Alternative Agents for Control of European Corn Borer and Corn Flea Beetle on Sweet Corn

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ABSTRACT. Small plot field trials were conducted in 2002 and 2003 to compare European corn borer (ECB) (*Ostrinia nubilalis* Hübner) control

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using currently recommended insecticides, carbofuran (FURADAN® 480F) and lambda-cyhalothrin (MATADOR® 120EC), with spinosad (SUCCESS® 480SC) and Bt-sweet corn (ATTRIBUTE®). In both years, foliar applications of spinosad, lambda-cyhalothrin or carbofuran, or Bt-sweet corn significantly reduced the number of ECB stalk tunnels, percent damaged plants and number of damaged kernels, tunnels and larvae on ears at harvest compared to the untreated control. More marketable ears were harvested from plots treated with the insecticides and Bt-sweet corn treatments than from untreated controls. Small plot field trials also were conducted to investigate the efficacy against corn flea beetle (CFB) (*Chaetocnema pulicaria* Melsheimer) of the seed treatment insecticides, imidacloprid (GAUCHO® 480FS) and clothianidin (PONCHO® 600F).

Imidacloprid was evaluated in both 2002 and 2003, clothianidin in 2003 only. Seed treatment with either insecticide significantly reduced numbers of CFB feeding damage marks compared to untreated controls. Clothianidin provided more effective control of CFB than imidacloprid. Overall, the results demonstrated that spinosad or Bt-sweet corn provided ECB control comparable to carbofuran and lambda-cyhalothrin, while imidacloprid or clothianidin seed treatments reduced sweet corn seedling injury from CFB. [Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <<http://www.HaworthPress.com>> © 2005 by The Haworth Press, Inc. All rights reserved.]

KEYWORDS. Bt-sweet corn, carbofuran, clothianidin, corn flea beetle, European corn borer, imidacloprid, insecticides, lambda-cyhalothrin, seed treatment, spinosad, sweet corn, *Zea mays*

INTRODUCTION

Sweet corn is an important horticultural crop with an economic value exceeding \$22 million in Ontario in 2002 (OMAF, 2003). European corn borer (ECB), *Ostrinia nubilalis* (Hübner), is the most serious insect pest of sweet corn in Ontario (Hudon and LeRoux, 1986; Hudon and McLeod, 1994). While larvae attack all above ground parts of the plants the most important damage is caused by feeding on developing ears. If ECB are not controlled, yield losses can approach 10% (AGCare, 1999). The corn flea beetle (CFB), *Chaetocnema pulicaria* Melsheimer, is another sweet corn pest (Pepper, 1967). Adults feed on the leaves causing characteristic linear areas of skeletonization (Pitblado and Garland, 1994). CFB also transmits Stewart's wilt (SW), caused by the bac-

terial pathogen *Erwinia stewartii* (Smith) Dye (Pepper, 1967). When SW susceptible varieties are grown, losses can reach 40-100% in epidemic conditions (Pataky, 2003). Infected plants display stunted growth, premature tasseling and they produce unmarketable ears (Kuhar et al., 2002).

The processing and fresh market sweet corn industries currently use foliar insecticides to manage ECB. Corn borer damage potential is highest during the reproductive stages of pollen shed and silking (Spangler and Calvin, 2000). The critical time to initiate ECB control is at the late-whorl or pre-tassel growth stage, followed by weekly insecticide applications until harvest (Harrison and Press, 1971; Ferro and Fletcher-Howell, 1985). Strategies to manage Stewart's wilt include planting resistant cultivars or applying insecticides to reduce CFB populations (Pataky et al., 2000). Recently, the systemic chloronicotinyl insecticides, imidacloprid (GAUCHO® 480FS, Bayer CropSciences Inc., Calgary, AB) and clothianidin (PONCHO® 600F, Bayer CropSciences Inc., Calgary, AB) have been registered as seed treatments for CFB control in Canada.

In Ontario, the carbamate insecticide carbofuran (FURADAN® 480F, FMC Corp., Philadelphia, PA) is preferred by processors for ECB control (Oliver, 1999; McRory, 2000). It is an effective, broad-spectrum insecticide with 7-10 days of residual activity. For years, there has been argument between sweet corn processors and beekeepers regarding serious honey bee (*Apis mellifera* L.) colony mortality supposedly resulting from exposure to carbofuran. Replacing carbofuran with more selective control agents could be an effective method of reducing bee kills. Recently registered alternative ECB control agents, which may reduce risk to honey bees foraging in treated sweet corn fields, include the naturalyte spinosad (SUCCESS® 480SC, Dow AgroSciences Canada Inc., Calgary, AB) and plants genetically engineered to express the *Bacillus thuringiensis* Berliner (Bt), endotoxin, Cry1Ab (ATTRIBUTE®, Syngenta Crop Protection Canada Inc., Guelph, ON). Scott-Dupree et al. (2001) reported that foliar application of spinosad to sweet corn effectively decreased ECB damage on ears. Bt-sweet corn also has been shown to effectively control several sweet corn pests, including ECB (Burkness et al., 2001). Beekeepers also have expressed concern about the potential risk of imidacloprid or clothianidin treated crops to honey bees (Dillon, 2000; Picketts 2001; Jeschke et al., 2003).

Suitability of spinosad and Bt-sweet corn for ECB control, or of imidacloprid and clothianidin for CFB control, can be determined by investigating both their efficacy and potential risk to honey bees. We report here on the efficacy of these control agents against ECB and CFB.

MATERIALS AND METHODS

European corn borer. In 2002, conventional sweet corn cvs. Precious Gem (sugar enhanced (SE) bicolor) and Seneca Dancer (SE bicolor) were seeded at the University of Guelph Cambridge Research Station (CRS) (Cambridge, ON) on May 16 and at the Agriculture and Agri-Food Canada, Delhi Research Farm (DRF) (Delhi, ON) on May 21. Plots were seeded in 4 row blocks, 15 m long using a 4-row planter (John Deere™, St. Thomas, ON). Rows were spaced on 0.75 m centers and with 20 to 22 cm in-row plant spacing. Treatments were replicated 4 times in a randomized complete block design (RCBD). At each location a separate block of Bt-sweet corn was seeded on June 19 using the same planting parameters. Bt-sweet corn, cv. BC 0801 (SE bicolor), and untreated control plots, 'Seneca Dancer', were planted in 4 row blocks, with 4 buffer rows separating each block. Bt-sweet corn was isolated from the conventional planting in time and by space to comply with government regulations (CFIA, 2001). For conventional sweet corn trials, commercial insecticide formulations were used (Table 1). Insecticides were applied to all 4 rows of each block at the CRS using a tractor-mounted boom sprayer that delivered 944 L·ha⁻¹ at 450 kPa (#8003VS nozzle, Teejet Spraying Systems Co., Wheaton, IL). At the

TABLE 1. Application rates of insecticides tested for management of European corn borer [*Ostrinia nubilalis* (Hübner)] or corn flea beetle (*Chaetocnema pulicaria* Melsheimer) on sweet corn grown at the Cambridge Research Station and Delhi Research Farm, 2002 and 2003.

Year	Treatment	Insecticide	Formulation	Rate Applied (a.i.)
2002	foliar	spinosad	SUCCESS® 480SC	70.0 g·ha ⁻¹
		lambda-cyhalothrin	MATADOR® 120EC	10.0 g·ha ⁻¹
		carbofuran	FURADAN® 480F	530.0 g·ha ⁻¹
	seed	imidacloprid	GAUCHO® 480F	1.6 g·kg ⁻¹ seed
2003	foliar	spinosad	SUCCESS® 480SC	40.0 g·ha ⁻¹
		spinosad	SUCCESS® 480SC	70.0 g·ha ⁻¹
		lambda-cyhalothrin	MATADOR® 120EC	10.0 g·ha ⁻¹
		carbofuran	FURADAN® 480F	530.0 g·ha ⁻¹
	seed	imidacloprid	GAUCHO® 480F	2.5 g·kg ⁻¹ seed
		clothianidin	PONCHO® 600FS	1.25 mg/kernel

DRF, insecticides were applied using a H-312-P Hahn Hi-Boy® (Hahn Inc., Evansville, IN) high clearance row crop sprayer that delivered 750 L·ha⁻¹ at 450 kPa (#8008VS nozzle, Teejet Spraying Systems, Wheaton, IL). Insecticides were first applied when the crop reached the late-whorl stage. Application dates are summarized in Table 2. In 2003, conventional and Bt-sweet corns were seeded at the DRF on May 26. Planting parameters and insecticide treatments were as described for 2002, except that a lower rate of spinosad was added. In both years, stalk damage assessments were made ca. one week prior to harvest by counting number of larval tunnels per stalk on 15 plants per plot. Counts also were made on these same 15 plants to determine the percent with characteristic foliar feeding damage (“window panes” and shot holes). In both years, samples of 25 ears were taken from the center 2 rows of each plot.

ECB control was determined by examining each ear for number of damaged kernels, tunnels and larvae, and by assessing marketability, which was determined using a standard processor’s scale (Warnock and Davis, 1998), with a rating of 1-9, where only ears with ratings of = 3 were considered to be of marketable quality.

Corn flea beetle. In 2002, sweet corn (cvs. Precious Gem, Seneca Dancer) was seeded at the CRS and DRF on May 16 and 21, respectively. Plots were seeded in 4 row blocks, which were 15 m long using a 4-row planter (John Deere™). Rows were spaced on 0.75 m centers with an in-row plant spacing of 20 to 22 cm. Seeds were either untreated

TABLE 2. Application dates for spinosad, lambda-cyhalothrin and carbofuran applied for control of European corn borer [*Ostrinia nubilalis* (Hübner)] on two sweet corn cultivars grown at the Cambridge Research Station and Delhi Research Farm, 2002 and 2003.

