Diversity, Abundance, and Effect of Genetically Modified Maize on Nontarget Predators in Sinaloa, Mexico[1]

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Abstract Maize (*Zea mays* L.) that has been genetically modified (GM) with the insertion of *Bacillus thuringiensis* Berliner (Bt) genes for pest control has become a useful tool in modern agriculture. In México, planting of GM maize is not approved; however, field tests focused on the biotechnological efficacy of GM maize in controlling pests and the effects on nontarget organisms were authorized and conducted from 2009 to 2013. In Sinaloa, Mexico, plantings of the Bt corn hybrids Agrisure™ 3000 GT, Agrisure® Viptera™ 3110, and Agrisure® Viptera™ 3111, along with their respective isolines without the Bt toxin, were compared for their impact on nontarget predators. An additional treatment with conventional insecticide also was included in the comparisons. Predator abundance, diversity, richness, and uniformity of diversity were estimated by sampling populations with yellow sticky traps, pitfall traps, and a standard insect sweep net. A total of 17,626 predators, representing nine taxonomic orders and 30 families, were collected over all treatments in the different localities. Although predator abundance was slightly higher on the GM hybrids than in non-GM lines, the differences were not statistically significant. Our results from these studies in Sinaloa, Mexico, conclude that GM maize expressing the Bt toxin had no adverse effect on the population density of nontarget predators.

Key Words *Bacillus thuringiensis*, nontarget, richness, diversity, transgenic

Transgenic or genetically modified (GM) crops were developed by applying recombinant DNA technology in agriculture (Chaparro 2011), incorporating genes using genetic engineering with the objective to introduce a new character to the plant which does not occur naturally (Gutiérrez et al. 2015, Shetty et al. 2018). The most widely used GM crop is maize, *Zea mays* L. (Poaceae), modified by inserting specific genes to express the crystal (Cry) protein (e.g., ∂-endotoxin) produced by *Bacillus thuringiensis* Berliner (Bt) (Bruck et al. 2006). This GM crop has an adverse, selective effect on phytophagous insects, primarily lepidopterans and coleopterans (Duan et al. 2008, Hardke et al. 2011, Niu et al. 2013, Yang et al. 2013).

Bt crops have been widely adopted in some regions due their environmental and economic benefits. Reducing the use of chemical insecticides saves money,

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reduces pollutants and worker exposure, and helps conserve nontargets, including many beneficial organisms (Chaparro 2011, Musser and Shelton 2003, Shelton 2012, Tabashnik et al. 2004).

Recent research, however, suggests extensive use of GM crops could result in biological safety problems (Yaqoob et al. 2016), among which may be negative effects on the beneficial entomofauna associated with the GM crop (García et al. 2017). The maize agroecosystem includes a trophic web of target and nontarget arthropods that may consume, directly or indirectly, plant parts containing the Cry toxin (Singh et al. 2006). Most authors, however, concede that Bt corn effects on nontargets are practically nonexistent (Candolfi et al. 2004, Daly and Buntin 2005, Fernandes et al. 2007, Hussein et al. 2012, Naranjo 2009), while others note the possibility that a Bt hybrid could have an adverse effect on natural enemies (Dively and Rose 2002) that naturally regulate key crop pests (Duan et al. 2008, Fernandes et al. 2007, Pilcher et al. 2005, Romeis et al. 2006).

Loss of biodiversity is an important issue in consideration of approving and releasing a GM hybrid (Singh et al. 2006). These concerns are magnified in México, the center of origin and diversity of maize (CONABIO 2020), thus, the crop is under strict biotechnological regulatory measures. The possible effects of Bt corn in Mexico are unknown, and there are concerns about potential negative impacts on organisms that are not targeted by the technology. This research examines the diversity and abundance of predators associated with GM corn in Mexico to identify any possible adverse effects on populations of nontarget species, specifically predators. These findings will aid policymakers in making informed decisions when considering the future of GM crops in Mexico.

Materials and Methods

The study was conducted in Oso Viejo, El Dorado, and El Camalote counties in Culiacan and in Navolato County in the state of Sinaloa during the 2011–2013 growing seasons. Experimental plots were planted 21 d later than and at least 500 m from commercial maize plantings to avoid risks of cross-pollination, as required by official regulations and test protocols (Halsey et al. 2005, LBOGM 2005). GM hybrids used were Agrisure™ 3000 GT expressing the Cry1Ab and Cry3A toxins, Agrisure® Viptera™ 3110 expressing the Cry1Ab and Vip3A20 toxins, and Agrisure® Viptera™ 3111 with the Cry1Ab, Vip3A20, and mCry3A toxins. These were compared with their conventional non-Bt isolines. Cry1Ab and Vip3A20 confer plant resistance to Lepidoptera and mCry3A to Coleoptera. All hybrids were provided by Syngenta Agro S. A. de C.V. México (Avenida Insurgentes Sur 1431, Piso 12, Colonia Insurgentes, Mixcoac, CP. 03920, Mexico City).

In 2011, Agrisure 3000 GT and Agrisure Viptera 3110 and their non-Bt controls were planted in a completely randomized block (RCB) design at Oso Viejo (Culiacan) on 28 January. Each treatment was replicated four times. In 2012, Agrisure 3000 GT and Agrisure Viptera 3111 were planted at Navolato on 15 February. Only Agrisure Viptera 3111 and its isoline were planted on 19 February at El Dorado. Each treatment was replicated three times in a RCB design at both locations.

In 2013, Agrisure Viptera 3111 was planted at El Camalote on 14 March and at Oso Viejo in Culiacan on 15 March. These tests included a conventional commercial hybrid and the non-GM isoline with an insecticide treatment. Emamectine benzoate (Denim® 19 CE, 200 ml active ingredient/ha, Syngenta Agro S. A. de C.V. México) was applied twice, first in the V4 stage and the second in the V8 stage, targeting fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), larvae.

Plots in each test were 10 rows, 5 m long, with a row spacing of 0.8 m. Fifty seeds were planted in each row and later thinned to 34 plants per row (85,000 plants/ha.). Each test was bordered by a buffer area of the same dimensions. Individual replicates within the tests were also buffered using a conventional hybrid throughout to obtain uniform conditions. