Evaluation of Thiamethoxam and Imidacloprid as Seed Treatments to Control European Corn Borer and Indianmeal Moth (Lepidoptera: Pyralidae) Larvae

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ABSTRACT Efficacy of thiamethoxam (Cruiser) and imidacloprid (Gaucho) were evaluated as seed treatments for controlling European corn borer, *Ostrinia nubilalis* (Hübner) and Indianmeal moth, *Plodia interpunctella* (Hübner) larvae in stored grain. At ≈22–26°C, all fifth instar European corn borers died after two or 4 d of exposure to corn treated with 250 and 500 ppm thiamethoxam, respectively, while mortality of larvae exposed for two and 4 d on corn treated with 6.3–937.5 ppm imidacloprid did not exceed 48% at any concentration. At 29°C, all nondiapausing fifth instars were killed after 3, 4, and 6-d exposure to 400, 300 and 200-ppm thiamethoxam, respectively, while survival increased at successively lower concentrations of 100, 50, 25, and 12.5 ppm. At 29°C, the LC_{50} decreased from 85.9 to 7.2 ppm as the duration of exposure on treated corn increased from 2 to 6 d. All second and third instar Indianmeal moth larvae died after a 5 d exposure period to corn grain treated with thiamethoxam at 50 ppm or higher, but as the larvae aged, higher concentrations and longer exposure periods were required to give 100% mortality of each larval instar. Similar results were obtained when larval Indianmeal moths were exposed on corn treated with imidacloprid, or on sorghum treated with thiamethoxam. Mature wandering phase fifth instars were the most tolerant larval stage of the Indianmeal moth.

KEY WORDS thiamethoxam, imidacloprid, European corn borer, Indianmeal moth, *Plodia interpunctella*

SYSTEMIC INSECTICIDES FOR SEED treatments are being developed and used in the field for insect control on a variety of crops around the world. Cruiser is a trademark for thiamethoxam, a second-generation neonicotinoid insecticide developed by Syngenta Crop Protection Inc. (Greensboro, NC). It provides excellent control of a wide variety of commercially important insect pests on a variety of crops including barley, cotton, sorghum, wheat, canola, and corn through contact, stomach and systemic activity (Gobel et al. 1999, Maienfisch et al. 1999, Hofer and Brandl 1999, Zang et al. 1998, Lawson et al. 1999).

Imidacloprid (Gaucho) is commonly used as a systemic seed treatment to protect seeds and seedlings against injury by early season insects (Wilde et al. 1999, Graham 1998, Burd et al. 1996, Almand 1995, McKirdy and Jones 1996). Imidacloprid (Gaucho) marketed by Gustafson Inc. (Dallas, TX), is effective in controlling many insects, including aphids, thrips, mites, wireworms, and true bugs (Bradley et al. 1998, Graham et al. 1995, Harvey et al. 1996), and is commonly used on several crops, including cotton, wheat, barley, sorghum, canola, corn, and sugar beets.

Although the effects of thiamethoxam and imidacloprid on pest insects on field crops are well documented, their effects on insects such as the European corn borer, *Ostrinia nubilalis* (Hübner) and Indianmeal moth, *Plodia interpunctella* (Hübner) present in or damaging stored grain have not been studied. The Indianmeal moth is an important pest of stored grain worldwide and its control in stored grain is an important concern of those storing grain for sale as food or seed (Arthur 1999). The European corn borer, while not considered a storage pest, may appear as a contaminant in grain stored for seed purposes and is thus a cause for concern by corn and sorghum hybrid seed producers (Wilde 1976). The objective of this study was to evaluate the efficacy of these two insecticides as seed treatment for controlling European corn borer, *Ostrinia nubilalis*, and Indianmeal moth, *Plodia interpunctella* in stored grain.

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Materials and Methods

The insecticides used in this study were thiamethoxam (Cruiser), a 47.8% 5 lbs/gallon (AI) product (600 mg/ml) supplied by Syngenta, and imidacloprid (Gaucho) 480 SL, a 40.7% (AI) 4 lbs per gallon product (480 mg/ml) supplied by Gustafson, Inc. The insects species and stages used for bioassays were fifth-instar European corn borer, obtained from French Agricultural Research Inc. (Lamberton, MN), and various stages of the Indianmeal moth, obtained from laboratory colonies reared as described by (Silhacek and Miller (1972).

