Effects of Timing and Insecticide on Management of Helicoverpa zea (Lepidoptera: Noctuidae) in Sweet Corn (Poales: Poaceae)

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Research

Effects of timing and insecticide on management of *Helicoverpa zea* (Lepidoptera: Noctuidae) in sweet corn (Poales: Poaceae)

Daniel L. Olmstead and Anthony M. Shelton*

Abstract

Helicoverpa zea Boddie (Lepidoptera: Noctuidae), the corn earworm, is a key pest of sweet corn (Poales: Poaceae) in many parts of the United States. Integrated pest management (IPM) practices for *H. zea* in fresh and processing sweet corn use pheromone trap counts of male moths for management decisions. In this study, we examined whether sweet corn could be protected more effectively if insecticides were applied to target the most attractive silking periods for female *H. zea* oviposition instead of current IPM practices using pheromone trap catches alone. Specifically, we investigated the relationship between insecticide application timing from tassel through silk stages and marketable yield at harvest. We also evaluated the effectiveness of 3 registered insecticide products with different active ingredients (methomyl, chlorantraniliprole, and lambda-cyhalothrin), under various timing scenarios. Results were compared with yields obtained using current IPM recommendations for the northeastern United States. Reduction of *H. zea* damage in sweet corn among insecticides and timing treatments varied within and between years. In year 1, only interaction effects between insecticide and timing were significant, but in year 2, only main effects of insecticide and timing were significant. Chlorantraniliprole produced inconsistent results in year 1 but had significantly higher percentages of clean sweet corn ears compared with lambda-cyhalothrin in year 2.

Key Words: corn earworm; integrated pest management; chlorantraniliprole; lambda-cyhalothrin; pyrethroid; efficacy

Resumen

Helicoverpa zea Boddie (Lepidoptera: Noctuidae), el gusano del maíz, es una plaga clave del maíz dulce (Poales: Poaceae) en muchas partes de los Estados Unidos. Las practicas de manejo integrado de plagas (MIP) para *H. zea* en maíz fresco y maíz dulce procesado utiliza el conteo de las polillas machos en trampas de feromonas para las decisiones de manejo. En este estudio, hemos examinado si el maíz dulce se podría proteger con mayor eficacia si se aplican insecticidas mas dirigidos a los períodos de floración que son más atractivos para la oviposición de las hembras de *H. zea* en lugar de las prácticas actuales de MIP utilizando solamente las capturas en las trampas de feromonas. Específicamente, se investigó la relación entre la sincronización de la aplicación de insecticidas desde la estapa de la borla (hebras) hasta la etapa de seda y rendimiento comercial en la cosecha. También, se evaluó la eficacia de 3 productos insecticidas registrados con diferentes ingredientes activos (metomilo, clorantraniliprol, y lambdacialotrina), bajo diferente tiempos. Los resultados fueron comparados con los rendimientos obtenidos con las recomendaciones actuales de MIP para el noreste de los Estados Unidos. La reducción de daño por *H. zea* en maíz dulce entre los insecticidas y tratamientos de sincronización varía dentro y entre años. En el año 1, sólo el efecto de la interacción entre el insecticida y el tiempo fue significativa, pero en el año 2, sólo el efecto principal del insecticida y el tiempo fue significativo. Clorantraniliprole produjó resultados inconsistentes en el año 1, pero tuvo un porcentaje significativamente más alto de mazorcas de maíz dulce limpias comparado con lambdacialotrina en el año 2.

Palabras Clave: gusano de maíz; gusano elotero; manejo integrado de plagas; clorantraniliprol; lambdacialotrina; piretroides; eficacia

Helicoverpa zea Boddie (Lepidoptera: Noctuidae), the corn earworm, is a key pest of sweet corn (Poales: Poaceae) in many parts of the United States (Barber 1943; Phillips & Whitcomb 1962; Coop et al. 1992, 1993; Shelton et al. 2013). *Helicoverpa zea* is restricted to the western hemisphere (Cohen et al. 1988; CABI 2014) and, if left unmanaged, can cause severe yield reduction and subsequent economic losses (Horner et al. 2003; Hutchison & Storer 2010; Shelton et al. 2013).

