Bollgard Cotton and Resistance of Tobacco Budworm (Lepidoptera: Noctuidae) to Conventional Insecticides in Southern Tamaulipas, Mexico

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ABSTRACT Insecticide susceptibility in tobacco budworm, *Heliothis virescens* (F.) (Lepidoptera: Noctuidae), was determined for 8 yr (1991–2001) with larvae sampled from cotton in southern Tamaulipas, Mexico. Before 1996, when Bollgard cotton expressing the Cry1A(c) δ-endotoxin was introduced into the region, two important patterns were documented. The first was economically significant increases in resistance to certain insecticide groups. The second was occurrence of virtually complete control failures in the field during 1994 and 1995. The largest resistance changes were recorded for the type II pyrethroids cypermethrin and deltamethrin. These products are the most widely used products in the region. Resistance ratios for these products increased up to >100-fold from 1991 to 1995. After 1996, the resistance levels declined. These findings did not occur with other products of scant use (e.g., permethrin, profenofos, and endosulfan) or low tobacco budworm efficacy coupled to a high use pattern (e.g., methyl parathion). This clear trend toward reversal of resistance to type II pyrethroids can be understood, in part, with respect to two factors: 1) the high adoption rate of transgenic cotton in the region, from 31.2% in the beginning (1996) to ≈90% in 1998; this has considerably curbed the use of synthetic insecticides, with the attending loss of selection pressure on this pest; and 2) the potential immigration to the region of susceptible tobacco budworms from cultivated and wild suitable hosts as well as from transgenic cotton might have influenced the pest population as a whole. The influence of transgenic cotton on southern Tamaulipas can be more clearly seen by the drastic reduction of insecticide use to control this important pest. Now tobacco budworms in this region are susceptible to type II pyrethroids. Two effective and fundamentally different pest management tools are now available to cotton growers in southern Tamaulipas: transgenic cotton, coupled with careful use of pyrethroids, offers the possibility of sustainable and profitable cotton production.

KEY WORDS cotton, insecticide resistance, Bollgard, pyrethroids, *Heliothis virescens*

Tobacco budworm, *Heliothis virescens* (F.), is distributed throughout agricultural areas of both American continents, between 40° N and 40° S latitude. The tobacco budworm feeds on a variety of crop plants, including tobacco, cotton, soybean, sunflower, chickpea, and tomato (Sudbrink and Grant 1985, Fitt 1989).

Inadequate management of this pest caused the ruin of cotton production in southern Tamaulipas, Mexico, during the 1970s (Adkisson 1972, Bottrell and Adkisson 1977). In the early 1960s, up to 230,000 ha of cotton was planted in this region (Vargas et al. 1979), and the control of *H. virescens* was based exclusively on the application of conventional insecticides. This led to a severe crisis when this species became highly resistant to methyl parathion (Bujanos-Muñiz 1983; Wolfenbarger et al. 1981, 1984; Martínez-Carrillo et al. 1991). This entomological disaster, in addition to low cotton prices globally, forced farmers to turn to more profitable crops such as soybean, maize, and sorghum. In the 1980s, encouraged by increased cotton prices and the introduction of pyrethroid insecticides, cotton boomed again. However, the irrational use of pyrethroids led to rapid resistance development. The loss of pyrethroid effectiveness in 1995 provoked another crisis in the control of *H. virescens* (Terán-Vargas 1996). This second disaster resulted in a 94.7% reduction in cotton cultivation the following year. In 1996 transgenic cotton (Bollgard), which expresses the δ-endotoxin Cry1A(c) of *Bacillus thuringiensis* Berliner variety *kurstaki* (Bt), was introduced and it effectively controlled *H. virescens.* With the possibility

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of controlling the tobacco budworm, farmers again became interested in this crop.

A series of benefits could be expected from use of Bt crops. These include reduction in the use of conventional insecticides, reduced environmental pollution, greater protection of beneficial fauna, low impact on human health, and higher yields and profits (Roush and Shelton 1997, Betz et al. 2000, Edge et al. 2001, Shelton et al. 2002, Traxler et al. 2002, Bennett et al. 2003). However, reduction in the level of resistance to conventional insecticides as a collateral effect of Bollgard cotton use has not been documented.