Tests with European Corn Borer. The insecticides used in this study were thiamethoxam (Cruiser), a 47.8% 5 lbs/gallon (AI) product (600 mg/ml) supplied by Syngenta, and imidacloprid (Gaucho) 480 SL, a 40.7% (AI) 4 lbs per gallon product (480 mg/ml) supplied by Gustafson, Inc. Fifth-instar European corn borer, obtained from a commercial source (French Agricultural Research Inc, Lamberton, MN), were used for the bioassays. Initial tests were done by exposing fifth-instar European corn borers on corn treated with 0, 50, 250, and 500 ppm thiamethoxam and 0, 6.3, 62.5, 312.5, 625, and 937.5 ppm imidacloprid. Rates were chosen based on label rates and the results of preliminary observations and all tests were conducted at room temperature (≈22–25°C). The insecticides were formulated in water. The label spray rate for both products is 295.6 ml (10 ounces) of formulated spray per 45.4 kg (100 lbs) of corn. For our tests individual lots of 1.5 kg were treated, with 9.8 ml of spray. For each application rate of each insecticide, serial dilutions of the commercial insecticides were formulated in tap water to produce solutions giving the chosen ppm levels when sprayed at the rate of 9.8 ml/1.5 kg of corn. Applications were made by spreading the corn out in a thin layer onto a 0.6 by 0.3 m plywood sheet, and using a Badger model 100 artists' airbrush (Franklin Park, IL) to mist 9.8 ml of the insecticide in water on the corn. The untreated control lot was misted with water alone.

Each lot of 1.5-kg corn treated at the various concentrations was subdivided into five replicates of ≈235 g each, which were put into plastic containers (diameter 8.5 cm, height 6.0 cm), and the remainder discarded. Ten fifth instar European corn borers were put inside the containers, and the containers, each with a mesh cover, were put into a plastic cooler with ≈10 cm of water at the bottom to maintain a high humidity level. Insect mortality was assessed after 2, 4, and 6 d. The criterion of death was no movement of larvae when prodded with a camel's-hair brush.

In a second test, fifth instar European corn borers were exposed on corn treated with 0, 12,5, 25, 50, 100, 200, 300, and 400 ppm thiamethoxam. All concentrations were formulated in tap water from the 600 mg/ml EC product as described earlier, and each concentration was applied at the rate of 9.8 ml formulated spray per 1.5 kg of corn. The untreated control was sprayed with tap water. Each 1.5 lot of each concentration from each replicate was subdivided into five replicates, each with 235 g of corn, and ten fifth instars added into each container as described earlier. The containers were then put inside a growth chamber at 29 ± 1°C and 50–70% RH with a photoperiod of 12:12 (L:D). Mortality was assessed after 2, 4, and 6 d.

Indianmeal Moth on Corn. Stock laboratory colonies of Indianmeal moth were maintained and reared as described by Silhacek and Miller (1972) at ≈27°C, 60% RH. Concentrations of thiamethoxam and imidacloprid used for the tests with Indianmeal moths were 0, 50, 100, 250, and 500 ppm, and 0, 62.5, 156.3, 312.5, 625, and 937 ppm for each insecticide, respectively. The individual concentrations of each insecticide were formulated as described earlier, and applied at the rate of 9.6 ml of spray per 1.5 kg of corn. The following instars were collected from the stock colony cultures, second instars, third instars, fourth instars, early fifth instars, and late fifth-instars (≈6–8, 9–11, 12–13, 14–15, and 16–17 d-old, respectively, for each stage). The instars were exposed separately, depending on the availability of a particular stage. Each lot of 1.5 kg treated corn and the untreated lot of 1.5-kg corn was subdivided into five replicates, which were put into the plastic containers as described before. Each instar was treated separately, and 20 instars were put into each of five replicate containers, which were put inside a growth chamber set at 29 ±°C, 50–70% RH and a photoperiod of 12:12 (L:D). A final set of mature fifth instars were held inside a plastic cooler, with water in the bottom, at room temperature of ≈22–25°C. Mortality of larvae held inside the chamber was assessed after 5, 10, and 15 d, while mortality of larvae held at room temperature was assessed after 6, 12, 24, and 38 d.

Indianmeal Moth on Sorghum. The response of Indianmeal moth larvae exposed on sorghum treated with thiamethoxam was also evaluated, using the same procedures as described for corn. Sorghum was treated and larvae were exposed as described for corn, except that all tests were conducted inside the growth chamber, and no tests were conducted at room temperature.