Year	Location	Cultivar	Application Date		
			First	Second	Third ^Z
2002	Cambridge	Precious Gem	11 July	23 July	30 July
		Seneca Dancer	11 July	30 July	6 August
	Delhi	Precious Gem	11 July	20 July	27 July
		Seneca Dancer	11 July	23 July	30 July
2003	Delhi	Precious Gem	19 July	27 July	2 August
		Seneca Dancer	28 July	2 August	11 August

^Z Third application for insecticides, spinosad (70 g·ha⁻¹, a.i.) and lambda-cyhalothrin (10 g·ha⁻¹, a.i.) only.

(control) or treated with imidacloprid at $1.6 \text{ g}\cdot\text{kg}^{-1}$, a.i. of seed by Gustafson Partnership LLC (Guelph, ON). Treatments were replicated 4 times in a RCBD. Commercial seed treatment formulations were used (Table 1). In 2003, sweet corn was seeded at the DRF only, on May 26. Planting parameters and treatments were as described for 2002, except for the addition of clothianidin at $1.25 \text{ mg}/\text{kernel}$ a.i. In both years, CFB pressure was monitored using yellow sticky cards (7.5 cm wide $\times$ 13 cm long) fastened with standard binder clips to vertical 1.0 m wooden stakes. Stakes were positioned 5 and 10 m from the end of each plot in the middle of the center 2 rows, with the cards positioned 0.6 m above the ground. CFB adults were counted weekly from spike emergence to the 5-leaf growth stage (ca. 4 weeks). All cards were changed after CFB adults were counted. Capture data for each plot for all collection dates were combined. In both years, CFB damage also was assessed each week from spike emergence to the 5-leaf growth stage by counting number of CFB feeding damage marks per plant on 15 plants per plot from the center 2 rows.

Data Analyses. Data were transformed by calculating square root, with exception of the proportions that were transformed using arcsine. Statistical significance of differences among treatments was determined using either analysis of variance (ANOVA) and a Fisher's Protected LSD for mean separation, or a Student's t-test (Statistix 2.2, Tallahassee, FL). In all cases, actual rather than transformed data are presented.

RESULTS AND DISCUSSION

Increased concern of Ontario corn growers and beekeepers over the impact of insecticides used for sweet corn pest control on honey bees stimulated investigation of alternative ECB and CFB control agents.

European corn borer. In this study, insecticide applications for ECB control cannot be directly compared with the Bt-sweet corn treatment as government regulations required separate trials for the two management programs. However, when evaluating efficacy of all ECB control agents it is reasonable to refer to the untreated controls between each respective trial as indicative of level of pest pressure.

In 2002, at both CRS and DRF and for both cultivars, application of spinosad, lambda-cyhalothrin or carbofuran significantly reduced the number of ECB stalk tunnels and damaged plants compared to the untreated controls (Table 3). Additionally, at both field sites, stalk tunnels

TABLE 3. Mean number of tunnels per stalk and % damaged plants from sweet corn (cvs. Precious Gem, Seneca Dancer) treated with foliar applications of spinosad, lambda-cyhalothrin or carbofuran, or engineered to express the Bt-endotoxin, Cry1Ab (cv. BC 0801, Bt-sweet corn), for European corn borer [*Ostrinia nubilalis* (Hübner)] control, 2002.

Cultivar	Treatment	Cambridge		Delhi	
		Total tunnels/stalk ($\pm$ SEM)	% Damaged plants ($\pm$ SEM)	Total tunnels/stalk ($\pm$ SEM)	% Damaged plants ($\pm$ SEM)
Precious Gem	spinosad	0.73 $\pm$ 0.05a Z	25.00 $\pm$ 6.87a	0.42 $\pm$ 0.02a Z	26.67 $\pm$ 5.44a
	lambda-cyhalothrin	0.68 $\pm$ 0.03a	30.00 $\pm$ 7.94a	0.60 $\pm$ 0.04a	18.33 $\pm$ 5.00a
	carbofuran	0.72 $\pm$ 0.03a	23.33 $\pm$ 5.77a	0.42 $\pm$ 0.03a	36.11 $\pm$ 7.56a
	untreated control	2.73 $\pm$ 0.06b	53.33 $\pm$ 2.72b	1.27 $\pm$ 0.05b	53.33 $\pm$ 3.85b
Seneca Dancer	spinosad	0.62 $\pm$ 0.04a Y	13.33 $\pm$ 4.71a	0.18 $\pm$ 0.02a	15.00 $\pm$ 6.87a
	lambda-cyhalothrin	0.87 $\pm$ 0.05a	6.67 $\pm$ 2.72a	0.15 $\pm$ 0.02a	13.33 $\pm$ 6.09a
	carbofuran	0.60 $\pm$ 0.03a	11.67 $\pm$ 7.39a	0.28 $\pm$ 0.04a	15.00 $\pm$ 5.00a
	untreated control X	2.87 $\pm$ 0.11b	45.00 $\pm$ 5.00b	0.82 $\pm$ 0.05b	51.07 $\pm$ 5.69b
BC 0801	Bt-sweet corn	0.00 $\pm$ 0.00a W	8.33 $\pm$ 1.67a	0.03 $\pm$ 0.02a	21.67 $\pm$ 1.67a
Seneca Dancer	untreated control X	0.73 $\pm$ 0.16b	46.67 $\pm$ 6.09b	0.18 $\pm$ 0.05b	50.00 $\pm$ 1.92b