Use of Bollgard cotton, between 1996 and 2001, allowed farmers in southern Tamaulipas to substantially reduce use of conventional insecticides against the tobacco budworm (Monsanto 1996, 1997, 1999, 2000, 2001, 2002). Considering that resistance to pyrethroids is unstable in the absence of selection pressure (Curtis 1987, Roush and McKenzie 1987, Plapp et al. 1990, Graves et al. 1991, Kanga et al. 1995) and that no cross-resistance between *B. thuringiensis* δ-endotoxins and conventional insecticides has been documented (Tabashnik 1994, Wu and Gou 2004), it was hypothesized that the use of Bollgard contributes to reduction of resistance to type II pyrethroids.

The objective of this study was to test the hypothesis by determining the changes in resistance to endosulfan, methyl parathion, profenofos, permethrin, cypermethrin, and deltamethrin in a field population of *H. virescens* before and after the cultivation of Bollgard cotton in the region.

Materials and Methods

Location. The study was conducted during 1991, 1994, 1995, 1997, 1998, 1999, 2000, and 2001 in the entomology laboratory at CESTAM (Southern Tamaulipas Experimental Station), a research center belonging to The Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Mexico (INIFAP-National Institute of Forestry, Agriculture and Livestock Research).

Insects. During September and October, the period in which cotton produces squares, flowers, and first bolls, at least 200 *H. virescens* larvae of different instars were collected in commercial fields of conventional cotton in southern Tamaulipas to establish that year's colony. After the introduction of Bollgard in 1996, the collections were made in the transgenic cotton refuge areas. Collected larvae were placed individually in 30-ml plastic cups with 15 ml of an artificial diet (Southland Products Incorporated, Lake Village, AR) and maintained in the laboratory until the pupal stage. Pupae were placed in 2-liter plastic boxes (Rubbermaid No. 3, Rubbermaid, Wooster, OH) lined with paper towels. In these boxes, the adults emerged, copulated, and oviposited. Adults were fed a solution of 10% sugar in distilled water and produced F1 or F2 generations for the bioassays. Every 2 d, eggs were collected, and neonate larvae were placed individually in plastic cups with 10 ml of the artificial diet. Insects were kept at 25 ± 2°C, 60–80% RH, and a photoperiod of 12:12 (L:D) h.

Insecticides. The following technical grade insecticides were used: endosulfan (Agrevo Mexicana, S.A. de C.V), methyl parathion (PolySciences Corporation, Miles, IL), profenofos (Ciba Geigy Corporation, Greensboro, NC), permethrin (Canamex, S.A. de C.V.), cypermethrin (Canamex), and deltamethrin (Agrevo Mexicana).

Bioassays. The bioassay method proposed by the Entomological Society of America (Anonymous 1970) was used to determine *H. virescens* resistance to insecticides with the modifications proposed by Staetz (1985), which include depositing a microliter of acetone with a known quantity of the toxic on the pronotum of third instars (25 ± 3 mg) with the aid of an electric microapplicator (ISCO model M, Instrumentation Specialties Company, Inc., Lincoln, NE) and a 500-μl microsyringe (Hamilton Company, Reno, NV). For each bioassay, a range of biological responses was determined. Subsequently, four to nine intermediate dosages were included to cover the range. Ten larvae per dosage per replication were used plus a control to which only acetone was applied. Three to four replications per colony were performed on different days. Mortality was evaluated 72 h after application. When mortality in the control was equal to or <10%, it was corrected using Abbott's formula (Abbott 1925). As a basis of comparison, a susceptible strain of *H. virescens* collected in 1982 in Obregón, Sonora, Mexico (referred in tables to as Obregón) (Martínez-Carrillo 1991) was used.

Statistical Analysis. The log dosage-probit response line was obtained with the Probit analysis (Polo-PC 1987). At a given level of mortality, it was considered that there were no significant differences in the response between the field and susceptible strains when the fiducial limits overlapped. The resistance ratio (RR) was calculated by dividing the LDx of the field strain by the LDx of the susceptible strain.