Statistical Analysis. Data for all studies were analyzed using the General Linear Models (GLM) and Means Procedures of the Statistical Analysis System (SAS Institute 2001). Because all observations at the various postexposure intervals were conducted on the same set of larvae, data were analyzed with days of exposure as a repeated measure. Means were separated using the Waller-Duncan k-ratio *t*-test option under the GLM Procedure of SAS ($P < 0.05$). Probit analysis susceptibility of fifth instar European corn borer to thiamethoxam was done using the POLO procedure (LeOra Software 1994).

Results

European Corn Borer on Corn. Concentration and ($F = 46.4$, df = 5, 8, $P < 0.01$) exposure interval ($F = 273.7$, df = 2, 8, $P < 0.01$) were significant for the tests

Table 1. Percent mortality (mean ± SEM) of 5th instar European corn borer exposed for 2, 4, and 6 d on corn treated with imidacloprid and thiamethoxam[a]

Concentration (ppm)	Exposure (days)		
	2	4	6
		imidacloprid	
0	1 ± 1.0c	5 ± 2.2d	35 ± 3.4b
6.25	8 ± 3.7bc	18 ± 7.3cd	52 ± 7.3ab
62.5	10 ± 4.4bc	34 ± 6.0ab	58 ± 8.0a
312.5	11 ± 3.1b	25 ± 2.7bc	49 ± 5.0ab
625.0	22 ± 4.9a	44 ± 8.7a	62 ± 7.3a
937.5	22 ± 2.0a	48 ± 8.6a	58 ± 8.6a
		thiamethoxam	
0	2 ± 2.0c	6 ± 4.0c	30 ± 4.4c
50	30 ± 9.4b	68 ± 10.7d	82 ± 9.6b
250	92 ± 8.0a	100a	100a
500	100a	100a	100a

[a] Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller-Duncan k-ration *t*-test, SAS Institute 2001).

with imidacloprid, with days of exposure as a repeated measure. Mortality of fifth instar European corn borer exposed on corn treated with imidacloprid at 6.2–937.5 ppm ranged from 6.0 ± 2.4% to 62.0 ± 7.3%, depending on concentration and exposure interval (Table 1). Concentration and ($F = 375.2$, df = 3, 8, $P < 0.01$) exposure interval ($F = 71.7$, d. f. = 2,8, $P < 0.01$) were also significant for the initial test with thiamethoxam. All larvae died within 2 d when exposed on corn treated with 500 ppm thiamethoxam, 92.0% and 100% of the larvae died after 2 d and 4 d, respectively, on corn treated with 250 ppm, and 30.0 and 68.0% died after two and 4 d of exposure on corn treated with 50 ppm (Table 1).

Concentration was also significant ($F = 737.6$, d. f. = 8, 16, $P < 0.01$) and exposure interval ($F = 262.2$, d. f. = 4, 16, $P < 0.01$), with exposure interval as a repeated measure, for the additional evaluation with thiamethoxam. All larvae died after 3 d of exposure on corn treated with 400 ppm, after 4 d of exposure on corn treated with 300 ppm, or after 6 d of exposure on corn treated with 200 ppm (Table 2). The calculated LC_{50} decreased from 85.9 ppm at 2 d to 7.2 ppm at 6d, while the LC_{90} was 399.3 and 46.9 ppm at two and 6 d, respectively (Table 3). Thiamethoxam was equally effective in controlling diapausing fifth instar European corn borer larvae. All exposed were dead after 4 d of exposure in corn treated with 500 ppm or after 10 d of exposure in corn treated with 250 ppm. There were 10.0% of the diapausing larvae surviving after 10 d in grain treated with 50 ppm, compared with 71.3% survival in the untreated control.

Indianmeal Moth on Corn. For each larval stage, the analysis for concentration of imidacloprid and exposure, with exposure as a repeated measure, was significant ($F = 79.5$, df = 4,12; $F = 597.7$, df = 4,12; $F = 364$, df = 4,8; $F = 542.7$, df = 4,8 and $F = 124.1$, df = 4,16 for second, third, fourth, early fifth, and mature fifth instars, respectively, $P < 0.01$). Exposure was also significant ($F = 25.1$, df = 4,16; $F = 43.9$, df = 3,16; $F = 243.5$, df = 2,16; $F = 364.5$, df = 4,16; and $F = 510.0$, df = 4,16 for second, third, fourth, early fifth, and mature fifth instars, respectively, $P < 0.01$). All interactions were also significant at $P < 0.01$. As larvae aged, longer exposure intervals were required at each concentration to kill all exposed individuals (Table 4). Some mature fifth instars survived after 20 d when exposed at the lower concentrations, and this instar was the most tolerant larval stage of the Indianmeal moth exposed to imidacloprid.

For each larval stage, the analysis for concentration of thiamethoxam and exposure, with exposure as a repeated measure for the fourth and fifth instars, was

Table 2. Percent mortality (mean ± SEM) of 5th instar European corn borer exposed for 2, 3, 4, 5, and 6 d on corn treated with thiamethoxam[a]

Concentration (ppm)	Exposure (days)				
	2	3	4	5	6
0	0 ± 0.0f	3 ± 1.6g	4 ± 1.6e	7 ± 3.0e	12 ± 3.2d
12.5	0 ± 0.0f	35 ± 2.5f	55 ± 4.9d	67 ± 5.1d	76 ± 3.4c
25	24 ± 2.7e	39 ± 2.5f	60 ± 6.3d	68 ± 2.4d	77 ± 5.5c
50	33 ± 3.0d	48 ± 3.2e	71 ± 1.6c	77 ± 1.6c	88 ± 1.3b
100	53 ± 2.0c	71 ± 2.7d	81 ± 4.4d	91 ± 1.6b	97 ± 1.6a
200	73 ± 2.1b	79 ± 1.3c	87 ± 2.1b	97 ± 1.6a	100a
300	85 ± 2.5a	87 ± 2.1b	100a	100a	100a
400	90 ± 1.0a	100a	100a	100a	100a

[a] Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller-Duncan k-ration *t*-test, SAS Institute 2001).

Table 3. Toxicity of thiamethoxam to 5th instar European corn borer at 29°C

Days	LC_{50} (95% FL)	LC_{90} (95% FL)	Slope	H^2	df
2	85.90 (73.4–100.0)	399.3 (327.5–508.7)	1.92 ± 0.14	16.29	33
3	40.50 (31.8–49.6)	349.5 (266.3–495.7)	1.37 ± 0.13	19.02	33
4	15.70 (10.8–20.8)	157.3 (121.3–219.9)	1.28 ± 0.15	28.76	33
5	10.40 (6.7–14.4)	84.3 (66.4–113.5)	1.41 ± 0.18	17.21	33
6	7.22 (4.0–10.5)	46.9 (36.9–62.5)	1.58 ± 0.24	15.34	33

Table 4. Percent mortality (mean ± SEM) of Indianmeal moth larvae exposed for 5, 10, 15, and 20 d on untreated corn and corn treated with imidacloprid and held at 29°C[a]

Concentration (ppm)	Exposure (days)				
	5	10	15	20	25
		2nd instars			
0	20 ± 3.5b	26 ± 2.5c	26 ± 2.5c	32 ± 2.6d	
6.3	17 ± 3.4b	21 ± 6.0c	27 ± 6.2c	38 ± 4.6b	
62.5	81 ± 4.5a	92 ± 1.2b	95 ± 1.6a	100a	
156.3	96 ± 1.0a	100a			
312.5	100a	100a			
		3rd instars			
0	15 ± 2.2c	19 ± 2.9b	20 ± 2.7b		
62.5	56 ± 5.0b	80 ± 3.1a	95 ± 2.7a		
156.3	100a	100a	100a		
312.5	100a	100a	100a		
625.0	100a	100a	100a		
		4th instars			
0	8 ± 3.0c	16 ± 4.0c	22 ± 3.4b		
62.5	21 ± 1.8b	54 ± 3.3b	85 ± 3.5a		
156.3	37 ± 3.3b	78 ± 2.5ab	90 ± 3.2a		
312.5	64 ± 7.6a	91 ± 2.4a	97 ± 1.2a		
625.0	78 ± 6.0a	93 ± 2.5a	100 ± 0.0a		
		early 5th instars			
0	1 + 1.0c	9 + 2.4c	17 + 3.0c		
62.5	2 + 1.2a	28 + 3.7b	73 + 3.4b		
156.3	20 + 3.2b	49 + 2.4b	94 + 1.9a		
312.5	45 + 3.5a	65 + 2.7a	100a		
625.0	61 + 4.0a	79 + 2.4a	100a		
		late 5th instars[b]			
0	1 ± 1.0b	2 ± 1.8b	29 ± 1.9b	33 ± 2.0b	
6.25	3 ± 2.0b	37 ± 1.2a	41 ± 4.6a	65 ± 3.2a	
62.5	1 ± 1.0b	41 ± 4.6a	65 ± 3.2a	77 ± 3.0a	
156.3	3 ± 1.2b	44 ± 2.4a	60 ± 3.5a	73 ± 5.8a	
312.5	49 ± 3.3a	48 ± 3.7a	56 ± 2.9a	78 ± 2.5a	

[a] Means within columns followed by the same letter are not significantly different ($P \geq 0.05$, SAS) Waller-Duncan k-ration *t*-test, SAS Institute 2001.
[b] Mortality of late 5th instars after 25 d, at 0, 6.25, 62.5, 156.3, and 312.5 ppm of exposure was 33.3 ± 2, 75.5 ± 4.7, 85 ± 2.2, 84 ± 1.6 and 100.0%, respectively.

significant ($F = 140.6$, df = 4, 23; $F = 421.3$, df = 4,23; $F = 64.4$ df = 4,8; $F = 503.0$ df = 4,16, and $F = 307.9$, df = 4,15 for second, third, fourth, early fifth, and mature fifth instars, respectively, $P < 0.01$). Exposure interval was also significant (Table 5) ($F = 34.9$, df = 2,16; $F = 2358.6$, df = 4,16; and $F = 690.0$, df = 4,16 for fourth, early fifth, and mature fifth instars, respectively, $P < 0.01$). All interactions were also significant at $P < 0.01$. As the Indianmeal moth larvae aged, they became less susceptible to thiamethoxam, and higher concentrations and longer exposure intervals were required to give 100% control (Table 6). Second and third instars were very susceptible and at least 98% of the exposed larvae died after 5 d on all concentrations. Mortality of fourth, early fifth, and mature fifth instars after 5 d of exposure on treated corn ranged from 64 ± 7.5–80 ± 5.5%, 1 ± 1–39 ± 4.0%, and 0–26 ± 2.4%, respectively. As the exposure interval increased, mortality increased, with 100% mortality occurring after 15, 20, and 25-d exposure of fourth, early fifth, and mature fifth instars, respectively.

Mature Fifth Instars Were Also the Most Tolerant of the Larval Stages Exposed to Thiamethoxam. When mature fifth instars were exposed on corn treated with imidacloprid and held at room temperature of ≈22–25°C, both concentration ($F = 84.1$, df = 5,24, $P < 0.01$) and exposure were significant ($F = 367.5$, df = 6, 24, $P < 0.01$), with exposure as a repeated measure. Mortality generally increased with both concentration and exposure (Table 7), and after 38 d ranged from 90 ± 4.2–100% in the insecticide treatments. Similar results were obtained for fifth instars exposed on corn treated with thiamethoxam and held at room temperature of ≈22–25°C. Both concentration ($F = 104.9$, df = 4,24, $P < 0.01$) and exposure were significant ($F = 604.1$, df = 6, 24, $P < 0.01$), with exposure as a repeated measure. Mortality of mature fifth instars at all concentrations was low during the first 12 d of exposure, then gradually increased to 66 ± 5.1–100% after 38 d (Table 7).

Indianmeal Moth on Sorghum. For each larval stage exposed on sorghum, the analysis for concentration of imidacloprid and exposure, with exposure as a repeated measure, was significant ($F = 8.2$, d. f. = 1, 23) for second instars, $F = 3376.7$ df = 4.8; $F = 593.6$, df = 4, 12; $F = 130.0$ df = 4, 12; and $F = 327.4$, df = 4, 16 for third, fourth, early fifth, and mature fifth instars, respectively, $P < 0.01$ for all stages). Days of exposure

Table 5. Percent mortality (mean ± SEM) of Indianmeal moth larvae exposed for 5, 10, and 15 d on untreated corn and corn treated with thiamethoxam and held at 29°C[a]