Z For comparisons of insecticide treatments for the cv. Precious Gem values in columns followed by the same letter are not significantly different, ANOVA and Fisher's Protected LSD ($P \leq 0.05$).

Y For comparisons of insecticide treatments for the cv. Seneca Dancer values in columns followed by the same letter are not significantly different, ANOVA and Fisher's Protected LSD ($P \leq 0.05$).

X Values differ due to separation in time and space of plantings.

W For comparison of 'BC 0801' to 'Seneca Dancer' values in columns followed by the same letter are not significantly different, Student's t-test ($P \leq 0.05$).

and damaged plants were significantly reduced in Bt-sweet corn compared to the untreated control (Table 3).

At both field sites and with both cultivars, application of spinosad, lambda-cyhalothrin or carbofuran significantly reduced numbers of ECB damaged kernels, tunnels and larvae on ears at harvest compared to untreated controls (Tables 4 and 5). For 'Precious Gem', at both field sites, marketability of ears harvested from all the insecticide treated plants was significantly better than that of ears from untreated controls (Tables 4 and 5). For 'Seneca Dancer' grown at CRS, marketability of ears harvested from spinosad treated plants was significantly better than ears treated with carbofuran or ears from untreated controls (Table 4); however, at DRF, marketability of ears harvested from plants treated with any of the insecticides was significantly better than that of ears from untreated controls (Table 5). With exception of 'Precious Gem' ears harvested from the untreated control at CRS in 2002, ears from all treatments in this trial, including the untreated control, were marketable (Tables 4 and 5).

At both field sites, numbers of ECB damaged kernels, tunnels and larvae on ears were significantly lower in Bt-sweet corn than in untreated conventional ears (Tables 4 and 5). Bt-sweet corn grown at both field sites also had significantly better marketability than the untreated controls; untreated conventional ears were not marketable (Tables 4 and 5).

The 2002 study showed that ECB damage in sweet corn either modified to express the Bt toxin or treated with spinosad was similar to sweet corn treated with carbofuran or lambda-cyhalothrin suggesting that registration and recommendation of these new ECB control agents should be considered. In September 2002, the Pest Management Regulatory Agency (PMRA) granted a User Request Minor Use Label Expansion (URMULE) registration of spinosad for ECB control on sweet corn (PMRA, 2003). However, both the recommended rate and number of applications approved were lower than those requested by the registrant. Spinosad efficacy at the registered rate required validation, and in 2003 we compared 2 applications at 40 g·ha⁻¹, a.i., the registered rate, with 3 applications at 70 g·ha⁻¹, a.i., evaluated in 2002.

In 2003, for both cultivars, application of spinosad, lambda-cyhalothrin or carbofuran significantly reduced the number of ECB stalk tunnels and damaged plants compared to the untreated controls (Table 6). Stalk tunnels and damaged plants also were significantly reduced in Bt-sweet corn compared to untreated controls (Table 6).

For both cultivars, application of the insecticides significantly reduced the number of ECB damaged kernels, tunnels and larvae at har-

TABLE 4. Mean number of damaged kernels, tunnels and larvae per ear, and processing marketability of ears harvested from sweet corn cultivars (cvs. Precious Gem, Seneca Dancer) treated with foliar applications of spinosad, lambda-cyhalothrin or carbofuran or engineered to express the Bt-endotoxin, Cry1Ab (cv. BC 0801, Bt-sweet corn), for European corn borer [*Ostrinia nubilalis* (Hübner)] control, Cambridge Research Station, 2002.