Results and Discussion

Type II pyrethroids that contain an α-cyano group in their chemical structure (Perry et al. 1998), such as cypermethrin and deltamethrin, constituted the most frequently used group of insecticides in the southern Tamaulipas to control *H. virescens* in cotton. The most important changes noted in the response of *H. virescens* were to this type of insecticide. From 1991 to 1995, the biological effectiveness of these insecticides progressively decreased. This decreased effectiveness, because of the intense type II pyrethroid selection pressure exerted on this pest and a high propensity toward resistance (Crowder et al. 1984, Forrester et al. 1993), led to serious control problems in the field. With the introduction of transgenic cotton expressing Cry1A(c) to this region in 1996, applications of insecticides to control tobacco budworm, where this technology was adopted, were no longer needed. Therefore, resistance to type II pyrethroids decreased

Table 1. ***H. virescens*** **resistance to insecticides in southern Tamaulipas, Mexico**

Insecticide	Strain	Yr	n	Slope (± SE)	DL$_{50}$ (μg/larvae) (95% CI)	RR$_{50}$	DL$_{95}$ μg/larvae (95% CI)	RR$_{95}$	χ^2
Endosulfan	Obregón	1995	240	2.64 ± 0.28	2.33 (1.95–2.77)	1.0	9.76 (7.30–14.87)	1.0	1.28
	Sur de Tam.	1995	320	1.99 ± 0.19	2.13 (1.47–3.19)	0.9	4.38 (7.88–44.17)	1.5	12.01
		1997	210	2.10 ± 0.26	3.53 (1.93–8.55)	1.5	21.33 (8.72–517.75)	2.2	17.86
		1998	150	1.66 ± 0.28	2.35 (1.55–3.22)	1.0	23.05 (13.43–62.18)	2.4	0.40
		1999	150	3.69 ± 0.51	3.63 (3.09–4.22)	1.5	10.13 (7.90–15.17)	1.0	2–02
		2000	200	2.44 ± 0.30	1.34 (0.77–2.74)	0.6	6.31 (2.98–94.94)	0.6	7.38
		2001	210	1.62 ± 0.21	2.72 (2.03–3.62)	1.2	28.07 (16.65–64.50)	2.9	3.03
Methyl parathion	Obregón	1995	280	2.28 ± 0.25	1.46 (1.19–1.75)	1.0	7.70 (5.74–11.79)	1.0	1.82
	Sur de Tam.	1991	210	1.99 ± 0.22	1.50 (1.16–1.96)	1.0	10.04 (6.62–18.43)	1.3	3.11
		1994	210	1.52 ± 0.19	1.41 (0.70–2.68)	0.9	17.09 (6.86–168.64)	2.2	11.23
		1995	360	1.79 ± 0.16	1.63 (1.33–2.02)	1.1	13.47 (9.13–22.97)	1.7	4.17
		1997	210	1.60 ± 0.19	0.96 (0.49–1.82)	0.6	10.19 (4.26–82.12)	1.3	11.45
		1998	270	1.14 ± 0.11	4.28 (2.96–6.25)	2.9	120.31 (63.34–306.67)	15.6	3.40
		1999	150	2.63 ± 0.34	0.24 (0.14–0.41)	0.2	1.00 (0.53–5.69)	0.1	4.64
		2001	180	2.84 ± 0.36	0.32 (0.26–0.38)	0.2	1.21 (0.88–1.95)	1.1	3.95
Profenofos	Obregón	1995	280	1.89 ± 0.19	0.13 (0.09–0.19)	1.0	0.96 (0.52–2.93)	1.0	7.94
	Sur de Tam.	1991	240	1.28 ± 0.14	0.63 (0.25–2.21)	4.7	12.22 (3.06–908.83)	12.7	24.80
		1994	280	3.33 ± 0.38	0.36 (0.31–0.42)	2.8	1.12 (0.87–1.64)	1.2	2.80
		1995	320	1.72 ± 0.16	0.58 (0.35–1.00)	4.4	5.20 (2.42–24.46)	5.4	15.36
		1997	210	2.64 ± 0.33	0.19 (0.15–0.24)	1.5	0.82 (0.58–1.37)	0.8	2.74
		1998	180	2.04 ± 0.28	0.33 (0.17–0.90)	2.5	2.11 (0.81–179.36)	2.2	12.45