Concentration (ppm)	Exposure (days)			
	5	10	15	20
	3rd instars[ab]			
0	13 + 3.7b			
50	99 + 1.0a			
100	98 + 1.2a			
250	100a			
500	100a			
	4th instars			
0	12 ± 3.4b	16 ± 2.9b		
50	64 ± 7.5a	85 ± 2.7a		
100	71 ± 4.0a	98 ± 2.0a		
250	67 ± 4.4a	98 ± 1.2a		
500	80 ± 5.5a	100a		
	early 5th instars			
0	0	26 ± 4.8b	26 ± 4.8b	
50	3 ± 1.2c	85 ± 2.2a	89 ± 2.9a	
100	1 ± 1.0c	94 ± 1.9a	100a	
250	15 ± 2.7b	96 ± 2.4a	100a	
500	39 ± 4.0a	100a	100a	
	late 5th instars[c]			
0	0b	7 ± 2.0c	16 ± 2.9b	16 ± 2.9c
50	0b	21 ± 4.0d	45 ± 2.2a	77 ± 4.6b
100	2 ± 2.0b	17 ± 3.0b	52 ± 3.4a	85 ± 1.6b
250	8 ± 2.5b	28 ± 3.7a	53 ± 2.5a	96 ± 1.9a
500	26 ± 2.4a	45 ± 3.2a	64 ± 2.4a	94 ± 4.4a

[a] Means within columns followed by the same letter are not significantly different (Waller-Duncan k-ration *t*-test, SAS Institute 2001).
[b] All 2nd–3rd instars were dead after 5 d exposure on treated corn.
[c] Mortality after 25 d at 0, 50, 100, 250, and 500 ppm was 16 ± 2.9, 89 ± 1.9, 96 ± 1.8, 100 and 100%, respectively.

Table 6. Percent mortality (mean ± SEM) of mature 5th instar Indianmeal moth exposed for 2 to 38 d on untreated corn and corn treated with imidacloprid and held at room temperature of about 22 to 25°C[a]

Concentration (ppm)	Exposure (days)						
	2	4	6	12	14	32	38
0	0	0b	4 ± 1.6b	16 ± 1.6a	20 ± 1.2b	24 ± 2.7b	26 ± 1.6b
156.3	0	2 ± 1.3b	8 ± 2.5b	20 ± 2.1a	34 ± 1.6b	66 ± 2.7a	90 ± 4.2a
312.5	0	2 ± 1.3b	8 ± 2.5b	20 ± 2.1a	82 ± 2.9a	90 ± 4.2a	100a
625.0	0	8 ± 2.5ab	14 ± 1.6ab	26 ± 3.4a	78 ± 5.3a	94 ± 2.7a	100a
937.5	0	16 ± 1.6a	22 ± 2.4a	32 ± 2.5a	86 ± 2.7a	100a	100a

[a] Means with columns followed by the same letter are not significantly different ($P \geq 0.05$, Waller-Duncan k-ratio *t*-test, SAS Institute 2001).

Table 7. Mortality (mean ± SEM) of mature 5th instar Indianmeal moth larvae exposed for 2 to 38 d on untreated corn and corn treated with thiamethoxam and held at room temperature of about 22 to 25°C[a]

Concentration (ppm)	Exposure (days)						
	2	4	6	12	24	32	38
0	0	0	0	6 ± 2.4	18 ± 5.8	24 ± 4.0	36 ± 4.0
50	0	0	2 ± 2.0	16 ± 6.7	40 ± 10.9	62 ± 9.9	66 ± 5.1
100	0	0	4 ± 2.4	16 ± 4.0	38 ± 8.0	82 ± 4.9	88 ± 4.9
250	0	0	4 ± 2.4	12 ± 2.0	24 ± 5.2	92 ± 3.7	98 ± 2.0
500	0	0	2 ± 2.0	12 ± 3.7	74 ± 8.7	98 ± 2.0	100 ± 0.0

[a] Means with columns followed by the same letter are not significantly different ($P > 0.05$, Waller-Duncan k-ratio *t*-test, SAS Institute 2001).