Helicoverpa zea infestation occurs when larvae enter the tip of sweet corn ears to feed (Hardwick 1965; Coop et al. 1992). This process begins when adult females are attracted to plant volatiles emitted by fresh corn silks (Flath et al. 1978; Cantelo & Jacobson 1979; Raina et al. 1992). After a suitable plant host has been located, one or more eggs are deposited directly on fresh silk and occasionally on other plant parts (Barber 1943). A single female can lay from 800 to 1,100 eggs in her lifetime (Akkawi & Scott 1984).

Sweet corn is a preferred host of *H. zea*, and infestation on this host results in higher rates of successful development than on other plant hosts (Johnson et al. 1975; Hayes 1988). The presence of a sin-

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gle *H. zea* larva or its damage renders a sweet corn ear unmarketable for the high-value fresh market. Typically, *H. zea* only infests the tip of the sweet corn ear, and the ear tip can be removed mechanically, allowing what is left of the cob to be used for processing (Shelton 1986).

Current integrated pest management (IPM) practices for fresh-market and processing sweet corn in the northeastern United States use pheromone traps to monitor male *H. zea* moth activity, from which treatment decisions are made (Boucher et al. 2014; Shelton et al. 2014). Treatment decisions are based on the number of moths captured over a pre-determined period of time during ear development, starting when the ear (female flower) produces silk (the stigma and style) to be pollinated (Clemson University Cooperative Extension 2015). Treatments continue in this manner until harvest. This approach is based on research showing that male moths captured in pheromone traps correspond well to female moth populations in the same area (Chowdhury et al. 1987a, 1987b). Growers may use multiple applications of pyrethroid insecticides to successfully manage *H. zea* infestations in sweet corn (Shelton et al. 2013). However, there is concern about pyrethroid resistance as well as interest for more efficacious, safer, and longer residual products to reduce damage (Jacobson et al. 2009).

A new insecticide class, the anthranilic diamides, includes products that are longer lasting, especially against Lepidoptera, and have a safer environmental profile than previously used insecticides (Hannig et al. 2009; Lai & Su 2011). This chemical class has not extensively been tested against *H. zea* under field conditions, but the lack of consistent *H. zea* damage reduction using pyrethroid insecticides makes evaluation of chlorantraniliprole as a reduced spray treatment a worthwhile pursuit (Shelton et al. 2013).

The 1st objective of this project was to evaluate reduction in *H. zea* damage in sweet corn by initiating an insecticide spray program earlier than the green silk stage as recommended in current IPM guidelines, starting instead at the late tassel/early silk stages of corn development. We hypothesized that targeting late tassel/first green silk with an insecticide would decrease *H. zea* damage compared with the traditional application timing that begins at the mid–green silk stage. The 2nd objective was to compare differences in reduction of *H. zea* feeding damage using various insecticides. We hypothesized that chlorantraniliprole would significantly reduce *H. zea* damage compared with products containing lambda-cyhalothrin and methomyl. Finally, we hypothesized that the greatest reduction in *H. zea* damage to sweet corn would be obtained by targeting late tassel/first green silk stages with chlorantraniliprole.

Materials and Methods

PLOT ESTABLISHMENT

Experimental plots were established on 14 Jun 2012 and 8 Jul 2014 at the Cornell University Agricultural Experiment Station Fruit and Vegetable Research Farm located in Geneva, New York (42.872692°N, 77.019242°W). Plots were established in 2013, but *H. zea* moth densities were unusually low and precluded efficacy testing. 'Obsession' and 'EX08767143' conventional sweet corn varieties were planted in 2012 and 2014, respectively (Seminis™ Vegetable Seeds, St. Louis, Missouri). Fields were seeded on 76 cm centers and 20 cm in-row plant spacing using a Monasem™ vacuum seeder (Edwardsville, Kansas). Nitrogen was added at a rate of 57 kg/ha in the furrow with seed at planting time. An additional 57 kg of N per ha was side-dressed when plants reached the 7-leaf stage.