		1999	120	4.11 ± 0.62	0.37 (0.31–0.43)	2.8	0.93 (0.73–1.41)	1.0	0.05
		2000	240	2.52 ± 0.29	0.29 (0.14–0.54)	2.2	1.30 (0.64–34.39)	1.3	17.94
		2001	180	3.21 ± 0.40	0.35 (0.27–0.47)	2.7	1.15 (0.77–2.62)	1.2	4.73
Permethrin	Obregón	1995	280	2.79 ± 0.27	0.18 (0.15–0.21)	1.0	0.69 (0.53–1.00)	1.0	1.67
	Sur de Tam.	1991	270	1.29 ± 0.13	0.38 (0.23–0.63)	2.1	7.17 (3.20–27.64)	10.3	10.11
		1994	120	1.72 ± 0.28	0.41 (0.27–0.58)	1.3	3.67 (2.07–10.20)	5.3	3.87
		1995	360	1.44 ± 0.13	0.78 (0.61–1.01)	4.4	10.86 (6.70–21.21)	15.6	2.16
		1997	210	1.32 ± 0.19	0.23 (0.05–0.48)	1.3	4.06 (1.53–81.54)	5.8	11.95
		1998	210	1.81 ± 0.21	0.26 (0.11–0.72)	1.5	2.13 (0.76–91.01)	3.1	20.40
		2001	240	1.92 ± 0.20	0.01 (0.01–0.02)	0.0	0.08 (0.05–0.17)	0.1	6.11
Cypermethrin	Obregón	1995	320	1.96 ± 0.19	0.02 (0.01–0.02)	1.0	0.11 (0.06–0.30)	1.0	12.6
	Sur de Tam.	1991	240	1.45 ± 0.16	0.23 (0.14–0.35)	14.4	3.14 (1.63–9.34)	29.1	6.49
		1994	300	0.96 ± 0.10	0.48 (0.25–0.93)	30.0	24.58 (7.66–240.13)	227.6	14.9
		1995	320	1.30 ± 0.13	0.92 (0.54–1.60)	57.7	16.95 (6.79–109.92)	157.0	12.9
		1997	210	1.47 ± 0.20	0.30 (0.20–0.42)	18.7	3.93 (2.34–9.02)	36.4	1.2
		1998	180	1.82 ± 0.24	0.10 (0.04–0.20)	6.0	0.77 (0.31–17.33)	7.1	11.4
		1999	150	1.95 ± 0.29	0.13 (0.09–0.17)	8.0	0.89 (0.56–1.95)	8.2	0.7
		2001	180	3.27 ± 0.41	0.31 (0.26–0.36)	19.3	0.98 (0.75–1.49)	9.1	3.2
Deltamethrin	Obregón	1995	240	3.15 ± 0.35	0.004 (0.003–0.007)	1.0	0.015 (0.009–0.062)	1.0	10.8
	Sur de Tam.	1991	150	1.88 ± 0.25	0.035 (0.018–0.071)	8.7	0.262 (0.112–2.332)	17.5	4.1
		1994	270	1.85 ± 0.16	0.063 (0.048–0.084)	15.7	0.806 (0.479–1.714)	53.7	4.5
		1995	320	1.21 ± 0.14	0.067 (0.045–0.099)	16.7	1.555 (0.734–5.592)	103.7	6.3
		1997	210	1.84 ± 0.22	0.050 (0.020–0.104)	12.5	0.394 (0.165–5.595)	26.3	17.4
		1998	210	1.77 ± 0.23	0.031 (0.018–0.065)	7.7	0.266 (0.106–3.858)	17.7	11.4
		1999	180	2.04 ± 0.28	0.012 (0.009–0.015)	3.0	0.074 (0.048–0.152)	4.9	3.2

RR, resistance ratio = lethal dose (LD) of the respective year for the field strain/LD for the susceptible strain.

significantly (Table 1). The resistance ratio (RR)$_{50}$ of cypermethrin increased drastically from 1991 to 1995 (from 14.4- to 57.7-fold). An even more pronounced trend emerged in RR$_{95}$ values (29.1- to 157-fold, respectively) with the highest value occurring in 1994 (227.6-fold) (Table 1). Throughout the studied years, the field and susceptible strains were significantly different in resistance. In general, resistance increased from 1991 to 1995 and descended after 1997. Because of its high biological effectiveness (100 g [AI]ha^{-1}) and its low price, cypermethrin was the most used type II pyrethroid for the control of *H. virescens* in conventional cotton during the study period.

Resistance to deltamethrin, another type II pyrethroid, followed similar trends. From 1991 to 1995, RR$_{50}$ increased from 8.7- to 16.7-fold, and RR$_{95}$ rose from 17.5- to 103.7-fold (Table 1). Like cypermethrin, the levels of resistance rose between 1991 and 1995 and decreased from 1997 to 1999. In 1999, RR$_{95}$ (4.9-fold) was not significantly different from the susceptible strain (Table 1). For control of *H. virescens* in conventional cotton, use of deltamethrin was less intense than use of cypermethrin. However, it should be noted that cross-resistance between the two products has been documented (Priester and Georghiou 1980, Holloway and McCaffery 1994).

The intense use of these products was due primarily to two factors: 1) tobacco budworm is the key lepidopteran cotton pest of the region, whereas corn earworm, *Helicoverpa zea* (Boddie), is nearly absent; and 2) when type II pyrethroids were initially introduced they were highly effective against *H. virescens.* In 1995, serious control problems were inferred from RR values (>100-fold) (Table 1). As a result, the area cultivated with cotton decreased by 94.7%, from 54,897 ha in 1995 to 2,868 ha in 1996 (Table 2).

Table 2. Area planted with conventional and Bollgard cotton and use of pyrethroid insecticides in southernTamaulipas, Mexico

Yr	Area planted				Rounds[c]	Pyrethroid type II use	
	Convencional cotton[a]		Bollgard cotton[b]			liters applied[c]	liters saved[d]
	ha	%	ha	%			
1990	19,648	100			2.0	19,648	
1991	33,443	100			2.0	33,442	
1992	20,294	100			2.0	20,294	
1993	22,685	100			2.5	28,356	
1994	61,223	100			4.0	122,446	
1995	54,897	100			5.0	137,243	
1996	1,972	68.8	896	31.2	5.0	4,930	2,240
1997	2,484	23.1	8,300	76.9	2.4	2,981	9,960
1998	840	11.5	6,460	88.5	2.1	882	17,230
1999	6,646	55.1	5,419	44.9	2.7	8,972	7,315
2000	6,084	58.4	4,332	41.6	2.4	7,301	5,198
2001	44	14.9	251	85.1	3.0	66	376

[a] Distrito de Desarrollo Rural 162 González y 161 Mante SAGARPA.
[b] Monsanto Comercial, S.A. de C.V.
[c] Conventional cotton (average rate 0.5 liters/ha of formulated product).
[d] Bollgard cotton.

The decrease in type II pyrethroid resistance after 1996 could be because of the following factors: 1) reduction of insecticide use and instability of resistance; 2) immigration of susceptible phenotypes into the cotton area; 3) emergence of nonselected individuals in areas planted with Bollgard cotton; 4) the huge reduction in cotton acreage resulted in a reduced tobacco budworm density; hence, insecticide-selected individuals might be crossed more efficiently with those from areas that were not exposed to pyrethroids (e.g., wild host plants, refuge, and Bt cotton).

As part of the government requirement to obtain permit to commercialize Bt cotton in Mexico, Monsanto analyzed cotton acreage planted, the rate and frequency of insecticide applications in conventional cotton, and the absence of insecticide use in Bollgard cotton against tobacco budworm. They estimated that the use of Bollgard cotton, from 1996 to 2001, reduced insecticide use by 115,610 liters (Monsanto, 1996, 1997, 1999, 2000, 2001, 2002). The Mexican Government verified the veracity of the data, according to regulations such as the Biosafety Law (CIBIOGEM 2005) and the Mexican Official Norm, NOM-056-FITO-1995 (SAGAR 1996). Of the total amount of insecticide applications against *H. virescens*, 70 to 80% were carried out with type II pyrethroids; among them cypermethrin, deltamethrin, β-cypermethrin, and λ-cyhalothrin had the highest use pattern (Monsanto 1997, 1998, 1999, 2000, 2001). Based on dosage rate, it was estimated that type II pyrethroid use was reduced by 42,319 liters (Table 2). In contrast, in a study done in Louisiana, *H. virescens* and *H. zea* resistance to pyrethroids remained high in spite of the large area planted with Bollgard cotton. This can be understood, in part, because in Louisiana, type II pyrethroids also exert heavy selection pressure on both insect species in alternative crops such as maize, sorghum, and soybean (Bagwell et al. 2001, Cook et al. 2002). In southern Tamaulipas, *H. virescens* is not exposed to type II pyrethroids in Bollgard cotton nor in alternative crops.

Another factor operates in pyrethroid resistance. Pyrethroid resistance can be unstable because of the reproductive disadvantages of resistant insects (Campanhola and Plapp 1989, McCutchen et al. 1989). When this phenomenon occurs, resistance significantly declines in absence of selection pressure (Campanhola et al. 1991, Clarke and Ottea 1997). We suspect this may have occurred in southern Tamaulipas where a significant reduction in the use of type II pyrethroid against *H. virescens* was estimated (Table 2).

Because tobacco budworm is not a pest in sorghum, soybean, maize, and tomatoes in southern Tamaulipas (Avila and Terán 1993), the use of type II pyrethroids in these crops does not influence the susceptibility to insecticides in *H. virescens.* Several wild plant species are suitable tobacco budworm hosts (Sudbrink and Grant 1985, Caprio and Benedict 1996). Of these wild species, 11 are present in the southern Tamaulipas region (Puig 1991). *H. virescens* density and capacity to develop and reproduce on them are unknown; however, wild host plants may play a major role in loss of resistance. This is especially true when tobacco budworm density in cotton areas is low as happened in 2001 when only 295 ha was planted (Table 2).

Similarly, the immigration of susceptible insects is an essential factor in the reduction of resistance levels over time (Georghiou 1972, Forrester et al. 1993, Leonard et al. 1995). It is likely that this factor contributed in the reversal of resistance to type II pyrethroids in southern Tamaulipas by providing susceptible individuals from wild plants.

Terán-Vargas (2005) studied *H. virescens* adult emergence from Bollgard and conventional cotton areas in 80:20 refuge option fields. Cages for adult emergence (Fife and Graham 1966) were set up in Bollgard and conventional cotton areas during growing season. A mean emergence of 500 tobacco budworm adults in Bollgard and 5,000 adults per hectare in conventional cotton was recorded. Based on this

Table 3. Estimation of adult *H. virescens* emergence in conventional and Bollgard cotton in southern Tamaulipas, México

Yr	Cultivated area (ha).		Adults (thousands)		Bollgard/ conventional proportion
	Conventional cotton[a]	Bollgard cotton[a]	Conventional cotton	Bollgard cotton	
1996	1,972	896	9,860	448	0.05
1997	2,484	8,300	12,420	4,150	0.33
1998	840	6,460	4,200	3,230	0.77
1999	6,646	5,419	33,230	2,709	0.08
2000	6,084	4,332	30,420	2,166	0.07
2001	44	251	220	125	0.57

[a] Average emergence of 500 tobacco budworm adults in Bollgard and 5,000 adults in conventional cotton.

information and the relative proportion of Bollgard cotton, an estimate of 0.05–0.77 tobacco budworm adults was produced in Bollgard cotton for every adult produced in conventional cotton during 1996–2001 (Table 3). Recent local studies indicate that the tobacco budworm population in southern Tamaulipas is susceptible to the Cry1A(c) δ-endotoxin (Martínez-Carrillo and Berdegue 1999); however, these individuals were not selected with type II pyrethroids. It is highly probable that these individuals together with those from wild host plants contributed substantially to the observed reversal in resistance. It is also possible that individuals from Bollgard cotton came from plants that do not express the Cry1A(c) δ-endotoxin (Gould 1998) or that express the toxin to a lesser degree. Substantial variations in toxin expression are because of the influence of genetic and environmental factors (Gould and Tabashnik 1998, Greenplate 1999, Benedict and Altman 2001).