Table 8. Mortality (mean ± SEM) of Indianmeal moth larvae exposed for 5–30 d on untreated sorghum and sorghum treated with thiamethoxam[a]

Concentration (ppm)	Exposure (days)				
	5	10	15	20	30
			2nd instar		
0	20 ± 2.2b				
50	97 ± 3.3a				
100	100a				
250	100a				
500	100a				
			3nd instar		
0	23 ± 3.0c	24 ± 2.4c			
50	86 ± 4.6b	94 ± 2.4b			
100	96 ± 1.9b	100a			
250	100a	100a			
500	100a	100a			
			4nd instar		
0	19 ± 4.8c	23 ± 4.3c	24 ± 3.7d		
50	79 ± 1.8b	90 ± 1.6b	96 ± 1.8a		
100	82 ± 6.0b	98 ± 1.2a	99 ± 1.1a		
250	81 ± 6.1b	98 ± 2.0a	100a		
500	100a	100a	100a		
			early 5th instar		
0	10 ± 2.2b	13 ± 1.2d	19 ± 1.9d	19 ± 1.9c	
50	18 ± 4.6b	62 ± 3.7b	82 ± 1.2c	93 ± 1.2b	
100	20 ± 5.7b	79 ± 3.3b	92 ± 2.0c	99 ± 1.0b	
250	15 ± 5.7b	61 ± 4.0b	94 ± 3.6b	100a	
500	80 ± 6.7a	100a	100a	100a	
			late 5th instar		
0	13 ± 2.2b	13 ± 2.0d	24 ± 1.8d	24 ± 1.8d	24 ± 1.8c
50	14 ± 1.8b	18 ± 2.0c	78 ± 2.5c	84 ± 1.7c	84 ± 1.7b
100	17 ± 2.0b	25 ± 2.7bc	84 ± 1.8b	88 ± 1.2c	97 ± 1.2b
250	16 ± 1.8b	32 ± 4.6b	88 ± 1.2ab	93 ± 2.0b	100a
500	26 ± 2.9a	46 ± 6.4a	93 ± 3.3a	100a	100a

[a] For each instar, means followed by the same letter are not significantly different ($P \geq 0.05$ Waller-Duncan k-ratio *t*-test, SAS Institute 2001).

was also significant ($F = 26.0$, df = 1,4; $F = 36.5$, df = 2,8; $F = 124$ df = 3,12, and $F = 704.8$, df = 4,16 for third, fourth, early fifth, and mature fifth instars, respectively, $P < 0.01$ for all instars). All interactions were also significant at $P < 0.01$. All second instars were killed when exposed on sorghum treated with thiamethoxam (Table 8). At each concentration, mortality generally decreased as larvae aged and increased with exposure interval, similar to results for Indianmeal moth exposed on corn. Although mortality of fifth instars was low for the first 10 d, a sharp increase in mortality occurred after 15 d at all tested doses. A mortality of 100% occurred after 20 and 25 d in the 500 and 250-ppm treatments, respectively, compared with mortalities of 84.0 and 97.0%, respectively, after 25 d in the 50 and 100-ppm treatments.

Discussion

As lepidopteran larvae develop, they often become more tolerant to insecticides. In our test, final instars of the Indianmeal moth were more difficult to kill compared with prior instars. Other tests with residual insecticides have shown that wandering-phase last-instar Indianmeal moth larvae are much more tolerant of insecticides than stored-product beetles. In tests where concrete was treated with the high and low label rates of 20% cyfluthrin wettable powder (100 and 200 mg/m^2), exposure intervals for 1–2 h would kill adults of the red flour beetle, *Tribolium castaneum* (Herbst), and the confused flour beetle, *T. confusum* (DuVal), for up to 12 wk after application (Arthur 1998a, b). However, when wandering-phase Indianmeal moths were exposed to the same concentration, there was little residual control and larvae were able to pupate and emerge as adults (Arthur 1999). In tests where cyfluthrin was applied directly to inshell peanuts, application rates of two and four ppm controlled adult red flour beetles, while application rates up to 22 ppm did not prevent adult emergence of Indianmeal moths exposed as wandering-phase larvae (Arthur 1995). Similar results have been obtained for other trials involving residual insecticides and residual exposures of Indianmeal moth and stored-product beetles (Arthur 1997). There are published reports of tests that imply equivalent control of Indianmeal moths and almond moths, *Cadra cautella* (Walker) and stored-product beetles, but in these tests the lepidopterans were exposed as eggs (Ardley 1976, Bengston et al. 1980, Bengston et al. 1987). Insecticidal applications that control coleopteran pests may not be effective against late-instar Indianmeal moths. Our results suggest that stored corn or sorghum grain treated with thiamethoxam or imidacloprid at rates commonly used to control field crop pests should be well protected from the possibility of infestations by these two lepidopteran species.

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