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MONITORING FOR PYRETHROID RESISTANCE IN BOLLWORM (HELICOVERPA ZEA) IN TEXAS - 2004

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Abstract

A statewide monitoring program for resistance to pyrethroids in males of bollworm (*Helicoverpa zea*) was conducted from April to September of 2004, surveying nine Texas counties. Moths were trapped near cotton fields using pheromone, Hercon Luretape® with Zealure. Moths were collected early in the morning and assays were performed the same day. Vials were prepared in the Toxicology Laboratory, Department of Entomology at Texas A&M University, College Station, Texas, and shipped as needed to Extension personnel. Moths from Burleson, Nueces, and Uvalde Counties, which had survivors at the highest dosage of 30 µg/vial in 2003, were tested at additional dosages of 60 and 100 µg/vial in 2004. A total of 2,070 moths were tested from Burleson County. Other counties in Texas participating in the monitoring program were: Hale, Hockley and Gaines Counties in the High Plains production region; Tom Green County in the Southern Rolling Plains region; Ellis and Williamson Counties in the Blacklands; Uvalde County in the Winter Garden region; and Nueces County in the Coastal Bend region. A total of 3,377 moths were tested for all areas outside Burleson County. Data from all areas in Texas was sent to Texas A&M University Toxicology laboratory and analyzed. Levels of resistance in Nueces County were nine times the LC50 value calculated in June for susceptible field populations studied by Kanga et al. (1996). Moths in

Ellis County in July were seven times more resistant. Uvalde County had resistance ratios of six in September, and in Burleson (September), Ellis (July), and Williamson (June/July) moths were five times more resistant. Bollworm populations from Hockley County were susceptible to pyrethroids in 2004, having similar susceptibility as populations tested by Kanga et al. (1996).

Introduction

We previously reported resistance to pyrethroids in bollworm (*Helicoverpa zea*) in Burleson Co., Texas (Pietrantonio et al., 2000; Pietrantonio and Sronce, 2001; Payne et al., 2001) and in Burleson, Nueces and Castro Counties (Pietrantonio et al., 2004). We continued the monitoring of pyrethroid resistance for bollworm during 2004, focusing in counties in which we suspected bollworm resistance could be present based in part on the production characteristics of the zone. Pyrethroid use is widespread in cotton and in other systems such as corn and grain sorghum, in the latter one against the "headworm" complex. The purpose of this study was to assess the susceptibility of bollworm to pyrethroids in the main production areas of Texas providing a summary of the context for pyrethroid use when possible for the different counties.

Materials and Methods

Moth Collection and Vial Assays:

Adult male *Helicoverpa zea* moths were trapped using pheromone, Hercon Luretape® with Zealure from Great Lakes IPM (Vestaburg, MI). Moths were collected early in the morning and assays were performed the same day. Moths were supplied with a sucrose solution until placed in vials. Only healthy, vigorous male moths with intact wing scales were used for bioassays. An adult vial test (AVT) similar to that described by Plapp et al. (1987, 1990) was used to monitor the susceptibility of bollworm to cypermethrin. Vials were prepared in the Department of Entomology, Toxicology Laboratory at Texas A&M University, College Station, Texas and shipped as needed to Extension collaborators throughout the state. Test vials were prepared by coating the inside of the vial with an acetone (EM Science, Gibbstown, NJ) solution of technical grade cypermethrin (95.2%). This was a generous gift of the FMC laboratory in Princeton, NJ, obtained in 2003 through the collaboration of Chuck States. Acetone was dehydrated for at least 48 h on 4Å molecular sieves (EM Science) before use. The control vials were coated with acetone only. Vials were prepared by dispensing 0.5 ml of acetone or cypermethrin solutions and dried on a cold "hot-dog" roller under the hood for at least 15 minutes. Insecticide dosages used in this study were 0.3, 1, 3, 5, 10, 30 µg cypermethrin/vial. Moths from Burleson, Nueces and Uvalde Counties, which had survivors at the highest dosage of 30 µg/vial in 2003, were tested at additional dosages of 60 and 100 µg/vial in 2004.

One moth was placed in each vial and the vials were stored at 27°C or room temperature. Mortality counts were taken after 24 h. Moths were evaluated as alive, dead, or "knocked-down". Moths that were alive but could not fly in a normal manner were considered "knocked-down" and were included as dead for calculations of percentage of mortality. Two discriminating cypermethrin dosages of 3 µg/vial and 10 µg/vial were used among the various tested. A 2.5 µg/vial dosage was recommended by Kanga et al. (1996) as discriminatory possibly killing all susceptible bollworms. The probit analysis graph shown by these authors suggests the dosage of 5 µg/vial was the ultimate discriminatory concentration for susceptible moths. The IRAC procedure utilized the 5 µg/vial for the same discrimination in previous monitoring efforts (Payne et al., 2001). The 10 µg/vial dosage was chosen because previous experience with the budworm, *Heliothis virescens* showed that this dosage should kill all heterozygote resistant as well as all susceptible insects (Plapp et al., 1987; Payne et al., 2001). Therefore, bollworms surviving the 10 µg/vial dosage are assumed to be homozygote resistant but we lack experimental verification of this in our laboratory. In July 2004 a bioassay was run on the *H. zea* laboratory colony at Texas A&M University. The laboratory colony was started in April of 2004 from neonates donated from Juan D. Lopez at the USDA-ARS, SPARC lab in College Station, Texas. These neonates were started from eggs received from the USDA/ARS at Stoneville, MS. Results of this bioassay were a LC50 of 1.21 µg/vial and a LC95 of 3.27.