Unlike the response observed with type II pyrethroids in southern Tamaulipas, other insecticides such as organochlorines (e.g., endosulfan), organophosphates (e.g., methyl parathion and profenfos), and type I pyrethroids that lack of α-cyano group (Perry et al. 1998) did not provoke major changes in *H. virescens* resistance. This is possibly because of their scant use (e.g., endosulfan, profenofos, and permethrin) and the low selection pressure of methyl parathion at the rate commonly used.

The RR_{50} to type I pyrethroid permethrin was low every year of the study, with values below 4.4-fold. The highest RR_{95} value was observed in 1995 (15.6-fold) and it decreased to 0.1-fold in 2001 (Table 1). In southern Tamaulipas, permethrin is not used to control *H. virescens* because of its low biological effectiveness, compared with the type II pyrethroids.

The response to endosulfan in the field strain was similar to that of the susceptible strain in all of the years evaluated, except at LD_{50} (3.63 μg per larvae, $RR_{50} = 1.5$-fold) in 1999 and LD_{95} (28.07 μg per larvae, $RR_{95} = 2.9$-fold) in 2001 (Table 1). This product is not commonly used in the region, with less than two applications per growing season at 537 g (AI) ha^{-1} targeting the boll weevil, *Anthonomus grandis grandis* Boheman. The low selection pressure from this insecticide, together with the low *H. virescens* propensity to resistance to this product, may be the most important factors impeding the development of resistance, as Forrester et al. (1993) have suggested.

From 1991 to 1997, the field strain response to methyl parathion was similar to the response of the susceptible strain at both LD_{50} and LD_{95}. In 1998, the largest differences between the two strains were observed, with RR_{50} and RR_{95} of 2.9- and 15.6-fold, respectively (Table 1). This insecticide is used intensively for the control of *A. grandis* as well, with an average of 15 applications per growing season (Monsanto 1999, 2000, 2001, 20002) at a rate of 720 g (AI) ha^{-1}, which is not effective for the control of *H. virescens* (A.P.T.-V., unpublished data). In 1999 and 2001, RR_{50} decreased to 0.2-fold, whereas in the same years, RR_{95} was 0.1- and 1.1-fold, respectively (Table 1).

At LD_{50}, response of *H. virescens* to profenofos was variable (Table 1). In 1997, 1998, and 2000, there were no significant differences between the field and the susceptible strain. However, in 1991, 1994, 1995, 1999, and 2001, the populations were different and the observed RR_{50} values were small (2.7- to 4.7-fold) (Table 1). At LD_{95}, the field strain was different from the susceptible only in 1991, with a RR_{95} of 12.7-fold (Table 1). The low levels of resistance to profenofos reflect the low use of this insecticide in the field, less than one application per crop season (Monsanto 1997, 2000, 2001).

When it first became available, two factors influence use of transgenic cotton in southern Tamaulipas. First, farmers were unfamiliar with transgenic cotton. Second, the Mexican government restricted the planted area (to 896 ha in 1996) because of agronomic and environmental uncertainties. Later, as cotton growers became aware of the advantages of this technology, cotton cultivation increased. In 1998, 16,460 ha of Bollgard cotton was planted, constituting 88.5% of the total cotton growing area (Table 2). In spite of this, the total cotton area planted (conventional and Bollgard) decreased considerably. In 2000, the world cotton price was estimated as low as $0.35 per pound (Aserca 2005). In this economic environment, southern Tamaulipas farmers significantly decreased cotton acreage during 2001. Together, the low price, low yield (1.4 ton cottonseed ha^{-1}) (Sagarpa 2001), and lack of adequate government support, cotton is no longer cultivated. Nonetheless, the availability of transgenic cotton and loss of resistance to type II pyrethroids create a very positive outlook for profitable cotton production in southern Tamaulipas.

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