INSECTICIDE TREATMENTS

Methomyl (Lannate® LV, DuPont™, Wilmington, Delaware), chlorantraniliprole (Coragen® SC, DuPont™, Wilmington, Delaware), and lambda-cyhalothrin (Warrior®, Syngenta™, Greensboro, North Carolina [2012] and Lambda-T®, Helena Chemical™, Collierville, Tennessee [2014]) were selected as insecticide treatments. All 3 insecticides were applied using maximum labeled rates of 504.3 g active ingredient (AI) methomyl, 73.2 g AI chlorantraniliprole, and 33.6 g AI lambda-cyhalothrin per ha.

Insecticide treatments were made using a 3 row CO_2 pressurized Hagie 200 High-Boy tractor (Hagie Equipment Company, Clarion, Iowa) equipped with 3 Tee-Jet flat fan 11003 nozzle tips per row (1 over the top and 1 drop nozzle on each side aimed at the ear zone), delivering 137 L H_2O per ha at 2.8 kg/cm^2 pressure and a speed of 5.1 kph. The adjuvant Dyne-Amic (Helena Chemical™, Collierville, Tennessee), a modified vegetable oil and organosilicone surfactant blend, was added to all treatments at a 0.1% v/v ratio.

INSECTICIDE TIMING

Insecticides were applied using either an assigned timing schedule based on plant reproductive phase or according to current IPM guidelines (Boucher et al. 2014; Shelton et al. 2014). Timing schedules were implemented to examine efficacy of a given insecticide during several phases of ear development (Clemson University Cooperative Extension 2015). Five timing schedules were used in this study. In timing schedule 1, insecticides were applied 3 times between first green silk and 25% dry silk stage. In timing schedule 2, insecticides were applied once at first green silk. In timing schedule 3, insecticides were applied at a frequency determined by IPM guidelines between first green silk and harvest. In timing schedule 4, insecticides were applied once at 50% tassel. In timing schedule 5, insecticides were applied 4 times between 50% tassel and 25% dry silk stages. In 2012, timing schedules 1, 2, and 3 were evaluated, but timing schedules 4 and 5 were not. In 2014, timing schedules 1 though 5 were evaluated.

Primary ears, those that develop first and highest on the plant, were evaluated. First green silk was defined as the date of first observed silk, of any length, emerging from any of 25 randomly sampled ear tips. Fifty percent green silk was defined as the day on which >50% of 25 randomly sampled ears reached the silk stage. Fifty percent tassel was defined as the date on which >50% of 25 randomly sampled plants displayed a tassel.

PEST PRESSURE

Treatments that followed timing schedule 3, the IPM guidelines, required an estimate of adult pest pressure based on pheromone trap catch values. Three Scentry™ Heliothis traps (Great Lakes IPM Inc., Vestaburg, Michigan) were placed around the perimeter of each field in 2012 and 2014. Traps were checked for adult male moths at 3 d intervals beginning when corn plants reached the final vegetative stages of development. Pheromone trap counts were then used to determine insecticide application frequency for plots assigned to timing schedule 3 (Boucher et al. 2014; Shelton et al. 2014) (Table 1).

EXPERIMENTAL DESIGN

Treatment plots consisted of 3 rows, 8 m in length. A randomized complete block design was implemented in 2012 and 2014 with each treatment replicated 4 times. In 2012, methomyl, chlorantraniliprole,

Table 1. Insecticide application dates and respective *Helicoverpa zea* pheromone trap catches upon which spray decisions were made for plots following timing schedule 3, IPM guidelines from 50% silk to harvest, in 2012 and 2014.