Cultivar	Treatment	Damaged kernels ($\pm$ SEM)	Tunnels ($\pm$ SEM)	Larvae ($\pm$ SEM)	Marketability ^V ($\pm$ SEM)
Precious Gem	spinosad	0.09 $\pm$ 0.02a ^Z	0.03 $\pm$ 0.00a	0.04 $\pm$ 0.00a	1.23 $\pm$ 0.03a
	lambda-cyhalothrin	0.30 $\pm$ 0.03a	0.01 $\pm$ 0.00a	0.10 $\pm$ 0.00a	1.47 $\pm$ 0.04ab
	carbofuran	0.77 $\pm$ 0.07a	0.06 $\pm$ 0.00a	0.17 $\pm$ 0.01a	1.89 $\pm$ 0.04b
	untreated control	2.78 $\pm$ 0.10b	0.34 $\pm$ 0.01b	0.72 $\pm$ 0.02b	3.88 $\pm$ 0.06c
Seneca Dancer	spinosad	0.22 $\pm$ 0.02a ^Y	0.04 $\pm$ 0.00a	0.05 $\pm$ 0.00a	1.32 $\pm$ 0.03a
	lambda-cyhalothrin	0.51 $\pm$ 0.02a	0.11 $\pm$ 0.00a	0.10 $\pm$ 0.00a	1.85 $\pm$ 0.04ab
	carbofuran	0.15 $\pm$ 0.01a	0.13 $\pm$ 0.00a	0.11 $\pm$ 0.00a	2.13 $\pm$ 0.05b
	untreated control ^X	1.13 $\pm$ 0.05b	0.15 $\pm$ 0.00b	0.25 $\pm$ 0.01b	2.34 $\pm$ 0.05b
BC 0801	Bt-sweet corn	0.00 $\pm$ 0.00a ^W	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.00 $\pm$ 0.00a
Seneca Dancer	untreated control ^X	2.48 $\pm$ 0.53b	0.31 $\pm$ 0.06b	0.30 $\pm$ 0.06b	3.07 $\pm$ 0.32b

^Z For comparisons of insecticide treatments for the cv. Precious Gem values in columns followed by the same letter are not significantly different. ANOVA and Fisher's Protected LSD ($P \leq 0.05$).

^Y For comparisons of insecticide treatments for the cv. Seneca Dancer values in columns followed by the same letter are not significantly different. ANOVA and Fisher's Protected LSD ($P \leq 0.05$).

^X Values differ due to separation in time and space of plantings.

^W For comparison of 'BC 0801' to 'Seneca Dancer' values in columns followed by the same letter are not significantly different. Student's t-test ($P \leq 0.05$).

^V Marketability based on a standard processor's scale with rating scale of 1-9: ears with ratings of ≤ 3 were considered marketable.

TABLE 5. Mean number of damaged kernels, tunnels and larvae per ear, and processing marketability of ears harvested from sweet corn cultivars (cvs. Precious Gem, Seneca Dancer) treated with foliar applications of spinosad, lambda-cyhalothrin or carbofuran or engineered to express the Bt-endotoxin, Cry1Ab (cv. BC 0801, Bt-sweet corn), for European corn borer [*Ostrinia nubilalis* (Hübner)] control, Delhi Research Farm, 2002.

Cultivar	Treatment	Damaged kernels ($\pm$ SEM)	Tunnels ($\pm$ SEM)	Larvae ($\pm$ SEM)	Marketability ^V ($\pm$ SEM)
Precious Gem	spinosad	0.00 $\pm$ 0.00a ^Z	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.00 $\pm$ 0.00a
	lambda-cyhalothrin	0.01 $\pm$ 0.00a	0.01 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.08 $\pm$ 0.01a
	carbofuran	0.01 $\pm$ 0.00a	0.00 $\pm$ 0.00a	0.09 $\pm$ 0.00a	1.10 $\pm$ 0.00a
	untreated control	0.97 $\pm$ 0.06b	0.16 $\pm$ 0.00b	0.28 $\pm$ 0.01b	2.23 $\pm$ 0.05b
Seneca Dancer	spinosad	0.00 $\pm$ 0.00a ^Y	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.41 $\pm$ 0.03a
	lambda-cyhalothrin	0.08 $\pm$ 0.00a	0.01 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.17 $\pm$ 0.02a
	carbofuran	0.07 $\pm$ 0.01a	0.03 $\pm$ 0.00a	0.09 $\pm$ 0.00b	1.25 $\pm$ 0.02a
	untreated control ^X	0.81 $\pm$ 0.05b	0.19 $\pm$ 0.01 ^b	0.23 $\pm$ 0.01c	2.14 $\pm$ 0.05b
BC 0801	Bt-sweet corn	0.00 $\pm$ 0.00a ^W	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.00 $\pm$ 0.00a
Seneca Dancer	untreated control ^X	6.17 $\pm$ 0.77b	0.78 $\pm$ 0.10b	0.89 $\pm$ 0.13b	5.31 $\pm$ 0.34b

^Z For comparisons of insecticide treatments for the cv. Precious Gem values in a column followed by the same letter are not significantly different, ANOVA and Fisher's Protected LSD ($P \leq 0.05$).

^Y For comparisons of insecticide treatments for the cv. Seneca Dancer values in a column followed by the same letter are not significantly different, ANOVA and Fisher's Protected LSD ($P \leq 0.05$).

^X Values differ due to separation in time and space of plantings.

^W For comparison of 'BC 0801' to 'Seneca Dancer' values in a column followed by the same letter are not significantly different, Student's t-test ($P \leq 0.05$).

^V Marketability based on a standard processor's scale with rating scale of 1-9; ears with ratings of ≤ 3 were considered marketable.

