TOXICITY OF SELECTED INSECTICIDES TO FALL ARMYWORMS (LEPIDOPTERA: NOCTUIDAE) IN LABORATORY BIOASSAY STUDIES

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ABSTRACT

Efficacy of conventional and experimental insecticides against the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), was evaluated in laboratory bioassays. In a laboratory diet bioassay, third instars of a laboratory-strain were more susceptible to novel insecticides, including chlorfenapyr, methoxyfenozide, spinosad, and tebufenozide, than to a recommended insecticide, thiodicarb. In other laboratory bioassays, fall armyworms were fed field grown cotton leaves, white flowers, or bolls treated with one of two recommended insecticides, L-cyhalothrin or thiodicarb, or one of four experimental insecticides, chlorfenapyr, emamectin benzoate, methoxyfenozide, or spinosad. First instar mortality was significantly greater on leaves treated with chlorfenapyr, L-cyhalothrin, or thiodicarb than for the untreated control at 24 h after infestation (HAI). First instar mortality was significantly greater on leaves treated with all insecticides, with the exception of methoxyfenozide, than for the untreated control at 48 HAI. Likewise, first instar mortality was significantly greater on white flowers treated with all insecticides, with the exception of methoxyfenozide, than for the untreated control at 24 HAI. First instar mortality on white flowers treated with all insecticides was significantly greater than the untreated control at 48 HAI. Fifth instar mortality on bolls was not significantly different among treatments at 1 day after infestation (DAI). At 3 and 5 DAI, fifth instar mortality was significantly greater on bolls treated with all insecticides, with the exception of methoxyfenozide and spinosad, than for the untreated control. At 7 DAI, fifth instar mortality was significantly greater on bolls treated with all insecticides, with the exception of spinosad, than for the untreated control. These data indicate that these recommended and experimental insecticides are effective in controlling early fall armyworm instars on cotton if larvae come in contact with these insecticides.

Key Words: *Spodoptera frugiperda*, efficacy, chemical control, insecticides

RESUMEN

La eficacia de insecticidas convencionales y experimentales contra el gusano cogollero del maíz, *Spodoptera frugiperda* (J. E. Smith), se evaluó con bioensayos de laboratorio. En un experimento de dieta, se documentó que instares terceros de una colonia de laboratorio eran más susceptibles a los insecticidas nuevos, incluyendo a chlorfenapyr, methoxyfenozide, spinosad, y tebufenozide, que a un insecticida recomendado, thiodicarb. En otros experimentos de laboratorio, los gusanos cogolleros se alimentaron con hojas de algodón, flores blancas, o bellotas tratadas con uno de dos insecticidas recomendados, L-cyhalothrin o thiodicarb, o uno de cuatro insecticidas experimentales, chlorfenapyr, emamectin benzoate, methoxyfenozide, o spinosad. La mortalidad del primer instar fue significativamente mayor en hojas tratadas con chlorfenapyr, L-cyhalothrin, o thiodicarb que en hojas control no tratadas 24 h después de la infestacion (HAI, "hours after infestation"). La mortalidad del primer instar fue significativamente mayor a las 48 HAI en hojas tratadas con cualquiera de los insecticidas, con la excepción de methoxyfenozide, que con cualquier hoja control no tratada. Igualmente, la mortalidad del primer instar fue significativamente mayor a las 24 HAI en flores blancas tratadas con cualquiera de los insecticidas, con la excepción de methoxyfenozide, que con el control. La mortalidad del primer instar a las 48 HAI en flores blancas tratadas con cualquiera de los insecticidas fue significativamente mayor que en los controles no tratados. La diferencia en la mortalidad del quinto instar en bellotas entre los tratamientos en el día 1 de la infestacion (DAI, "day of infestation") no fue significativa. En los DAI 3 y 5, la mortalidad del quinto instar fue significativamente mayor en bellotas tratadas con cualquiera de los insecticidas, con la excepción de methoxyfenozide y spinosad, que con el control no tratado. En el DAI 7, la mortalidad del quinto instar fue significativamente mayor en botones tratados con cualquiera de los insecticidas, con la excepción de spinosad, que en el control no tratado. Estos datos indican que los insecticidas recomendados y experimentales mencionados aquí son eficaces para el control de instares pequeños del gusano de *Spodoptera frugiperda* en algodón si las larvas contactan estos insecticidas.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is a pest of many crops in the southern United States, including rice, *Oryza sativa* L.; field corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.; and cotton, *Gossypium hirsutum* L. (Young 1979). Historically, this insect is considered as a sporadic pest on cotton, but it has become an annual economic cotton pest in Georgia, Alabama, and Florida (Smith 1985). In 1977, this pest caused significant damage to cotton throughout the southeastern United States (Bass 1978), and in 1984, caused economic damage in the Winter Garden region of Texas (King et al. 1986). In 1985, it was the single most damaging cotton pest reported in Mississippi (King et al. 1986). Recently, local outbreaks of fall armyworms have been reported on transgenic *Bacillus thuringiensis* (Bt) cotton cultivars in Alabama and Georgia (Hood 1997, Smith 1997).