Year	Application no.	Date	Mean trap catch per day	Corresponding spray interval (d)
2012	tassel	12 Aug	0	—
	1	15 Aug	7.0	4
	2	19 Aug	28.3	3
	3	22 Aug	30.0	3
	4	25 Aug	22.3	3
	5	28 Aug	18.0	3
	6	31 Aug	13.7	3
	harvest	2 Sep	—	—
2014	tassel	2 Sep	0	—
	1	5 Sep	1.3	4
	2	9 Sep	3.0	4
	3	13 Sep	1.4	4
	4	17 Sep	0	—
	harvest	22 Sep	—	—

and lambda-cyhalothrin were evaluated in combination with timing schedules 1, 2, and 3. In 2014, chlorantraniliprole and lambda-cyhalothrin were evaluated combined with timing schedules 1, 2, 3, 4, and 5.

FIELD EVALUATION

Treatments were evaluated at harvest, 21 d after first green silk in each year. Twenty-five randomly selected primary ears of corn were harvested from the 3 center rows of treatment plots. Ears without damage or larvae in the silk or on the kernels inside the husk were classified as clean. Ears with larvae in the silk or on the ear were classified as damaged.

STATISTICAL ANALYSES

JMP 11.0 for Macintosh (SAS Institute, Cary, South Carolina) was used for statistical analyses. Pest pressure was much higher in 2012 compared with 2014. In 2012, methomyl, lambda-cyhalothrin, and chlorantraniliprole were evaluated using timing schedules 1, 2, and 3. In 2014, lambda-cyhalothrin and chlorantraniliprole were evaluated using timing schedules 1, 2, 3, 4, and 5, and methomyl was excluded from the analysis. For these reasons, 2012 and 2014 datasets were not combined. Instead, each year was evaluated separately using linear mixed model regression. Insecticide and timing were assigned as main effects, insecticide*timing interaction effects were measured, and replicate was assigned as a random effect. Tukey's honest significant difference (HSD) test (P = 0.05) was used to separate treatment means when appropriate. The untreated control was not included in the analyses, but results are presented. We already know from prior studies that without prophylactic insecticide treatment, sweet corn is all but certain to become infested even at low population densities (Shelton et al. 2013). We felt it was more appropriate to evaluate the nuanced similarities and differences between treatments based on frequency and timing of insecticide applications rather than presence or absence.

Results

In 2012, the main effects of insecticide (F = 1.8521; df = 2; P = 0.1763) and timing (F = 1.8723; df = 2; P = 0.1732) were not significant. In contrast, the interaction effect between insecticide and timing was significant (F = 6.1220; df = 4; P = 0.0012) (Table 2). Similar levels of *H. zea* damage reduction were achieved regardless of application timings for lambda-cyhalothrin and chlorantraniliprole. In contrast, methomyl treatments applied 3 times from first green silk to 25% dry silk (3 sprays) resulted in significantly less damage than methomyl applied using current IPM guidelines, applied from 50% green silk to harvest (as needed).

In 2014, the main effects of insecticide (F = 7.8148; df = 1; P = 0.0090) and timing (F = 4.7464; df = 4; P = 0.0044) were significant, but the interaction between insecticide and timing was not significant (F = 0.6458; df = 4; P = 0.6342) (Tables 3 and 4). In 2014, lambda-cyhalothrin treatments had a significantly lower percentage (57.8 ± 3.4%) (± SE) of clean ears compared with chlorantraniliprole treatments (69.8 ± 3.7%). Among the 2014 timing treatments, insecticides applied 4 times from 50% tassel to 25% dry silk had significantly higher percentages of clean ears (76.5 ± 3.2%) than insecticides applied once at 50% tassel (47.5 ± 5.5%). Other treatments were not significantly different from each other.

Discussion

Chlorantraniliprole is an efficacious insecticide with systemic activity and long-lasting protection against arthropod pests (Hannig et al. 2009). However, our results from 2012 showed superior ear protection to other treatments in only 1 case, namely, when chlorantraniliprole had been applied using timing schedule 3 (IPM guidelines) compared with methomyl applied using timing schedule 3 (Table 2). Although 9 insecticide timing treatments were evaluated in 2012, chlorantraniliprole significantly reduced *H. zea* damage in only 1 instance and there was no evidence of superior ear protection compared with other chemistries. In 2014, insecticide was significant as a main effect and chlorantraniliprole resulted in significantly greater numbers of undamaged ears compared with lambda-cyhalothrin treatments (Table 3). However, in 2014 *H. zea* density was lower compared with 2012 (Table 4).