TABLE 6. Mean number of tunnels per stalk and % damaged plants from sweet corn (cvs. Precious Gem, Seneca Dancer) treated with foliar applications of spinosad, lambda-cyhalothrin or carbofuran, or engineered to express the Bt-endotoxin, Cry1Ab (cv. BC 0801, Bt-sweet corn), for European corn borer [*Ostrinia nubilalis* (Hübner)] control, Delhi Research Farm, 2003.

Cultivar	Treatment	Total tunnels/stalk ($\pm$ SEM)	% Damaged plants ($\pm$ SEM)
Precious Gem	spinosad Rate 1 ^Z	0.10 $\pm$ 0.01a ^Y	10.00 $\pm$ 1.92a
	spinosad Rate 2 ^Z	0.12 $\pm$ 0.01a	20.00 $\pm$ 10.36a
	lambda-cyhalothrin	0.15 $\pm$ 0.01a	23.33 $\pm$ 8.34a
	carbofuran	0.13 $\pm$ 0.02a	13.33 $\pm$ 6.67a
	untreated control ^W	0.35 $\pm$ 0.02b	45.00 $\pm$ 1.67b
Seneca Dancer	spinosad Rate 1	0.15 $\pm$ 0.02a ^X	15.00 $\pm$ 7.39a
	spinosad Rate 2	0.10 $\pm$ 0.01a	16.67 $\pm$ 3.33a
	lambda-cyhalothrin	0.07 $\pm$ 0.01a	16.67 $\pm$ 4.03a
	carbofuran	0.07 $\pm$ 0.01a	18.33 $\pm$ 1.67a
	untreated control ^W	0.28 $\pm$ 0.02b	40.00 $\pm$ 2.72b
BC 0801	Bt-sweet corn	0.00 $\pm$ 0.02a ^V	11.67 $\pm$ 1.67a
Precious Gem	untreated control ^W	0.30 $\pm$ 0.02c	36.67 $\pm$ 7.94b
Seneca Dancer	untreated control ^W	0.17 $\pm$ 0.02b	41.97 $\pm$ 11.98b

^Z Rate 1 = 40 g·ha⁻¹, a.i. ($\times$ 2); Rate 2 = 70 g·ha⁻¹, a.i. ($\times$ 3).

^Y For comparison of tunnels and % damage for the cv. Precious Gem values in a column followed by the same letter are not significantly different, ANOVA ($P \leq 0.05$).

^X For comparison of tunnels and % damage for the cv. Seneca Dancer values in a column followed by the same letter are not significantly different, ANOVA ($P \leq 0.05$).

^W Values differ due to separation in time and space of plantings.

^V For comparison of 'BC 0801' to cvs. Precious Gem and Seneca Dancer values in a column followed by the same letter are not significantly different, Student's t-test ($P \leq 0.05$).

vest compared to the untreated controls (Table 7). Marketability of ears harvested from all insecticide treated plots was significantly better than those from untreated controls (Table 7). Sweet corn from all treatments and controls in this trial was of marketable quality, with exception of controls harvested from 'Seneca Dancer' (Table 7).

No significant difference in ECB damage was found between the low (40 g·ha⁻¹, a.i.) and high (70 g·ha⁻¹, a.i.) application rates of spinosad with either cultivar. The low rate registered for use effectively controlled corn borer on sweet corn under the conditions encountered in 2003 (Tables 6 and 7). However, it is important to point out that ECB pressure was relatively low in 2003.

TABLE 7. Mean number of damaged kernels, tunnels and larvae per ear, and processing marketability of ears harvested from sweet corn cultivars (cvs. Precious Gem, Seneca Dancer) treated with foliar applications of spinosad, lambda-cyhalothrin or carbofuran or engineered to express the Bt-endotoxin, Cry1Ab (cv. BC 0801, Bt-sweet corn), for European corn borer [*Ostrinia nubilalis* (Hübner)] control, Delhi Research Farm, 2003.

