The objectives of this study were to determine: (1) the effectiveness of spinosad by direct, direct/residual and residual contact for control of larval and adult WFT on greenhouse cucumber leaves, and (2) the impact of spinosad on three different adult greenhouse biological control agents, *A cucumeris* and *O insidiosus* associated with WFT control on greenhouse cucumbers, and *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) used for greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) control.

2 MATERIAL AND METHODS

2.1 Insect rearing

2.1.1 Laboratory studies

In 2001, WFT was obtained from a greenhouse population at Agriculture and Agri-food Canada's Greenhouse and Processing Crops Research Center in Harrow, ON (GPCRC). The colony was reared on white and yellow pom chrysanthemums (cultivars: Surf and Yellow Favour, respectively) for the direct/residual and residual contact bioassays. The thrips were held in a growth chamber for four weeks on the rearing-host plant at 27 (±1) °C, 75% RH and 16:8 h light:dark photoperiod to ensure that they reached the adult stage. Two pots of chrysanthemums were placed in the growth chamber each week.

Orius insidiosus, an effective predatory bug, was obtained from Koppert Canada Ltd (Scarborough, ON) in 500-ml bottles of Thripor®. On arrival, they were transferred to a Tupperware® rearing container (40 × 27.5 × 14 cm) containing fresh kidney bean (*Phaseolus vulgaris* L) leaves, stems and pods. Two moistened filter paper discs (5.5 cm diameter) were covered with a thin layer of *Ephestia kuehniella* Zeller eggs (Beneficial Insectary, Oak Run, CA) to serve as a food source.

Amblyseius cucumeris, a predatory mite that attacks immature WFT stages, was obtained from Koppert Canada Ltd in packets of Thripex-plus®. The bran/egg mixture was sifted and eggs that passed through a fine mesh screen were collected on the bottom of a 9-cm Petri dish. Using a compound microscope (50× magnification), 30 eggs (0.15 mm) were removed individually using a moistened camel's hair brush and placed on the ventral surface of a kidney bean leaf. A small leaf piece (20 mm^2) was placed over the eggs for shelter. The leaf was floated, ventral surface face-up, in a 14-cm Petri dish containing distilled water to maintain high RH and to prevent the mites from leaving the leaf surface after they had hatched. The Petri dishes were incubated at 25 (±1) °C and 12:12 h light:dark photoperiod until the mites reached the nymphal stage. Then they were fed frozen first- and second-instar WFT and were transferred to a new leaf after each molt. Once adults appeared (*ca* 5–6 days after hatching) they were placed in a glass vial (1 female:1 male) without a food source for 24 h to ensure that they would be mated and starved for the laboratory bioassays.

Encarsia formosa, a parasitic wasp that attacks whitefly, was obtained from Koppert Canada Ltd on En-strip® cards. Packages of 50 cards were placed in a screened Tupperware container (14 × 27.5 × 40 cm) and the wasps were incubated at 21 (±1) °C and 45 (±5)% RH until eclosion. Whiteflies are common pests of greenhouse vegetable crops in Canada. *Encarsia formosa* was included in this study since bioinsecticides directed at WFT control also could have an impact on whitefly biological control agents.

2.1.2 Greenhouse trials

WFT used in the greenhouse trial were from the original culture. *Orius insidiosus, A cucumeris* and *E formosa* were obtained from Global Horticultural Inc (Beamsville, Ontario). WFT and the biological control agents were cultured as described in Section 2.1.1.

2.2 Insecticide treatments

2.2.1 Laboratory studies

Two formulated products were evaluated: (1) spinosad 120 g liter^{-1} SC (Conserve® 120 SC, Turf and Ornamental Insect Control, Dow AgroSciences Canada Inc, Calgary, AB) applied at the USA rate (SRR), 60 mg AI liter^{-1}; 50 ml formulation liter^{-1}, and at 75% of the recommended rate (S75RR), 45 mg AI liter^{-1}; 38 ml formulation liter^{-1}, and (2) endosulfan 500 g kg^{-1} WP (Thiodan® 50 WP, Bayer CropScience, Calgary, AB) applied at the recommended rate for whitefly control (ERR), 500 mg AI liter^{-1}; 1.0 g formulation liter^{-1}, and at 3× the recommended rate (E3xRR), 1500 mg liter^{-1}; 3.0 g formulation liter^{-1}. In Canada, endosulfan is registered for whitefly control on greenhouse cucumbers but also has some impact on WFT, and so was considered to be the industry standard for comparison, although WFT appears to be developing resistance to it. Distilled water was used as the control.