The effects of insecticide–timing treatment combinations were not consistent. In 2012, timing schedule made no difference when lambda-cyhalothrin was used, nor was it significant for chlorantraniliprole (Table 2). However, ear damage was significantly reduced when methomyl was applied using timing schedule 1, from first green silk to 25% dry silk, and timing schedule 3, IPM guidelines from first green silk to harvest. In 2014, the main effect of timing significantly increased the percentage of undamaged ears when insecticides were applied from 50% tassel to 25% dry silk, compared with 1 spray at 50% tassel (Table 4). Insecticide applications made using current IPM guidelines did not significantly differ from insecticide applications made with any other timing schedule evaluated in this study.

The 2014 analysis of application timing schedule as a main effect showed a numerical advantage in ear damage reduction when applications were made using timing schedule 5, from 50% tassel to 25% dry silk (76.5 ± 3.2% undamaged ears), compared with timing schedule 3, IPM guidelines from first green silk to harvest (64.0 ± 6.5% undamaged ears) (Table 4). However, we could not provide statistical support for these differences. The 12.5% difference is notable and could arguably serve as justification for further research. A larger sample size with more replications would increase statistical power and reduce variance. Effects of application timing schedules within the reproductive phase of sweet corn development should be researched further.

The ability of chlorantraniliprole to consistently reduce *H. zea* ear damage is unclear despite our research. In 2012, a significant differ-

Table 2. Percentages of undamaged sweet corn ears by *Helicoverpa zea* based on interaction of insecticide and application timing in 2012.

Effect	Insecticide	Timing	*n*	% undamaged ± SE[a]
Insecticide*timing	lambda-cyhalothrin	1[b]	4	60.5 ± 2.5 ab
		2[c]	4	62.2 ± 3.6 ab
		3[d]	4	65.5 ± 1.6 ab
	chlorantraniliprole	1[b]	4	68.0 ± 5.8 ab
		2[c]	4	67.3 ± 1.0 ab
		3[d]	4	75.8 ± 3.7 a
	methomyl	1[b]	4	80.7 ± 4.3 a
		2[c]	4	68.5 ± 11.1 ab
		3[d]	4	45.5 ± 3.1 b
	untreated check	—	4	37.0 ± 11.8 ---

[a]Means followed by different letters are significantly different (Tukey's HSD test, P = 0.05).
[b]Insecticides applied according to timing schedule 1 were applied 3 times between first green silk and 25% dry silk stages.
[c]Insecticides applied according to timing schedule 2 were applied once at first green silk.
[d]Insecticides applied according to timing schedule 3 were applied as needed, according to current IPM guidelines, between first green silk and harvest.

Table 3. Percentages of sweet corn ears undamaged by *Helicoverpa zea* with insecticide as a main effect in 2014.

Effect	Insecticide	*n*	% undamaged ± SE[a]
Insecticide	lambda-cyhalothrin	20	57.8 ± 3.4 b
	chlorantraniliprole	20	69.8 ± 3.7 a

[a]Means followed by different letters are significantly different (Tukey's HSD test, P = 0.05).

ence was detected between chlorantraniliprole (75.8 ± 3.7% undamaged ears) and methomyl (45.5 ± 3.1% undamaged ears) using timing schedule 3, IPM guidelines from first green silk to harvest (Table 2). In 2014, however, chlorantraniliprole (69.8 ± 3.7%) resulted in a significantly higher percentage of undamaged ears than lambda-cyhalothrin (57.8 ± 3.4%) (Table 3). Based on these findings, the suitability of chlorantraniliprole as a consistent and effective insecticide for protecting sweet corn from *H. zea* is unclear.

The 2014 results showed not only that chlorantraniliprole provided significantly better ear protection from *H. zea* than lambda-cyhalothrin (Table 3) but also that insecticides applied using timing schedule 5, from 50% tassel to 25% dry silk, produced numerically greater yields than other timing schedules (Table 4). These results are mixed. Because we could not find strong, consistent statistical support, we rejected our hypothesis that reductions in *H. zea* ear damage can be achieved by targeting the late tassel/first green silk stages with chlorantraniliprole.

Table 4. Percentages of sweet corn ears undamaged by *Helicoverpa zea* with application timing as a main effect in 2014.

Effect	Schedule	*n*	% undamaged ± SE[a]
Timing	1[b]	8	64.0 ± 6.1 ab
	2[c]	8	67.0 ± 3.6 ab
	3[d]	8	64.0 ± 6.5 ab
	4[e]	8	47.5 ± 5.5 b
	5[f]	8	76.5 ± 3.2 a

[a]Means followed by different letters are significantly different (Tukey's HSD test, P = 0.05).
[b]Insecticides applied according to timing schedule 1 were applied 3 times between first green silk and 25% dry silk stages.
[c]Insecticides applied according to timing schedule 2 were applied once at first green silk.
[d]Insecticides applied according to timing schedule 3 were applied as needed, according to current IPM guidelines, between first green silk and harvest.
[e]Insecticides applied according to timing schedule 4 were applied once at 50% tassel.
[f]Insecticides applied according to timing schedule 5 were applied 4 times between 50% tassel and 25% dry silk stages.

Additional studies with more replications and samples to increase statistical power and reduce variance are warranted.

Pyrethroid insecticides are the most commonly used insecticides in sweet corn production because they are inexpensive and have been effective against the European corn borer, *Ostrinia nubilalis* Hübner (Lepidoptera: Crambidae), the traditional main pest of sweet corn prior to the emergence of *H. zea*. However, significant yield improvements using lambda-cyhalothrin with standard IPM guidelines (timing schedule 3), or even modified timing to target very early silk stages (schedule 1) were not achieved in this study. The reasons are unclear. Pyrethroid resistance has been reported in *H. zea* populations from the southern United States (Pietrantonio et al. 2007; Hopkins & Pietrantonio 2009, 2010)Helicoverpa zea (Boddie, and in the Midwest (Jacobson et al. 2009)"plainCitation":"(Jacobson et al. 2009. There is no published evidence of resistance in New York. However, it is possible that resistance contributed to the failure of lambda-cyhalothrin to protect sweet corn ears from *H. zea* feeding damage in our experiments. Laboratory screening assays of New York field-collected adults in 2010 and 2011 have been conducted and suggested that a low level of resistance was present (Olmstead & Shelton unpublished).

Chlorantraniliprole represents a relatively new insecticide class. Anthranilic diamides have a very specific mode of action (Cordova et al. 2006), have few non-target effects in the field (Preetha et al. 2009; Brugger et al. 2010; Gradish et al. 2011; Huang et al. 2011), have long-lasting plant systemic activity, and have anti-feeding effects on target pest insects (Hannig et al. 2009). However, results of this study suggest that the suitability of chlorantraniliprole for use in sweet corn to reduce *H. zea* infestation and ear damage is variable. When the 2014 results are considered alone, chlorantraniliprole was more efficacious compared with lambda-cyhalothrin (Table 3).

In 2014, timing schedule 5, from 50% tassel to 25% dry silk, used 4 insecticide sprays. A comparison of environmental impact quotient values (EIQ) (Kovach et al. 1992) demonstrated similar ecological benefits of using chlorantraniliprole or lambda-cyhalothrin. At the rates used in our study, chlorantraniliprole and lambda-cyhalothrin had per application EIQ values of 3.1 and 2.4, respectively (NYSIPM, www.nysipm.cornell.edu/EIQCalc/input.php), with the smaller number being more environmentally favorable. The total EIQ for all applications (n = 4) based on current IPM guidelines were 12.4 for lambda-cyhalothrin and 9.6 for chlorantraniprole.

This research demonstrated that *H. zea* management in sweet corn is influenced by both insecticide chemistry and application timing. The results also showed that successful reduction in ear damage caused by *H. zea* varied between years. In 2012, only the interaction effects between insecticide and timing were significant, whereas in 2014 only main effects of insecticide and timing were significant. Chlorantraniliprole provided inconsistent results in 2012 but had significantly higher percentages of undamaged sweet corn ears among treatments compared with lambda-cyhalothrin in 2014.