Locations:

In Burleson County six wire cone traps were placed in the Brazos River Bottom near cotton and sorghum fields. Traps were located along a two-mile span on Highway 60 and County Road 265. Moths were collected approximately every two weeks beginning April 8, 2004 and ending September 10, 2004. Bioassays were performed at 27°C. From Burleson County 2,070 moths were tested. Other counties in Texas participating in cypermethrin monitoring were: Ellis and Williamson Counties in the Blacklands production region; Nueces County

in the Coastal Bend production region (two traps); Gaines, Hale, and Hockley Counties in the High Plains production region; Tom Green County in the Southern Rolling Plains production region; and Uvalde County in the Wintergarden production region. Numbers of wire cone traps used differed at each location and bioassays were performed at room temperature. A total of 3,377 moths were tested from other areas in Texas.

Data Analysis:

Data from all areas in Texas was sent to the Texas A&M University Toxicology laboratory to be analyzed using Probit-PC, Probit and Logit Analysis and graphed using SigmaPlot. A baseline for susceptibility to cypermethrin in 2003 was established from two areas in Texas with low LC50 values, Hockley County and Wharton County, these values were pooled to obtain a baseline LC50 of 0.283 µg/vial (Pietrantonio et al., 2004). In addition to this in 2004 the LC50 value of 0.44 µg/vial from Kanga et al. Burleson County studies in 1988, 1989, and 1993 was used to calculate resistance ratios (Kanga et al., 1996).

Results and Discussion

Monitoring for bollworm resistance to cypermethrin was conducted from April to September, being particularly intensive in Nueces and Burleson Counties due to their history of resistance in 2003 and previous years (Pietrantonio et al., 2004).

In Nueces County the frequency of resistant individuals increased significantly (p <0.05) from April to June in 2004. Excellent control of bollworm was achieved in May with one pyrethroid application. The resistance ratio rapidly increased from 2.9 and 1.6 in late April and early May, respectively, to 7 in late May. The situation continued to deteriorate through June, reaching resistance ratios of 9 to perhaps 14 depending on which baseline LC_{50} is used for calculations (Table 1). The peak LC_{50} was detected the week of June 18 to 24. Not only had the LC_{50}s increased through the season but also for the first time we detected resistant individuals that survived the 60 µg/vial concentration (Figure 1). Although we do not know the mechanism of resistance at the molecular level, this result is worrisome because it is reminiscent of levels of resistance that can be explained by the target site insensitivity mechanism of resistance (kdr-like or even super kdr-like) in other insect species. Field control failures were first detected south of Corpus Christi in early June and subsequently North of Corpus Christi by late June. Due to these failures, beginning at about the second or third week of flowering in Coastal Bend cotton, control was achieved with 1-3 applications of insecticides with different modes of actions such as indoxacarb, a sodium channel blocker (Steward™), emamectin benzoate (Denim™), a chloride channel(s)/glutamate receptor activator or spinosad (Tracer™), a nicotinic acetylcholine receptor modulator. Steward™ or Denim™ was probably used more.

Table 1. Nueces Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Date	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	LC50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
4/23-30/04	1.305 (.746-2.064)	2.97	4.61	17.156 (8.325-71.451)	2.204	3	180
5/4-13/04	.7407 (.312-1.357)	1.68	2.62	6.745 (2.792-186.313)	.857	1	100
5/23-27/04	3.156 (1.672-4.370)	**7.17**	**11.15**	12.366 (7.856-48.749)	2.585	3	180
5/28-6/2/04	1.341 (.915-1.842)	3.05	4.74	12.598 (7.928-25.720)	2.140	4	270
6/18-22/04 ***	4.092	**9.30**	**14.46**	29.479	2.051	2	180
6/23-24/04	4.005 (2.343-8.713)	**9.10**	**14.15**	109.340 (30.628-3222.532)	1.630	3	180
6/30-7/2/04	1.999 (.420-4.816)	4.543	**7.064**	24.988 (8.776-1052.181)	6.231	4	180

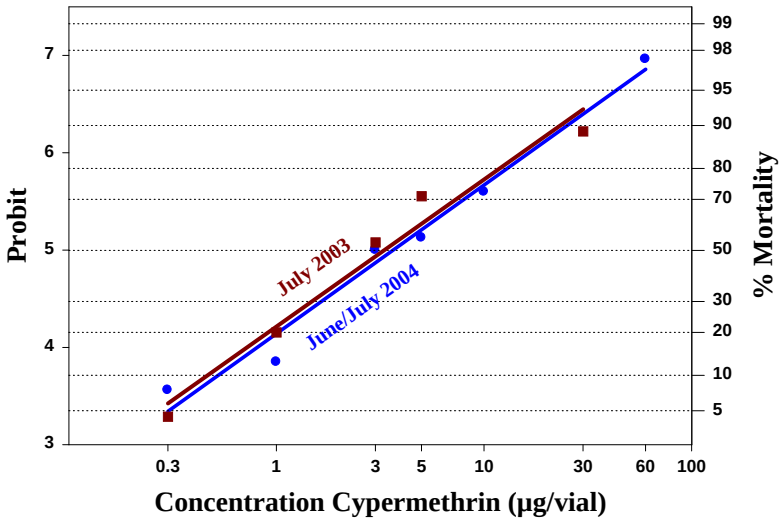

Figure 1. Concentration-mortality lines for bollworm moths collected in 2003 and 2004 in Nueces County and exposed to cypermethrin in the vial assay. Lines are statistically equal and parallel.

The statistical analysis of the probit lines from Nueces County between 2003 and 2004 indicated that the dosage-mortality lines are equal (and parallel), again with the exception of the detection of surviving moths at 60ug/vial in 2004 (Fig. 1).

In addition, trap captures also indicated that this year was unusual in the high population density of bollworm detected. The average daily capture of male moths per week reached a maximum of 70 during the week of June 18th, followed by peak numbers on May 28 (30 moths), May 7 (15 moths) and April 9 (20 moths). Also the period of high population density was longer than usual, trap catches averaged 11.2 moth/day (Parker, 2004). This situation was observed throughout the state.

Table 2. Nueces County % Corrected Survival (µg/vial), 2004

Date	Control	0.3µg/v	1µg/v	3µg/v	5µg/v	10µg/v	30µg/v	60µg/v	100µg/v
4/23/04	100	85	55	35	10	0	5	0	0
5/04-13/04	100	80	30	20	0	0	0	0	0
5/23-27/04	95	89.5	89.5	42.1	36.8	5.3	0	0	0
5/28-6/02/04	100	86.7	63.3	23.3	13.3	6.7	3.3	0	0
6/18-22/04	95	100	94.7	47.4	**47.4**	**26.3**	0	**5.3**	0
6/23-24/04	100	85	85	55	**45**	**30**	0	0	0
6/30-7/02/04	90	100	50	38.9	**38.9**	**11.1**	**5.6**	0	0

The field failures can easily be explained from data shown in Table 2. After June 18 about 47% to 38% of moths were able to survive the discriminatory dosages of 3-5 ug/vial indicating that these percentages corresponded to resistant insects (see percentages in red, Table 2). A smaller percentage survived the 10ug/vial discriminatory dosage for heterozygote insects, from 30% to 11%; 5.3% of insects survived the 60ug/vial concentration. Pyrethroids (many types) were also used for one treatment on 78% of the sorghum acreage (estimated 180,000 acres in Nueces County) to control headworms (*Helicoverpa zea*) and stink bugs during May. The widespread use of pyrethroids in Coastal Bend grain sorghum may have contributed substantially to exert a high selection pressure for pyrethroid resistance in bollworm. Cotton yields in the region were generally good from 850 to 1300 lb/acre in the dry-land acreage. Some fields where water stood had much lower yields. The production activity in the region included 370,000 sorghum acres, 315,000 cotton acres, and 95,000 corn acres in Kleberg, Jim Wells, Nueces, San Patricio, Refugio, and Victoria counties. Transgenic Bt cotton was about 23% of the planted acreage on the Lower Coastal Bend that includes generally the above-mentioned counties.

In **Burleson County**, about 11,500 acres were planted with cotton, approximately 90% being transgenic Bt cotton varieties. Sorghum acreage was 4,800 and corn acreage was 9,200. County Extension agent Dusty Tittle reported no significant problems with insects this year; however some midge damage occurred in sorghum. The main problem faced by growers in 2004 was the heavy rainfall and consequently, wet fields. Cotton planted along County Road 265 was treated once with Mustang Max™ (Z-cypermethrin) in early July for cotton bollworms.