2.2.2 Greenhouse trial

Spinosad 120 g liter^{-1} SC was applied at the recommended rate of 60 mg liter^{-1}. Tap water was used as the control.

2.3 Laboratory bioassays

2.3.1 *Direct contact toxicity*

Ten to 15 immature WFT (10 replicates; $n = 145$) per treatment were exposed to an 8-ml aliquot of insecticide solution using a Potter spray tower at the GPCRC. Treated insects were transferred to an excised cucumber leaf (*Cucumis sativus* L cv Bodega) placed upside down on a piece of moistened filter paper and cotton on the bottom of a Petri dish. A screen cover was placed over the dish, which was then wrapped with Parafilm®. Cages were held at 25 (±1) °C, 75% RH and 12:12 h light:dark photoperiod and were examined at 24 h and 48 h to assess mortality. Distilled water was used as the control. This procedure also was followed using 13–15 immature (10 replicates; $n = 145$) and 10 adult WFT (10 replicates; $n = 100$) and nine *O insidiosus* (10 replicates; $n = 90$) per treatment. The latter were provided with *E kuehniella* eggs as a food source.

2.3.2 *Residual contact toxicity*

Residual contact toxicity of spinosad and endosulfan was determined using a leaf dip bioassay. The petiole of an excised cucumber leaf (*C sativus* cv Bodega) was inserted through the rubber septum of a rose vial filled with 3 ml of distilled water. Each prepared leaf was dipped for 5 s in one of the four insecticide treatments (Section 2.2) and left to dry in a fume hood for *ca* 1.5 h.

Plastic 20-dram vials with two holes (1 cm diameter) cut into their sides were used for the LD bioassays with 12 immature (15 replicates; $n = 180$) and 9–12 adult (25 replicates; $n = 240$) WFT, 10 *O insidiosus* (15 replicates; $n = 150$) and 10–14 *E formosa* (15 replicates; $n = 185$) per treatment. One hole had a cork inserted into it, the other had a piece of thrips-proof screening (BioQuip Products Inc, Gardena, CA) over it. Observation of larval WFT and *E formosa* was improved by reducing the vial length to 2.5 cm and gluing a clear piece of Plexiglass® over the cut end to seal the chamber. A moistened filter paper disk (Whatman, 42.5 mm diameter) was placed into the lid of each vial. A leaf was then placed upside down over the lid and snapped into the vial.

Using an aspirator, adult WFT or *O insidiosus* were gently blown into each vial. *Orius insidiosus* were fed *E kuehniella* eggs attached to a strip of moistened filter paper and suspended between the vial and the cork. Strips of parasitized whitefly pupae were suspended in a similar manner for *E formosa* bioassays and were removed after 24 h. All vials were held at 27 (±1) °C, 75% RH and 16:8 h light:dark photoperiod. Mortality was assessed after 24 h and 48 h.

2.3.3 *Direct/residual contact toxicity*

Direct/residual contact toxicity of spinosad and endosulfan to adult WFT, *O insidiosus* and *A cucumeris* was determined using the bioassay described in Section 2.3.1. However, instead of applying the insecticides to 10–12 immature (26 replicates; $n = 300$) and 12–15 adult (26 replicates; $n = 350$) WFT, 10 *O insidiosus* (15 replicates; $n = 150$) and 10–12 *A. cucumeris* (15 replicates; $n = 170$) per treatment and then transferring them to a clean leaf, the insects or mites and leaves were sprayed simultaneously.

2.4 Greenhouse trial

The greenhouse trial was conducted in a polyethylene covered greenhouse (7.6 × 7.6 m) at the GPCRC. Cucumbers (*C sativus* cv Bodega) were grown in rockwool slabs, using commercial production practices, until they reached full canopy. Spinosad 120 g liter^{-1} SC was applied at the recommended rate of 60 mg AI liter^{-1} (0.50 ml formulation liter^{-1}) using a low pressure/high volume carbon dioxide sprayer (R and D Sprayers Inc, Opelousas, LA) at 276 kPa, to both upper and lower leaf surfaces until runoff. Tap water was applied in a similar fashion as the control.

Plexiglass clip bioassay cages were used to confine immature and adult WFT, and adult *O insidiosus, A cucumeris* and *E formosa* to the abaxial surface of treated cucumber leaves. The clip cages were 5 cm diameter × 0.5 cm high with a 3 cm diameter hole on the bottom covered with thrips-proof screening for ventilation. The inner surface of each cage was treated with spinosad at the same rate (60 mg liter^{-1}) and time as the cucumber leaves in the greenhouse and the cages were immediately affixed to the lower leaf surface using padded fold-back clips.

Twenty to 25 WFT larvae and adults were placed in separate bioassay cages affixed to treated leaves 1, 3, 8, 15, 22, 28, 36, 43, 50 and 57 DAT. The same number of *O insidiosus* were affixed to leaves in assay cages 1 and 8 DAT; *A cucumeris* and *E formosa* 1, 8 and 28 DAT. Eight replicates were completed for treatments and control at each residual time. Mortality counts were made after 48 h.

2.5 Data collection and analysis

2.5.1 *Laboratory bioassays*

Corrections for natural mortality were made using Abbott's formula.[10] Insects were considered dead if they did not move after being touched with a probe and/or did not respond to light. Data were arcsine transformed before being subjected to an analysis of variance.[11] All mortality means were separated by a least significant difference (LSD) test[11] with actual means shown in tables. Insecticides were ranked: harmless (<25% mortality), slightly harmful (25–50% mortality), moderately harmful (51–75% mortality) and harmful (>75% mortality) according to IOBC guidelines.[9]

2.5.2 *Greenhouse trials*

Data were treated as described in Section 2.5.1. When significant differences in mortality means among residual ages were found by ANOVA, the means were separated using the Student-Newman-Kuels (SNK) multiple range test.

3 RESULTS AND DISCUSSION

3.1 Laboratory bioassays

After 24 and 48 h, both spinosad treatments were significantly more toxic to immature and adult WFT as direct (Table 1), residual (Table 2) and direct/residual (Table 3) contact applications than the endosulfan treatments. Both spinosad treatments caused >90% mortality of larval and adult WFT after 48 h in all laboratory bioassays. The toxicities of the two spinosad treatments after 24 and 48 h were not significantly different in any of the tests (Tables 1–3) with either larval or adult WFT. A previous contact toxicity study performed on WFT-infested Transvaal daisies (*Gerbera jamesonii* H Bolus ex Hook f), reported that spinosad 120 g $liter^{-1}$ SC applied at 50 mg AI $liter^{-1}$ (0.44 ml formulation $liter^{-1}$), 100 mg AI $liter^{-1}$ (0.88 ml formulation $liter^{-1}$) and 200 mg $liter^{-1}$ (1.76 ml formulation $liter^{-1}$) caused 94, 98 and 91% mortality, respectively, of adult WFT after 48 h.[12] Another study, using the same rates of spinosad on bean pods, reported that these concentrations would exceed that required to provide >90% WFT mortality in field situations.[13]

Larval and adult WFT were significantly less susceptible to endosulfan then to either of the spinosad treatments by direct (Table 1), residual (Table 2) or direct/residual (Table 3) contact. Low toxicity and the fact that there was little or no significant difference between ERR and E3xRR, suggest that this WFT population has developed a high level of resistance to endosulfan. Resistant WFT strains have undoubtedly developed due to the lack of effective alternative pesticides that can be incorporated into management programs.

When applied by direct contact, the toxicity of spinosad and endosulfan to adult *O insidiosus* ($n = 90$ per treatment) was not significantly different 24 or 48 h after treatment with exception of the 24 h E3xRR treatment, which caused significantly higher mortality than any of the other treatments (Table 1). All direct contact applications of spinosad and endosulfan were classified as slightly to moderately harmful to adult *O insidiosus* ($n = 90$ per treatment; Table 1).

Spinosad and endosulfan were ranked harmful to *O insidiosus* by direct/residual contact (Table 3). However, as a residual contact treatment, endosulfan was moderately harmful to *O insidiosus* ($n = 150$ per treatment), whereas, spinosad was ranked as harmless (Table 2). These data agree with residual studies done by Elzen *et al*,[7] Miles and Dutton[14] and Pietrantonio and Benedict,[9] who reported spinosad as harmless to *O insidiosus*. Moreover, *O insidiosus* is most active when greenhouse conditions are >25 °C and 77 kPa (ie early morning).[15] Therefore, direct contact toxicity may be minimized if spinosad is not applied under these conditions.