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References Cited

Akkawi MM, Scott DR. 1984. The effect of age of parents on the progeny of diapaused and non-diapaused *Heliothis zea*. Entomologia Experimentalis et Applicata 35: 235–239.

Barber GW. 1943. Oviposition habits of the earworm moth in relation to infestation in the ears and to control. Journal of Economic Entomology 36: 611–618.

Boucher T, Dowling Z, Hazzard R, McKeag L. 2014. Corn, Sweet. *In* New England Vegetable Guide. https://nevegetable.org/crops/insect-control-6 (last accessed 20 Dec 2014).

Brugger KE, Cole PG, Newman IC, Parker N, Scholz B, Suvagia P, Walker G, Hammond TG. 2010. Selectivity of chlorantraniliprole to parasitoid wasps. Pest Management Science 66: 1075–1081.

CABI (Centre for Biosciences and Agriculture International). 2014. *Helicoverpa zea*. *In* Invasive Species Compendium. http://www.cabi.org/isc (last accessed 20 Nov 2014).

Cantelo WW, Jacobson M. 1979. Corn silk volatiles attract many pest species of moths. Journal of Environmental Science and Health Part A 14: 695–707.

Chowdhury MA, Chalfant RB, Young JR. 1987a. Comparison of sugarline sampling and pheromone trapping for monitoring adult populations of corn earworm and fall armyworm (Lepidoptera: Noctuidae) in sweet corn. Environmental Entomology 16: 1241–1243.

Chowdhury MA, Chalfant RB, Young JR. 1987b. Ear damage in sweet corn in relation to adult corn earworm (Lepidoptera: Noctuidae) populations. Journal of Economic Entomology 80: 867–869.

Clemson University Cooperative Extension. 2015. Growth stages of corn. http://www.clemson.edu/extension/rowcrops/corn/guide/growth_stages.html (last accessed 20 Apr 2015).

Cohen RW, Waldbauer GP, Friedman S. 1988. Natural diets and self-selection: *Heliothis zea* larvae and maize. Entomologia Experimentalis et Applicata 46: 161–171.

Coop LB, Drapek RJ, Croft BA, Fisher GC. 1992. Relationship of corn earworm (Lepidoptera: Noctuidae) pheromone catch and silking to infestation levels in Oregon sweet corn. Journal of Economic Entomology 85: 240–245.

Coop LB, Croft BA, Drapek RJ. 1993. Model of corn earworm (Lepidoptera: Noctuidae) development, damage, and crop loss in sweet corn. Journal of Economic Entomology 86: 906–916.

Cordova D, Benner EA, Sacher MD, Rauh JJ, Sopa JS, Lahm GP, Selby TP, Stevenson TM, Flexner L, Gutteridge S, Rhoades DF, Wu L, Smith RM, Tao Y. 2006. Anthranilic diamides: a new class of insecticides with a novel mode of action, ryanodine receptor activation. Pesticide Biochemistry and Physiology 84: 196–214.

Flath RA, Forrey RR, John JO, Chan BG. 1978. Volatile components of corn silk (*Zea mays* L.): possible *Heliothis zea* (Boddie) attractants. Journal of Agricultural and Food Chemistry 26: 1290–1293.

Gradish AE, Scott-Dupree CD, Shipp L, Harris CR, Ferguson G. 2011. Effect of reduced risk pesticides on greenhouse vegetable arthropod biological control agents. Pest Management Science 67: 82–86.

Hannig GT, Ziegler TM, Marçon PG. 2009. Feeding cessation effects of chlorantraniliprole, a new anthranilic diamide insecticide, in comparison with several insecticides in distinct chemical classes and mode-of-action groups. Pest Management Science 65: 969–974.

Hardwick DF. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 97: 5–247.

Hayes JL. 1988. A comparative study of adult emergence phenologies of *Heliothis virescens* (F.) and *H. zea* (Boddie) (Lepidoptera: Noctuidae) on various hosts in field cages. Environmental Entomology 17: 344–349.

Hopkins BW, Pietrantonio PV. 2009. Differential efficacy of three commonly used pyrethroids against laboratory and field-collected larvae and adults of *Helicoverpa zea* (Lepidoptera: Noctuidae) and significance for pyrethroid resistance management. Pest Management Science 66: 147–154.

Hopkins BW, Pietrantonio PV. 2010. The *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) voltage-gated sodium channel and mutations associated with pyrethroid resistance in field-collected adult males. Insect Biochemistry and Molecular Biology 40: 385–393.

Horner TA, Dively GP, Herbert DA. 2003. Development, survival and fitness performance of *Helicoverpa zea* (Lepidoptera: Noctuidae) in MON810 *Bt* field corn. Journal of Economic Entomology 96: 914–924.

Huang J, Wu S, Ye G. 2011. Evaluation of lethal effects of chlorantraniliprole on *Chilo suppressalis* and its larval parasitoid, *Cotesia chilonis*. Agricultural Sciences in China 10: 1134–1138.

Hutchison WD, Storer NP. 2010. Expanded use of pyramided transgenic maize hybrids expressing novel *Bacillus thuringiensis* toxins in the southern US: potential for area-wide suppression of *Helicoverpa zea* (Lepidoptera Noctuidae) in the Mississippi Delta. The Southwestern Entomologist 35: 403–408.

Jacobson A, Foster R, Krupke C, Hutchison W, Pittendrigh B, Weinzierl R. 2009. Resistance to pyrethroid insecticides in *Helicoverpa zea* (Lepidoptera: Noctuidae) in Indiana and Illinois. Journal of Economic Entomology 102: 2289–2295.

Johnson MW, Stinner RE, Rabb RL. 1975. Ovipositional response of *Heliothis zea* (Boddie) to its major hosts in North Carolina. Environmental Entomology 4: 291–297.

Kovach J, Petzoldt C, Degni J, Tette J. 1992. A method to measure the environmental impact of insecticides. New York's Food and Life Sciences Bulletin, Number 139.

Lai T, Su J. 2011. Effects of chlorantraniliprole on development and reproduction of beet armyworm, *Spodoptera exigua* (Hübner). Journal of Pest Science 84: 407–415.

Phillips JR, Whitcomb WH. 1962. Field behavior of the adult bollworm, *Heliothis zea* (Boddie). Journal of the Kansas Entomological Society 12: 242–246.

Pietrantonio PV, Junek TA, Parker R, Mott D, Siders K, Troxclair N, Vargas-Camplis J, Westbrook JK, Vassiliou VA. 2007. Detection and evolution of resistance to the pyrethroid cypermethrin in *Helicoverpa zea* (Lepidoptera: Noctuidae) populations in Texas. Environmental Entomology 36: 1174–1188.

Preetha G, Stanley J, Suresh S, Kuttalam S, Samiyappan R. 2009. Toxicity of selected insecticides to *Trichogramma chilonis*: assessing their safety in the rice ecosystem. Phytoparasitica 37: 209–215.

Raina AK, Kingan TG, Mattoo AK. 1992. Chemical signals from host plant and sexual behavior in a moth. Science 255: 592–594.

Shelton AM. 1986. Management of Lepidoptera on processing sweet corn in western New York. Journal of Economic Entomology 79: 1658–1661.

Shelton AM, Olmstead DL, Burkness EC, Hutchison WD, Dively G, Welty C, Sparks AN. 2013. Multi-state trials of *Bt* sweet corn varieties for control of the corn earworm (Lepidoptera: Noctuidae). Journal of Economic Entomology 106: 2151–2159.

Shelton A, Nault B, Hoffmann M. 2014. Sweet corn, pp. 329–353 *In* Reiners S, Petztoldt C [eds.], Cornell Integrated Pest Management Guidelines for Commercial Vegetable Production. Cornell University Cooperative Extension, Ithaca, New York.