Cultivar	Treatment	Damaged kernels ($\pm$ SEM)	Tunnels ($\pm$ SEM)	Larvae ($\pm$ SEM)	Marketability U ($\pm$ SEM)
Precious Gem	spinosad Rate 1 Z	0.04 $\pm$ 0.00a Y	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.07 $\pm$ 0.00ab
	spinosad Rate 2 Z	0.01 $\pm$ 0.00a	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.07 $\pm$ 0.01ab
	lambda-cyhalothrin	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.02 $\pm$ 0.00a
	carbofuran	0.20 $\pm$ 0.02a	0.02 $\pm$ 0.00a	0.14 $\pm$ 0.00b	1.36 $\pm$ 0.02b
	untreated control W	0.68 $\pm$ 0.05b	0.22 $\pm$ 0.01b	0.46 $\pm$ 0.03c	2.27 $\pm$ 0.05c
Seneca Dancer	spinosad Rate 1 Z	0.53 $\pm$ 0.05a X	0.00 $\pm$ 0.00a	0.07 $\pm$ 0.00a	1.41 $\pm$ 0.03a
	spinosad Rate 2 Z	0.14 $\pm$ 0.02a	0.00 $\pm$ 0.00a	0.01 $\pm$ 0.00a	1.10 $\pm$ 0.01a
	lambda-cyhalothrin	0.12 $\pm$ 0.01a	0.01 $\pm$ 0.10a	0.01 $\pm$ 0.00a	1.26 $\pm$ 0.02a
	carbofuran	0.32 $\pm$ 0.03a	0.03 $\pm$ 0.00a	0.07 $\pm$ 0.00a	1.44 $\pm$ 0.03a
	untreated control W	2.79 $\pm$ 0.11b	0.18 $\pm$ 0.01b	0.36 $\pm$ 0.01b	3.30 $\pm$ 0.06b
BC 0801	Bt-sweet corn	0.03 $\pm$ 0.00a V	0.01 $\pm$ 0.00a	0.00 $\pm$ 0.00a	1.10 $\pm$ 0.01a
Precious Gem	untreated control W	0.72 $\pm$ 0.05b	0.11 $\pm$ 0.00b	0.13 $\pm$ 0.00b	2.03 $\pm$ 0.05b
Seneca Dancer	untreated control W	1.64 $\pm$ 0.08c	0.11 $\pm$ 0.00b	0.29 $\pm$ 0.01c	2.62 $\pm$ 0.05c

Z Rate 1 = 40 g·ha⁻¹, a.i. ($\times$ 2); Rate 2 = 70 g·ha⁻¹, a.i. ($\times$ 3).

Y For comparisons of insecticide treatments for the cv. Precious Gem values in a column followed by the same letter are not significantly different, ANOVA ($P \leq 0.05$).

X For comparisons of insecticide treatments for the cv. Seneca Dancer values in a column followed by the same letter are not significantly different, ANOVA ($P \leq 0.05$).

W Values differ due to separation in time and space of plantings.

V For comparison of 'BC 0801' to cvs. Precious Gem and Seneca Dancer values in a column followed by the same letter are not significantly different, Student's t-test ($P \leq 0.05$).

U Marketability based on a standard processor's scale with rating of 1-9; ears with ratings of ≤ 3 were considered marketable.

Numbers of ECB damaged kernels, tunnels and larvae at harvest were significantly lower for Bt-sweet corn compared to the controls (Table 7). While, Bt sweet corn also had significantly better marketability than the controls, corn from all treatments was of marketable quality (Table 7).

Results from both 2002 and 2003 showed that control of ECB damage by application of spinosad to cvs. Precious Gem or Seneca Dancer, or by Bt-sweet corn was equivalent to that provided by carbofuran or lambda-cyhalothrin, the current industry standards.

Corn flea beetle. Adams and Los (1986) reported the most effective way to capture CFB was using yellow sticky cards placed close (0.6 m) to the ground. Kuhar et al. (2002) found that unbaited yellow sticky cards placed in untreated sweet corn fields captured an average of 29.1 CFB per card per week. In 2002, sticky card captures either untreated or treated plots (Table 8). At both field sites, there were no significant differences in the number of CFB captured in either untreated or treated plots (Table 8).

In 2003 field trials at DRF, sticky cards counts indicated that CFB populations were again very low. For both sweet corn cultivars, no significant differences were found between CFB numbers captured in either untreated or treated plots (Table 8).

Despite low CFB populations, in both years, typical damage marks were identified on both cultivars indicating that adults were actively feeding in the plots immediately following emergence. In 2002, at both CRS and DRF and for both cultivars, seeds treated with imidacloprid significantly reduced the number of CFB feeding marks 7, 14 and 21 d after emergence compared to the controls (Figures 1A,B,C,D).

In 2003, for 'Precious Gem', seed treated with clothianidin or imidacloprid significantly reduced numbers of CFB damage marks compared to controls every time CFB damage was estimated (Figure 2A). In addition, significantly fewer feeding marks were recorded on clothianidin seed treated plants compared to those treated with imidacloprid 7 and 21 d after emergence (Figure 2A).

In 2003, seed treated with clothianidin significantly reduced numbers of CFB damage marks on 'Seneca Dancer' for each of the 4 damage estimates compared to the control (Figure 2B), while seed treated with imidacloprid significantly reduced numbers of damage marks at 7, 14 and 21 d after emergence compared to controls (Figure 2B). In addition, on each of the 4 damage estimates, significantly fewer damage marks were recorded on plants from clothianidin treated seed, than on plants from seed treated with imidacloprid (Figure 2B).

TABLE 8. Mean number of corn flea beetles (*Chaetocnema pulicaria* Melsheimer) (CFB) captured on yellow sticky cards in plots of sweet corn grown from untreated and imidacloprid or clothianidin treated seed (cvs. Precious Gem, Seneca Dancer), 2002 and 2003.