Based on the results of the direct/residual contact bioassay (Table 3), spinosad was ranked harmless to the predatory mite, *A cucumeris* ($n = 170$ per treatment), suggesting that it could be applied effectively in the greenhouse without harm to current or future *A cucumeris* populations. These results are similar to those of Miles and Dutton,[14] who reported no detrimental effect on *A californicus* (McGregor) exposed to spinosad residues (19.2 g AI hl^{-1}) on bean plants.

Encarsia formosa ($n = 185$ per treatment; Table 3) was very sensitive to spinosad and endosulfan by residual contact. These results agree with those reported by Miles and Dutton,[14] who measured the impact of spinosad residues by releasing wasps on the day of treatment and 7 DAT (Tracer SC 480; 9.6 and 36 g AI hl^{-1}) of whitefly-infested tomato plants. Spinosad was harmful to wasps on the day of application; however, it was only slightly harmful 7 DAT. *Encarsia formosa* is a relatively inexpensive biological control agent, so re-introduction is a viable and practical option. It would be important for growers to monitor biological control agent populations after spraying insecticides to reassess biological control programs and make decisions on necessary re-introduction rates.

Orius insidiosus and *E formosa* were negatively impacted by residual contact applications of endosulfan, with the E3xRR being significantly more toxic than the ERR (Tables 2, 3). These results clearly

Table 1. Direct contact toxicity of different rates of spinosad and endosulfan to larva and adult western flower thrips (WFT) and adults of the biological control agent, *Orius insidiosus*, on cucumbers

		Mortality (%) (±SEM)[a]					
		WFT Larvae		WFT Adults		*Orius insidiosus*	
Treatment[b]	Rate (mg $liter^{-1}$)	24 h	48 h	24 h	48 h	24 h	48 h
ERR	500	3 (±1.8) a	7 (±3.0) a	2 (±1.1) a	6 (±2.3) a	33 (±8.8) a	38 (±12.7) a
E3xRR	1500	18 (±6.0) b	13 (±3.3) a	13 (±6.2) b	14 (±3.0) b	62 (±9.6) b	63 (±8.9) a
S75RR	48	82 (±2.6) c	90 (±2.6) b	100 c	100 c	33 (±6.9) a	47 (±11.1) a
SRR	60	81 (±2.8) c	97 (±1.8) b	100 c	100 c	35 (±5.9) a	54 (±3.9) a
$P \leq 0.05$		$F_{3,36} = 106.4$	$F_{3,36} = 136.0$	$F_{3,36} = 630.6$	$F_{3,36} = 1959.0$	$F_{3,32} = 4.0$	$F_{3,32} = 1.6$

[a] Values in a column followed by the same letter were found not to be significantly different ($P \geq 0.05$, least significance difference test). Mortalities were arcsine transformed before ANOVA. Means (±SE) of untransformed data are reported.
[b] ERR and E3xRR = endosulfan at its recommended and three times its recommended rate; S75RR and SRR = spinosad at 75% and its recommended rate.

Table 2. Residual contact toxicity of different rates of spinosad and endosulfan to western flower thrips (WFT) larvae and adults, and adults of the biological control agents, *Orius insidiosus* and *Encarsia formosa*, on cucumbers

		Mortality (%) (±SEM)[a]							
		WFT Larvae		WFT Adults		*Orius insidiosus*		*Encarsia formosa*	
Treatment[b]	Rate (mg liter^{-1})	24 h	48 h	24 h	48 h	24 h	48 h	24 h	48 h
ERR	500	13 (±2.2) a	18 (±3.2) a	2 (±0.9) a	15 (±3.2) a	63 (±4.3) a	93 (±2.1) a	44 (±5.6) a	86 (±3.7) ab
E3xRR	1500	16 (±2.5) a	26 (±2.7) b	3 (±1.4) a	22 (±3.7) a	82 (±3.6) b	98 (±1.2) a	77 (±4.8) b	97 (±2.2) a
S75RR	48	100 b	100 c	100 b	100 b	5 (±1.5) c	14 (±3.9) b	51 (±5.8) a	81 (±5.9) b
SRR	60	100 b	100 c	100 b	100 b	10 (±3.6) c	23 (±5.6) b	48 (±4.1) a	95 (±2.0) a
$P \leq 0.05$		$F_{3,36} = 2341.2$	$F_{3,36} = 303.7$	$F_{3,96} = 1778.0$	$F_{3,96} = 929.1$	$F_{3,52} = 75.3$	$F_{3,52} = 153.6$	$F_{3,56} = 8.0$	$F_{3,56} = 3.8$

[a] Values in a column followed by the same letter were found not to be significantly different ($P \geq 0.05$, least significance difference test). Mortalities were arcsine transformed before ANOVA. Means (±SE) of untransformed data are reported.