Fall armyworms on cotton are difficult to control with insecticides. Larvae are usually distributed low in the plant canopy (Ali et al. 1990), and inadequate insecticide deposition in the lower portions of the cotton plant seems to be one limiting factor in controlling this pest (Mink & Luttrell 1989). Insecticides that are used to control the tobacco budworm, *Heliothis virescens* (F.), and the cotton bollworm, *Helicoverpa zea* (Boddie), often are ineffective against fall armyworms (Smith 1985). Pyrethroids may have some effect on young fall armyworm larvae, but in general provide little overall control, while carbaryl and methyl parathion are completely ineffective for controlling this pest on cotton (Smith 1985). Although the CryIA (c) ∂-endotoxin is expressed throughout genetically engineered transgenic Bt cotton plants, this particular ∂-endotoxin should be classified as sublethal to fall armyworm larvae (Jenkins et al. 1992, Jenkins et al. 1997, Adamczyk et al. 1998). In addition, many studies have shown that fall armyworms are resistant to a number of compounds including carbaryl, methyl parathion, trichlorfon, and numerous pyrethroids (Young & McMillian 1979, Wood et al. 1981, McCord & Yu 1987, Yu 1991), which further complicates control of this pest on cotton. The purpose of these studies was to examine the toxicity of selected conventional and experimental insecticides to fall armyworm larvae in laboratory bioassays.

Materials and Methods

Diet Bioassay with Experimental Insecticides

A fall armyworm colony consisting of the corn-associated strain (Pashley 1986), which had been reared in the laboratory for at least 30 generations, (obtained from Dr. H.W. Fescemyer, Clemson University, Department of Entomology) was tested with a recommended insecticide, thiodicarb (Larvin® 3.2F [flowable], Rhône-Poulenc Ag. Co., Research Triangle Park, North Carolina), as well as four novel compounds including chlorfenapyr (Pirate® 3SC [soluble concentrate], American Cyanamid, Princeton, New Jersey), methoxyfenozide (Intrepid® 80WP [wettable powder], Rohm & Haas Co., Philadelphia, Pennsylvania), spinosad (Tracer® 4SC, Dow AgroSciences, Indianapolis, Indiana), and tebufenozide (Confirm® 2F, Rohm & Haas Co., Philadelphia, Pennsylvania).

The surface-treated diet bioassay methods were similar to those described by Joyce et al. (1986), Chandler & Ruberson (1994), and Mascarenhas et al. (1996). Three ml of a soybean/protein meridic diet (King & Hartley 1985) were pipetted into 30 ml cups and allowed to cool at room temperature for approximately 1 h. For each insecticide tested, serial dilutions of formulated material (100 µl aliquots) were pipetted onto the diet surface, agitated to distribute evenly, and allowed to dry for approximately 30 min.

Third instar fall armyworms (30-45 mg) were placed into a series of cups that contained 4-5 different concentrations (ppm) of formulated insecticide, along with untreated controls to determine the LC_{50} for a given insecticide. Each cup contained one larva. The cups were sealed with corresponding lids and bioassays were conducted under constant light at 22 ± 1°C and 40 ± 5% RH. A minimum of 30 larvae per dose were tested for each insecticide, and mortality was assessed at 120 h after treatment (HAT). Larvae were considered dead if no movement was observed after prodding with blunt forceps for 10 s. Control mortality never exceeded 5%. LC_{50}'s were considered significantly different from one another if the 95% confidence limits did not overlap. Data were analyzed and LC_{50}'s generated with POLO-PC using probit analysis (LeOra Software 1987).

Toxicity of Cotton Plant Parts Treated with Insecticides to Fall Armyworm Larvae

Fall armyworm larvae were collected from field corn in May 1997 at the Macon Ridge Location of the Northeast Research Station (Louisiana State University Agricultural Center, Louisiana Agricultural Experiment Station) near Winnsboro, LA. F_1 generation larvae were used in all tests. Cotton plants (cv. DP 5690 ≈ 1.0 m tall) were sprayed with selected foliar insecticides using a high clearance sprayer, and compressed air system, calibrated to deliver 56.1 L total spray/ha through Teejet TX-8 hollow cone nozzles (2/row) at 3.3 kg/cm^2. Selected insecticides included methoxyfenozide, L-cyhalothrin (Karate® 1EC [emulsifiable concentrate], Zeneca Ag. Products, Wilmington, Delaware), thiodicarb, chlorfenapyr, emamectin benzoate (Proclaim® 5SG [soluble granule], Novartis, North Carolina), and spinosad. Treatments were arranged in a randomized complete block design (RCB) and replicated 4 times. Plots consisted of 4 rows (1.0 m centers) × 15.2 m. Cotton leaves, white flowers, and bolls, were removed from the lower 0.5 m of treated plants 2 HAT, and transported to the laboratory for each test.

The toxicity of insecticide-treated cotton leaves and white flowers to first instar (1-d-old) fall armyworms was evaluated. Five first position white flower subtending leaves, and entire white flowers, were removed from treated plants within the center 2 rows of each plot. Individual leaves were placed into 9.0 cm plastic Petri dishes, and entire white flowers were placed into individual 236.6 ml paper Solo® cups. A moistened filter paper was placed into each dish or cup to delay plant tissue desiccation. Fall armyworm larvae were reared on artificial diet for 24 hours to minimize disease effects, and healthy larvae transferred to treated leaves or white flowers. Five larvae were placed in each dish or cup (5 larvae/5 dishes or cups/plot, and replicated 4 times = 100 larvae/treatment) using a small camel-hair brush. The dishes or cups were sealed with corresponding lids. Both dishes and cups were maintained at 25º ± 1ºC and 40 ± 5% RH. Larval mortality was assessed at 24 and 48 h after infestation (HAI) and were considered dead if no movement was observed after being probed gently with a camel-hair brush for 5 s. Mean mortality was calculated for each dish or cup, and these means were analyzed using ANOVA and treatments separated using the Waller-Duncan k-ratio t-test (PRM 1995).

The toxicity of insecticide-treated cotton bolls to fifth instar (200-350 mg) fall armyworms was evaluated using similar methods. Cotton bolls were age-classed using the methods described in Adamczyk et al. (1997a). White flowers from the lower 0.5 m from plants were tagged at anthesis and heat unit (HU) accumulation was recorded. Bolls had accumulated 187.0 HU at the time insecticides were applied. These bolls were removed from the plants and placed into individual 110.9 ml plastic cups. One fifth instar was placed in each cup (10 bolls/plot and replicated 4 times = 40 larvae/treatment), and the cups were sealed with corresponding lids. These containers were maintained in an environmental chamber at 26 ± 1ºC and a photoperiod of 14:10 (L:D) h. Larval mortality was assessed from 1-9 days after infestation (DAI) and were considered dead if no movement was observed after being probed with blunt forceps for 10 s. Results were analyzed using ANOVA and treatments separated using the Waller-Duncan k-ratio t-test (PRM 1995).

Results and Discussion

Diet Bioassay with Experimental Insecticides

The fall armyworm consists of two host-associated strains that widely differ in their susceptibility to insecticides (Adamczyk et al. 1997b). Therefore, it is essential that fall armyworm insecticide efficacy studies identify the host from which the test insects were collected. Our data contain baseline susceptibility information for corn-associated fall armyworms treated with four novel insecticides which can be used in the future for monitoring insecticide susceptibility. LC_{50} values ranged from 4.4 ppm for spinosad, to 492.9 ppm for thiodicarb (Table 1). The four novel insecticides (chlorfenapyr, methoxyfenozide, spinosad, and tebufenozide) were more toxic than the recommended insecticide, thiodicarb. The LC_{50} values for these new insecticides are similar to those reported by Mascarenhas et al. (1996) for the beet armyworm, *Spodoptera exigua* (Hübner), using these same methods.

Toxicity of Cotton Plant Parts Treated with Insecticides to Fall Armyworm Larvae

First instar mortality was significantly greater on cotton leaves treated with chlorfenapyr, L-cyhalothrin, or thiodicarb than for the untreated control at 24 HAI (Table 2). At 48 HAI, mortality for all treatments, with the exception of methoxyfenozide, was significantly greater than for the untreated control.

First instar mortality was significantly greater on white flowers for all treatments, with the exception of methoxyfenozide, than for the untreated control at 24 HAI (Table 2). At 48 HAI, mortality for all treatments was significantly greater than for the untreated control.

Fifth instar mortality on bolls was not significantly different among treatments at 1 DAI (Table 3). Larval mortality for all treatments, with the exception of methoxyfenozide and spinosad, was significantly greater than for the untreated control at 3 and 5 DAT. Fall armyworm larval mortality for all treatments, with the exception of spinosad, was significantly greater than for the untreated control at 7 DAT.

Most of the insecticides tested against fall armyworms were equally effective. While spinosad was very effective against first instars, the activity against fifth instars was numerically lower compared to methoxyfenozide, L-cyhalothrin, thiodicarb,

TABLE 1. SUSCEPTIBILITY OF THIRD INSTAR FALL ARMYWORMS FROM A LABORATORY STRAIN[1] AFTER FIVE DAYS OF EXPOSURE TO DIET TREATED WITH SELECTED INSECTICIDES.

			95% Confidence Limits			
Insecticide	No. Tested	LC_{50}[2] (ppm)	Low	High	Slopes (SE)	X^2
Chlorfenapyr	150	8.3	7.0	9.7	10.47 (1.75)	4.15
Methoxyfenozide	130	197.9	138.8	294.9	1.82 (0.42)	1.83
Spinosad	135	4.4	1.7	6.8	1.43 (0.42)	1.72
Tebufenozide	135	30.1	20.0	40.6	2.09 (0.44)	0.63
Thiodicarb	135	492.9	357.7	602.6	3.55 (0.74)	0.62

[1]Clemson University, Department of Entomology.
[2]LC_{50}'s significantly different if 95% confidence limits do not overlap.

chlorfenapyr, and emamectin benzoate. An insect growth regulator, methoxyfenozide, was very effective against both larval stages, but required considerably longer to maximize mortality compared to the other insecticides. In bioassays using field treated cotton parts, the pyrethroid, L-cyhalothrin, and carbamate, thiodicarb, were as effective as the newer compounds.

Our studies generally agree with the results of other fall armyworm research. Fall armyworms are susceptible to numerous insecticides if the larvae are exposed to the

TABLE 2. TOXICITY OF INSECTICIDE RESIDUES ON COTTON LEAVES AND WHITE FLOWERS[1] TO FIRST INSTAR FALL ARMYWORMS.

		% Mortality			
		Leaves		White Flowers	
Treatment	Rate (kg AI/ha)	24 HAI[2]	48 HAI	24 HAI	48 HAI
Chlorfenapyr	0.34	69.7 a	84.1 a	47.7 ab	87.3 ab
Emamectin benzoate	0.01	54.3 ab	81.5 a	67.0 a	92.0 a
L-cyhalothrin	0.04	54.7 a	77.6 a	74.4 a	91.4 ab
Methoxyfenozide	0.51	25.6 c	54.7 b	31.0 bc	77.3 b
Spinosad	0.10	52.6 ab	85.8 a	50.3 ab	94.8 a
Thiodicarb	0.84	58.6 a	87.8 a	54.8 ab	86.5 ab
Untreated		30.7 bc	43.7 b	11.8 c	44.6 c
F value		4.3	5.9	4.6	11.7
($P > F$) ANOVA		<0.01	<0.01	<0.01	<0.01

Means in a column followed by the same letter are not significantly different ($\alpha = 0.05$; Waller-Duncan k-ratio t-test).
[1]Leaves and white flowers removed 2 hours after insecticide treatment.
[2]Hours After Infestation.

TABLE 3. TOXICITY OF INSECTICIDE RESIDUES ON COTTON BOLLS[1] TO FIFTH INSTAR FALL ARMYWORMS.

Treatment	Rate (kg AI/ha)	% Mortality 1 DAI[2]	3 DAI	5 DAI	7 DAI
Chlorfenapyr	0.34	10.0 a	42.5 a	52.5 a	57.5 a
Em. benzoate	0.01	10.0 a	32.5 a	50.0 a	50.0 ab
L-cyhalothrin	0.04	20.0 a	32.5 a	40.0 ab	45.0 ab
Methoxyfenozide	0.51	5.0 a	10.0 b	35.0 abc	55.0 a
Spinosad	0.10	5.0 a	7.5 b	12.5 bc	22.5 bc
Thiodicarb	0.84	25.0 a	42.5 a	47.5 a	52.5 a
Untreated		0.0 a	2.5 b	7.5 c	15.0 c
F value		2.4	6.6	4.3	3.8
($P > F$) ANOVA		0.07	<0.01	<0.01	<0.01

Means in a column followed by the same letter are not significantly different ($\alpha = 0.05$; Waller-Duncan k-ratio t-test).
[1]Bolls removed 2 hours after insecticide treatment.
[2]Hours After Infestation.

insecticide (Mink & Luttrell 1989), but first instars are more susceptible to insecticides compared to later instars (Yu 1983). In addition, inadequate penetration of insecticide sprays to the lower portions of the cotton plant continues to be a limiting factor in controlling this pest (Mink & Luttrell 1989, Ali et al. 1990). Thus, it may be beneficial for a producer to manage excessive plant height with plant growth regulators (PGR s) in geographical areas where fall armyworms are an annual cotton pest.

ENDNOTE

The authors would like to thank Cotton Incorporated for financial support of this project. We would like to thank Larry Daigle, Jon Holloway, Victor Mascarenhas, and David Nyagah for their assistance in many aspects of these studies. This manuscript is approved for publication by the Director of the Louisiana Agricultural Experiment Station as Manuscript No. 98170068.

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