Cultivar	Treatment	Mean number of CFB/sticky card ($\pm$ SEM)	
		Cambridge	Delhi
2002			
Precious Gem	imidacloprid	0.56 $\pm$ 0.25a ^Z	0.43 $\pm$ 0.26a ^X
	untreated control	0.37 $\pm$ 0.18a	0.25 $\pm$ 0.14a
Seneca Dancer	imidacloprid	0.44 $\pm$ 0.16a	0.13 $\pm$ 0.13a
	untreated control	0.38 $\pm$ 0.15a	0.44 $\pm$ 0.16a
2003			
Precious Gem	imidacloprid	---	0.56 $\pm$ 0.27a
	clothianidin	---	0.81 $\pm$ 0.20a
	untreated control	---	0.50 $\pm$ 0.13a
Seneca Dancer	imidacloprid	---	0.62 $\pm$ 0.15a
	clothianidin	---	0.50 $\pm$ 0.22a
	untreated control	---	0.62 $\pm$ 0.18a

^Z Values in columns followed by the same letter are not significantly different, Student's t-test ($P \leq 0.05$), cvs. Precious Gem and Seneca Dancer analyzed separately.

^Y Cambridge Research Station study conducted in 2002 only.

^X Values in columns followed by the same letter are not significantly different, ANOVA ($P \leq 0.05$), cvs. Precious Gem and Seneca Dancer analyzed separately.

Results from both 2002 and 2003 showed that seed treated with imidacloprid or clothianidin effectively reduced CFB feeding on the sweet corn cultivars. Treatments with clothianidin provided CFB control similar or superior to imidacloprid.

APPLICATIONS

Heavy reliance on pesticides can have a serious negative impact on agroecosystem health. Excessive application of pesticides is thought to be the single most significant factor reducing populations of beneficial insects in agricultural crops (Winston, 1997). Evolution of pest control into the practice of integrated pest management (IPM), a program which links management tactics with economic and environmental

FIGURE 1. Mean number of corn flea beetle (*Chaetocnema pulicaria* Melsheimer) feeding damage marks per plant on sweet corn (cvs. Precious Gem, Seneca Dancer) treated with the seed treatment insecticide, imidacloprid, 2002. Bars with the same letter are not significantly different for any given day, Student's t-test ($P < 0.05$).

FIGURE 2. Mean number of corn flea beetle (*Chaetocnema pulicaria* Melsheimer) damage marks per plant on sweet corn (cvs. Precious Gem, Seneca Dancer) treated with the seed treatment insecticides, imidacloprid or clothianidin, 2003. Bars with the same letter are not significantly different for any given day, ANOVA and Fisher's Protected LSD ($P < 0.05$).

costs, has substantially decreased pesticide use, and in turn, reduced the environmental impact of agro-chemicals.

Current tactics for ECB and CFB control in Ontario do not include all of the necessary components of effective IPM. For example, there has been conflict between Ontario sweet corn processors and beekeepers as a result of honey bee colony mortality attributed to insecticides used to control sweet corn insect pests (McRory, 2000). Applications of spinosad or use of Bt-sweet corn provided effective ECB control. Replacement of the preferred carbamate insecticide, carbofuran, all, or in part, with one of these reduced-risk approaches could effectively reduce honey bee colony losses (Bailey, 2004). Spinosad exhibits wide margins of safety to many beneficial insects (Bret et al., 1997; Halsall, 2003; Mayes et al., 2003) and other studies have shown that Bt-crops also have minimal risk to non-target insects (Picard-Nizou et al., 1997; Malone et al., 1999; Mendelsohn et al., 2003).

Systemic seed treatment insecticides are a new option for CFB control in sweet corn. While these insecticidal seed treatments provide promising control (Pataky et al., 2000), their environmental compatibility with respect to impact on beneficial insects has been questioned (Dillon, 2000). However, studies have shown that residue levels of these insecticides in treated crops are negligible and unlikely to have adverse effects on pollinators in crops such as sunflower, canola and sweet corn grown from treated seeds (Schmuck et al., 2001; Scott-Dupree and Spivak, 2001; Schmuck and Keppler, 2003). These observations, along with our findings, suggest that inclusion of imidacloprid and clothianidin in the management program should provide effective CFB control, while posing minimal risk to non-target insects.

An effective pest management program relies on integration of several compatible control tactics that minimize crop losses with minimal environmental impact (Pedigo, 2002). Our results show that application of spinosad or use of Bt-sweet corn provided ECB control equivalent to that of both the currently preferred control agent, carbofuran, and to lambda-cyhalothrin, another industry standard. To implement a more acceptable ECB pest management program sweet corn growers could apply carbofuran or lambda-cyhalothrin at late whorl and spinosad during tasseling or choose to plant Bt-sweet corn cultivars. Our data also show that imidacloprid or clothianidin seed treatments effectively control CFB at very low application rates.

Adoption of this modified treatment program using reduced-risk alternative pest control agents for sweet corn would contribute substantially to development of more effective IPM programs for this important horticultural crop.

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