[b] ERR and E3xRR = endosulfan at its recommended and three times its recommended rate; S75RR and SRR = spinosad at 75% and its recommended rate.

Table 3. Direct/residual contact toxicity of different rates of spinosad and endosulfan to western flower thrips (WFT) larvae and adults, and adults of the biological control agents, *Orius insidiosus* and *Amblyseius cucumeris,* on cucumbers

		Mortality (%) (±SEM)[a]							
		WFT Larvae		WFT Adults		*Orius insidiosus*		*Amblyseius cucumeris*	
Treatment[b]	Rate (mg liter^{-1})	24 h	48 h	24 h	48 h	24 h	48 h	24 h	48 h
ERR	500	7 (±1.9) a	15 (±3.3) a	31 (±4.8) a	32 (±5.9) a	63 (±3.1) a	65 (±2.9) a	5 (±1.6) a	10 (±2.1) a
E3xRR	1500	17 (±2.6) b	32 (±6.4) b	47 (±4.3) b	51 (±6.1) b	97 (±1.7) b	100 b	20 (±2.7) b	23 (±2.8) b
S75RR	48	99 (±0.0) c	100 c	100 c	100 c	36 (±2.7) c	97 (±1.6) b	20 (±4.4) b	25 (±5.0) b
SRR	60	98 (±1.0) c	100 c	100 c	100 c	25 (±1.6) d	100 b	14 (±5.0) ab	17 (±5.4) ab
$P \leq 0.05$		$F_{3,115} = 858.7$	$F_{3,84} = 654.1$	$F_{3,106} = 203.0$	$F_{3,88} = 157.3$	$F_{3,56} = 6.2$	$F_{3,56} = 4.1$	$F_{3,70} = 192.1$	$F_{3,63} = 142.9$

[a] Values in a column followed by the same letter were found not to be significantly different ($P \geq 0.05$, least significance difference test). Mortalities were arcsine transformed before ANOVA. Means (±SE) of untransformed data are reported.

[b] ERR and E3xRR = endosulfan at its recommended and three times its recommended rate; S75RR and SRR = spinosad at 75% and its recommended rate.

demonstrate that spinosad has potential as a safe, effective biopesticide for use in IPM programs that include a biological control component, while endosulfan can have a substantial detrimental effect. Endosulfan will not effectively control resistant WFT and it will be deleterious to the success of biological control programs.

3.2 Greenhouse bioassay

Twenty-eight-DAT spinosad residues were still highly toxic to adult WFT, causing 96% mortality (Table 4). There was no significant difference ($P > 0.05$) in toxicity to either immature or adult WFT from 1 to 28 DAT (Table 4). Residual toxicity was still evident 57 DAT, resulting in 28% mortality of immature and adult WFT. This extended period of residual activity could be related to the rate of photodegradation. When applied to field crops, spinosad is known to undergo relatively rapid photodegradation via photolysis that ultimately affects its residual toxicity.[4] The slower rate of dissipation under greenhouse conditions could be due to several variables, including greenhouse covering (eg glass or polyethylene—single or double), temperature, crop and shade provided by crop canopy. The results indicate that spinosad is an effective biopesticide for WFT control on greenhouse cucumbers for at least 28 DAT.

Spinosad was harmful (IOBC guidelines)[9] to *E formosa* up to the final day of sampling 28 DAT (Table 4). Data were not collected 15 and 22 DAT because *E formosa* was not available from the commercial supplier during this time. There was no significant difference in residual toxicity to *E formosa* for any of the sampling dates up to 28 DAT. This result indicates that growers would not be able to re-introduce/introduce *E formosa* into a greenhouse for at least 4 weeks after a spinosad treatment.