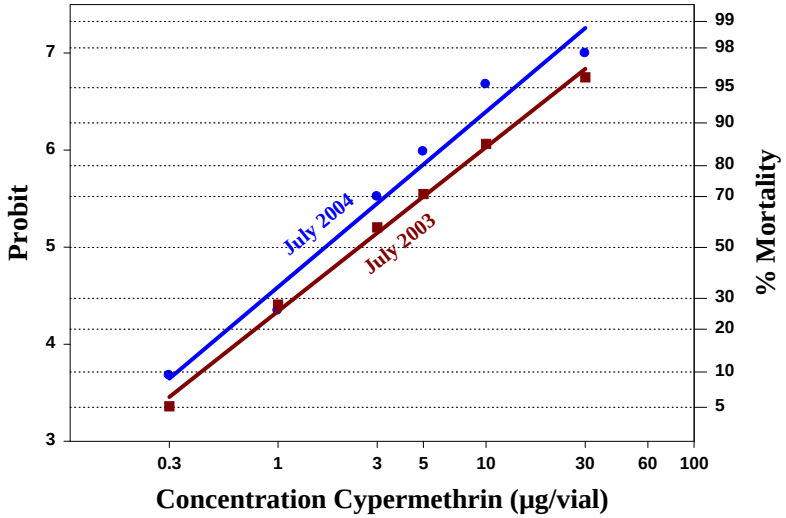

Figure 2. Concentration-mortality lines for bollworm moths collected in 2003 and 2004 in Burleson County and exposed to cypermethrin in the vial assay. Lines are statistically equal and parallel ($p < 0.05$).

Grain sorghum in the area was also treated once with chlorpyrifos (Lorsban™) in June. Acephate (Orthene®) was used for stink bugs in August. Although to our knowledge no field control failures of bollworm were reported, levels of resistance to pyrethroid remained high and similar to those observed in 2003 (Figure 2).

Resistant bollworms were detected throughout the season however the resistance ratios were of concern starting in June and were substantially higher in September (Table 3).

Table 3. Monthly Pooled Burleson Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Dates Pooled	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	LC50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
4/08/04 4/23/04	.894 (.534-1.309)	2.032	3.159	4.466 (2.782-10.838)	7.7103	6	340
5/6/04 5/19/04	.825 (.442-1.200)	1.875	2.915	4.532 (3.014-9.451)	1.5738	2	340
6/02/04 6/16/04	1.656 (.764-2.720)	3.764	**5.852**	9.732 (5.328-39.186)	4.151	3	405
7/14/04 7/21/04	1.844 (1.328-2.396)	4.191	**6.516**	11.790 (8.309-19.847)	3.095	4	360
7/29/04 8/03/04 8/19-20/04	1.034 (.707-1.402)	2.350	3.654	11.361 (7.482-20.891)	2.8623	4	355
9/10/04	2.268 (.982-3.516)	**5.155**	**8.014**	18.775 (8.698-384.795)	1.1443	2	270

Beginning in mid-July and through September, there was an 11-21% survivorship of resistant individuals presumptively heterozygote, and during July, the 8-10% survivorship corresponded presumptively to homozygote resistant bollworms, because they survived the 10 µg /vial concentration (Table 4).

Table 4. Burleson County % Corrected Survival (µg/vial), 2004

Date	Control	0.3µg/v	1µg/v	3µg/v	5µg/v	10µg/v	30µg/v	60µg/v	100µg/v
4/08/04	85	100	35.3	11.8	5.9	0	0	0	0
4/23/04	100	85	30	10	10	0	0	0	0
5/06/04	86.2	80	44.1	8.1	3.9	0	0	0	0
5/19/04	90	66.7	66.7	11.1	0	0	0	--	--
6/02.04	90	100	63	25.9	14.8	11.2	0	0	0
6/16/04	86.7	100	61.5	46.1	7.7	0	0	0	0
6/30/04	100	70	45	20	5	0	0	0	0
7/14/04	95	89.5	84.2	10.5	**15.8**	0	**5.3**	0	0
7/21/04	100	95.7	69.6	47.8	**17.4**	**8.7**	0	0	0
7/29/04	100	80	45	10	**20**	**10**	0	0	0
8/03/04	90	88.9	55.6	22.2	**11.1**	0	0	--	--
8/19-20/04	100	80	60	20	**20**	0	6.7	--	--
9/10/04	93.3	89.3	75	46.4	**21.4**	0	0	0	0

In **Ellis County** all moths were trapped from two fields in the same area, located in the Boyce Community of central Ellis County. Bollworm pressure was heavier in this area in 2004 in comparison to the last five seasons. Densities of up to 36 worms per 100 plants were fairly common for 2004 compared to an average of about 7 worms per 100 plants for the previous 4 to 5 seasons.

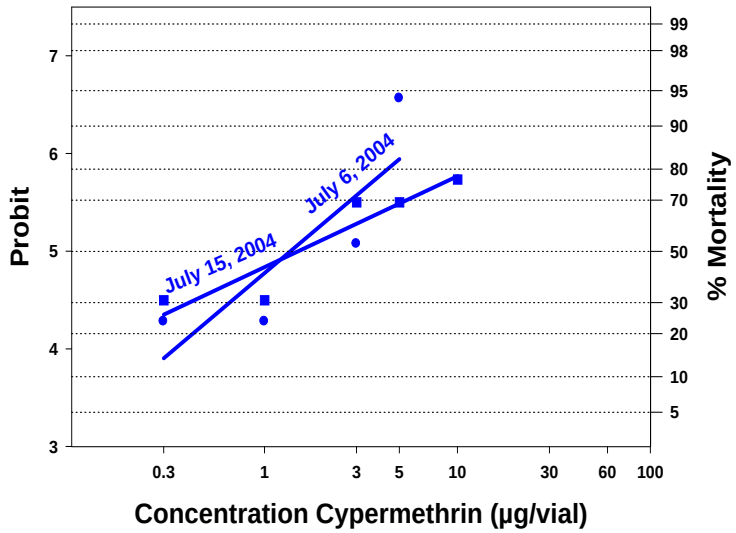

Figure 3. Concentration-mortality lines for bollworm moths collected in 2004 in Ellis County exposed to cypermethrin in the vial assay.

Insecticide applications for bollworms/ tobacco budworms were made July 7 and 14, 2004. The population ratio was 83 % bollworm and 17 % tobacco budworm. The synthetic pyrethroids performed well in most cases with only a few escapes of larger worms. The pyrethroids or pyrethroids mixed with thiodicarb (Larvin®) or profenofos (Curacron®) performed acceptably. Up to two treatments were applied at 7-day intervals. Insecticides used were lambda-cyhalothrin (Karate® 2.08; 0.06 lb./acre) plus thiodicarb (Larvin® 0.2 lb./ac.); lambda-cyhalothrin (Karate® 0.06 lb/acre plus profenofos (Curacron® 0.24 lb./acre) and lambda-cyhalothrin (Karate® 0.069 lb/acre) plus vegetable oil 1%, or cyfluthrin (Baythroid® 0.04 lb./acre). Notice in Table 5 that the escapes observed in the field could well correspond to resistant insects that were at least 6-30% (5 µg/vial diagnostic concentration) of the population in July. A 23% survivorship was also detected at the diagnostic concentration of 10 µg /vial possibly indicating homozygote resistant insects. The resistance ratio was correspondingly high (7.1 to 11) during July indicating that the population was resistant to pyrethroids (Table 6).

Table 5. Ellis County % Corrected Survival (µg/vial), 2004

Date	Control	0.3 µg/v	1 µg/v	3 µg/v	5 µg/v	10 µg/v	30 µg/v
7/06-09/04	85	76.5	76.5	47.1	**5.9**	0	0
7/15-17/04	86.7	69.2	69.2	30.8	**30.8**	**23.1**	0

Table 6. Ellis Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Date	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	LC50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
7/06/04 & 7/09/04	3.14	**7.136**	**11.095**	5.273	2.6256	2	140
7/15/04 7/17/04	1.533 (.252-3.581)	3.484	5.417	79.244 (18.986-27153)	1.1941	3	105

In Ellis and Navarro Counties FCS certified acreage for cotton was 47,000 acres of which 19, 500 was transgenic Bt (Bollgard®). It is estimated that in 2004 there were 47,000 acres of wheat, 43,000 acres of corn, 37,000 acres of sorghum and 7,000 acres of soybeans.

In **Williamson County**, D. Mott indicated that bollworm pressure was the highest seen since 1997 in the Southern Blacklands. The crop acreage was: corn 66,000, sorghum 36,000 and cotton 29,000. High levels of *H. zea* were present in corn and moderate levels in some fields of grain sorghum. Some of the sorghum, perhaps about 15% of the acreage, was sprayed for pyrethroids and control was generally acceptable around mid- to late June.

Insects from Williamson County were collected from 6 traps located within one mile of each other at the Stiles Farm near Thrall, TX. Most of the worm pressure in cotton occurred from the last week of June through the third week of July. Producers observed and were concerned about the fact that the first treatment with a full rate of pyrethroid provided only about 70% control. Wet conditions made it difficult for some producers to retreat a second time or rain delayed subsequent applications and thus more damage was sustained before fields were re-treated.

Field control failures occurred with full label rates of pyrethroids (including cyfluthrin (Baythroid®), lambda-cyhalothrin (Karate®) and others) in many locations in non-Bt cotton fields on larvae that were less than 3-4 days old around July 3rd. Subsequently, acceptable control was achieved in these fields (now with larger larvae) with spinosad (Tracer®; 2.2 to 2.5 oz/ac.) or spinosad (Tracer®) tank mixed with the lowest label rate of pyrethroids. Emamectin benzoate (Denim®) was also used in mixtures with a low label rate of pyrethroid. The use of these mixtures started approximately the 10th of July and provided very good control. Transgenic Bt cotton (Bollgard®) was about 80% of the cotton acreage and producers were concerned with the high density of worms in some Bollgard® cotton. Excellent worm control was achieved with low label rate of pyrethroid only. As much as 25% of the Bollgard® cotton was sprayed with pyrethroids to control worms and maybe other pests (i.e. stink bugs).

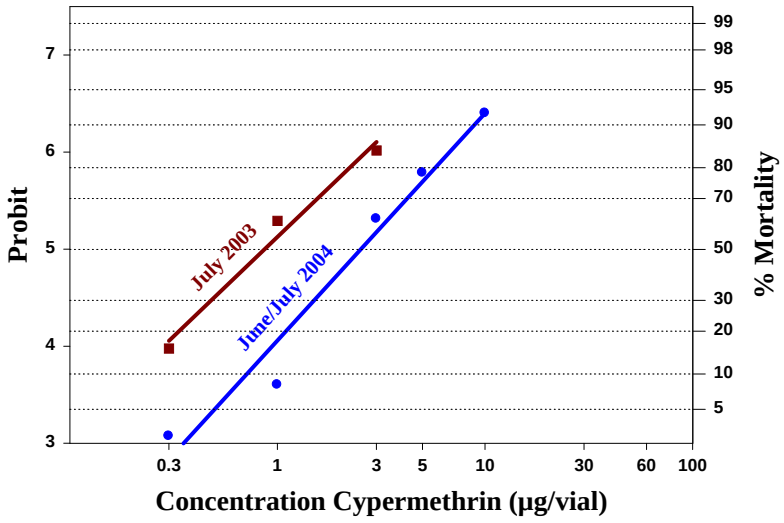

Figure 4. Concentration-mortality lines for bollworm moths collected in 2003 and 2004 in Williamson County and exposed to cypermethrin in the vial assay. Lines are statistically different but parallel ($p < 0.05$).

Notice in Fig. 4 that the population was significantly more resistant in 2004, which is in agreement with the field failures observed in early July. In addition, in Table 7, the resistance ratio of early July when field failures were observed is >5.

Table 7. Williamson Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Date	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	LC50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
6/30-7/2/04	2.533 (1.644-3.286)	**5.757**	**8.951**	10.999 (7.778-21.958	1.096	3	228

In **Uvalde County,** overall, bollworm pressure in cotton has been high during the last two years. This year there were some control problems in transgenic Bt cotton with bollworms escaping control while in blooms or bloom tags; control was achieved later on larger worms when they were more exposed on the plant. Insects from Uvalde County were collected from six traps located in a cotton field surrounded by cornfields to the east and south. There were 430 cotton acres (3 fields) treated with Z-cypermethrin (Mustang Max™ 3 oz./acre) for armyworm. One field was sprayed an additional time. Treatments were in early May one time as ground rig and a second application was as aerial spraying. The fields were harvested September 2nd and yields were good, averaging 3.2 bales/acre. Notice that the resistance to pyrethroids in bollworm was very significant at the beginning of September when cotton was being harvested (Table 8). The total acreage for cotton was 13,692, of which 95% of it was Bt cotton.

The total acreage for grain sorghum was 11,764 acres. There were no treatments to control headworm (*H. zea*) in grain sorghum in 2004, unlike 2003. Sorghum was treated twice with the pyrethroid lambda cyhalothrin (Warrior®) for sorghum midge on the 13th and 18th of July. Approximately 25-30% of 4000 acres of sorghum were sprayed once for stink bug with lambda cyhalothrin (Warrior®) in mid-July.

Table 8. Uvalde Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Date	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	L 50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
8/03/04	1.453 (.457-2.711)	3.302	5.979	17.122 (7.575-162.900)	3.4278	3	225
8/04/04	1.296 (.465-2.388)	2.945	4.580	19.429 (8.144-192.349)	1.0326	3	135
9/03/04	2.677	**6.084**	**9.459**	38.932	6.267	3	360

In **Tom Green County** moths were collected from only one trap and only one significant flight; the trap was located one mile east of Veribest, TX on FM 380. No bollworm control problems were seen in the area and control failures were not reported. It was observed, however, that this was the highest bollworm density recorded in the last 8 years. Pyrethroids were not used until August 13. The length of *Helicoverpa zea* pressure during the season surprised producers but this was due perhaps to lack of any real bollworm pressure in the past 8 years. The total acreage for cotton was 237,000, with 30% being transgenic Bt cotton. Sorghum acreage was 179,000 and corn 8000.

In **Gaines County** bollworm pressure was light in 2004, there were no control problems or field failures reported or observed. The reason for testing *H. zea* for pyrethroid resistance was due to producers concerns about the impact of the high number of pyrethroid applications against pink bollworm might have on *H. zea.* Problems in the area consisted of high numbers of pink bollworms, with adjacent fields having been treated as many as 11 times and 18 times through September with z-cypermethrin (Fury®) at the rate of 1 gal./30 acres. The fields in the southern area had been treated more times than those in the north. Moths of *H. zea* were collected in two locations with three traps each. One location was a cotton field in the WNW area of Gaines County and the other in the WSW region. Distance separating the two fields was 7.5 miles north to south. Gaines County total cotton acreage was 257,276; the area with irrigated cotton was 159,623 acres and non-irrigated cotton was 97,653acres. There were 59,000 acres of irrigated peanuts. It is obvious from the results in Tables 9 and 10 that resistance to pyrethroids was also present

in bollworms from Gaines County. About 25% survived the discriminatory concentration that should kill all susceptible insects and also 5% survived the accepted discriminatory concentration for heterozygotes (Table 9). It is indeed possible that the high pyrethroid pressure against pink bollworm could have contributed to these levels of resistance in bollworm. We did not detect any survivors beyond the 10 µg/vial concentration. Notice that the highest resistance ratios were detected in September (Table 10).

Table 9. Gaines County % Corrected Survival (µg/vial), 2004

Date	Control	0.3 µg/v	1 µg/v	3 µg/v	5 µg/v	10 µg/v	30 µg/v
8/11/04	100	87.5	62.5	**45**	**25.6**	**5.1**	0
9/21/04	100	97.3	78.9	**44.7**	**21.1**	0	0

Table 10. Gaines Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Date	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	LC50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
8/11/04	1.760 (.959-2.948)	4	**6.219**	18.718 (8.475-122.219)	3.4148	3	278
9/21/04	2.364 (1.834-3.104)	**5.373**	**8.353**	13.241 (8.264-30.153)	.3854	2	264

Hale and Swisher Counties: Insects were collected from two pheromone traps with collections of moths and placement in vials made on September 30. Ninety-nine percent of the non-Bt cotton fields in the Plains Integrated Pest Management Program were treated for cotton bollworm with pyrethroids. Observations of fields in the Plains IPM programs indicated that excellent control (95 to 100%) was achieved. About 20-25% of fields in these counties were transgenic cotton, Bollgard® or Bollgard® II, although the transgenic Bt cotton fields in the Plains Integrated Pest Management Program were less that 20%. A few of the Bollgard® fields were treated for bollworms when thresholds were exceeded. Good residual insecticide activity was observed, perhaps due to the cooler than normal and cloudy weather in August. Most of the consultants that work in this area also indicated that they treated a major portion of their cotton fields for bollworms and they indicated no control failures. Products commonly used in this area were cypermethrin, cyhalothrin, zeta-cypermethrin and cyfluthrin. Cypermethrin (Ammo®) and z-cypermethrin (Mustang® Max) were inexpensive, therefore higher rates were applied and extremely good control and residual activity were noted. Yields are averaging from 700 lbs to 1,250 lbs. per acre, but grades are poor due to the lack of heat units this year.

Bollworm (*H. zea*) had a very low impact during 2004 in all crops in **Hockley** and **Cochran Counties**. Crop acreage in the county was 11,000 acres of sorghum and 240,000 acres of cotton (transgenic Bt cotton, 21,000; non-Bt cotton 219,000). In general, no pyrethroids were used in this area, with the exception of an area 15 miles west of the area where traps were placed, which did receive applications of pyrethroids for acute infestations in mid-August. No control failures were reported. This is in agreement with the low percentage of individuals surviving the 3 µg /vial concentration (Table 11) and the low resistance ratio (Table 12), indicating that the population of bollworms was, in general, susceptible to pyrethroids. Overall, there was less bollworm activity throughout the season in Hockley and Cochran counties in 2004 than in the previous 3-4 years. The area experienced an unusual weather pattern this season (extremely cool-wet, cloudy summer) and the different direction and velocity of prevailing winds, moth activity may have been affected. Normally prevailing winds are from the south and west while this season north winds were common, possibly affecting moth movements. In support of this, it is noticeable that in 2003 we detected moths surviving the 5 and 10 µg /vial concentrations but not this year (Figure 5).

Insects for this study were collected from three traps separated by 1/4 mile, and no pyrethroids were used in the area where the traps were located. The nearest fields treated with a pyrethroid for *Lygus sp.* control were about 5 miles away.

Table 11. Hockley County % Corrected Survival (µg/vial), 2004

Date	Control	0.3 µg/v	1 µg/v	3 µg/v	5 µg/v	10 µg/v	30 µg/v
9/22/04	91.4	71.9	18.7	6.2	0	0	0

Table 12. Hockley Co. Cypermethrin Bioassay for bollworm, *Helicoverpa zea*, 2004

Date	LC50 µg/vial (Confidence Limits)	LC50 Resist. Ratio (.44 µg/vial)	LC50 Resist. Ratio Baseline 2003 (.283 µg/vial)	LC95 µg/vial (Confidence Limits)	χ^2	df	# Moths Tested
1989 (Kanga et al. 1996)	0.44 (0.39-0.49)	1	1.555	--	0.34	--	3051
9/22/04	.491	1.116	1.734	2.681	1.145	1	245

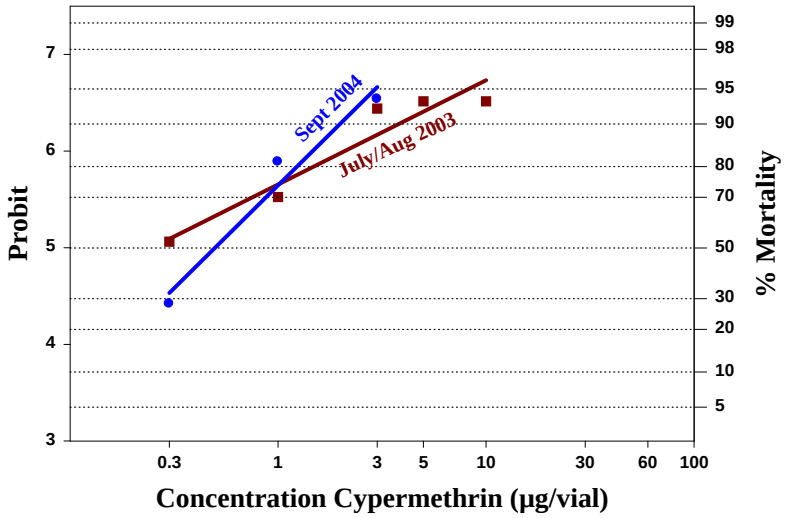

Figure 5. Concentration-mortality lines for bollworm moths collected in 2003 and 2004 in Hockley County and exposed to cypermethrin in the vial assay. Lines are statistically equal but not parallel ($p < 0.05$).

Overall, resistance to pyrethroids is present in Texas, widely distributed and causing field failures in certain areas as discussed above. Figure 6 clearly shows that Hockley County had the most susceptible population while Nueces County experienced the highest level of resistance, both in LC50 and in the frequency of highly resistant individuals that survive the 60 µg /vial concentration.

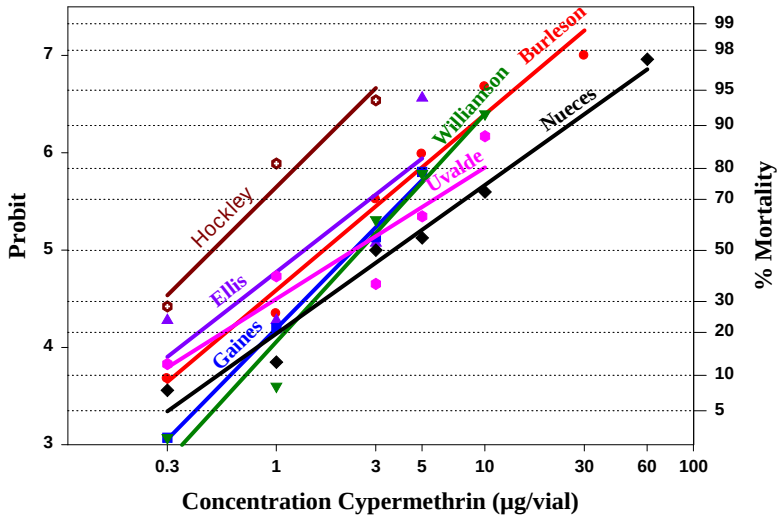

Figure 6. Summary of concentration-mortality lines for bollworm moths collected in 2004 Texas. Data for these lines was from June for Nueces Co.; July for Burleson, Ellis and Williamson Counties and September for Gaines, Hockley and Uvalde Counties. Regression lines selected are those in which moths surviving the highest concentrations were detected in each County (see map).

The map (Figure 7) shows the highest level of resistance for individual moths detected in the respective counties.

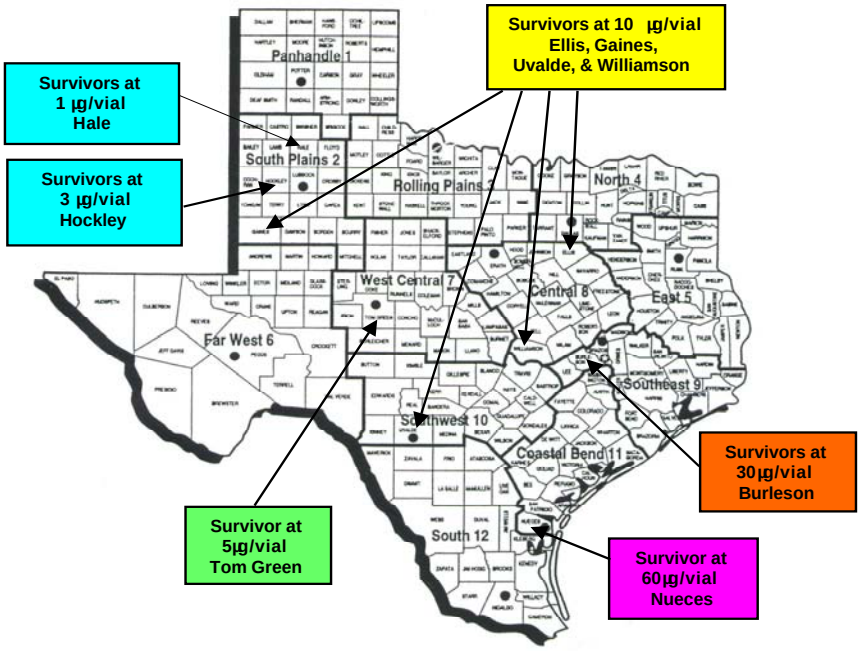

Figure 7. 2004. Highest concentration at which moth survivorship was observed in each County.

However, the rank order for pyrethroid resistance risk based on the highest calculated population resistance rations is (highest to lowest): Nueces > Ellis > Uvalde > Williamson > Gaines > Burleson > Hockley. See resistance ratios in tables 1, 6, 8, 10, 3, 12, respectively.

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