One DAT, residues of spinosad were slightly harmful (IOBC guidelines)[9] to *O insidiosus*, causing 35% mortality. Residual toxicities 1 and 8 DAT were significantly different for *O insidiosus* exposure (Table 4), and by 8 DAT had decreased to a level (17.0% mortality) considered harmless (<25% mortality) by IOBC guidelines.[9] Data were not collected 15 and 22 DAT because *O insidiosus* were not available from the commercial supplier during this time. Twenty-eight DAT spinosad residual toxicity decreased to 11.0%. Therefore, although spinosad may be slightly harmful to *O insidiosus* in a greenhouse at the time of application, greenhouse growers can safely re-introduce it beginning 8 DAT.

Amblyseius cucumeris was the most tolerant biological control agent (13.4% adult mortality 1 DAT) demonstrating that spinosad is harmless (IOBC guidelines)[9] to this predatory mite (Table 4). Eight-DAT mortality decreased significantly ($P > 0.05$) to 4.4%. These results indicate that populations of A *cucumeris* existing in a greenhouse at the time of spinosad application would not be seriously impacted. In addition, *A cucumeris* populations could be bolstered 1 DAT without threat of serious repercussion to long-term establishment.

4 CONCLUSIONS

In a cucumber IPM program, the emphasis is on preventative biological, cultural and physical control, with minimal chemical use. When chemicals are the only option, they must be used in a way to sustain their effectiveness as long as possible. Thus, it is important to apply the chemical only after an established economic threshold level of the pest has been reached. On greenhouse cucumbers this is 3.5 and 4.5 adult WFT per flower during high and low temperatures, respectively. Withholding treatment until WFT populations reach this level will limit the number of insecticide applications, control costs and reduce selection pressure.[16] Accurate timing enables the grower to achieve effective WFT control, while causing minimal harm to biological control agents. Spinosad can be applied at the recommended rate for WFT control with minimal or no harm to *A cucumeris*. In contrast, *O insidiosus* is more susceptible and should

Table 4. Persistence of biological activity of spinosad applied to cucumbers at 60 mg liter^{-1} to western flower thrips (WFT) larvae and adults, and to three biological control agents, *Amblyseius cucumeris, Orius insidiosus* and *Encarsia formosa*, exposed to 1–57-day foliage residues for 48 h under greenhouse vegetable production conditions

Days after treatment	Mortality (%) (±SEM)[a]				
	WFT larvae	WFT adults	*Amblyseius cucumeris*	*Orius insidiosus*	*Encarsia formosa*
1	100 a	100 a	13 (±2.1) a	35 (±7.7) a	100 a
3	100 a	100 a			
8	99 (±0.6) a	100 a	4 (±1.7) b	17 (±5.2) b	99 (±0.6) a
15	99 (±0.6) a	100 a			
22	98 (±1.3) a	100 a			
28	96 (±3.0) a	96 (±1.5) a		11 (±2.9) b	97 (±1.8) a
36	78 (±10.2) b	80 (±4.6) b			
43	87 (±3.7) b	78 (±9.4) b			
50	57 (±8.9) c	31 (±8.9) c			
57	28 (±7.0) c	31 (±7.0) c			

[a] Values in a column followed by the same letter were found not to be significantly different ($P \geq 0.05$, Student-Newman-Kuels multiple range test).

not be (re) introduced until at least 8 DAT. *Encarsia formosa* was susceptible to spinosad until final data collection at 28 DAT. Additional research is required to determine at what point the toxicity of spinosad decreases enough to recommended reintroduction of this biological control agent into greenhouses following the use of this control product.

Although spinosad applied in greenhouse situations appears to be more persistent than in the field, spot treatments are a viable option for isolated WFT outbreaks. This practice has proven less harmful to biological control agents,[17] resulting in less pesticide residue on the crop overall. Biological control agents can be re-introduced into the hot-spots after a re-entry period has been established for a specific pesticide, biological control agent and crop combination. It is important to use spinosad wisely and in conjunction with other control methods to slow resistance development. Rotating it and other insecticides with different modes of action will reduce selection pressure. Robb and Parrella[18] suggested rotating pesticides every four to six weeks.

Currently, spinosad is not registered for use on greenhouse vegetable crops in Canada. Registration of biopesticides, such as spinosad, is critical to the development of successful IPM programs. Spinosad's unique mode of action, high toxicity to WFT and moderate to low toxicity to *O insidiosus* and *A cucumeris*, the two biological control agents commonly used to control WFT in greenhouses, makes it an effective and reliable biopesticide for greenhouse vegetable IPM in Canada.

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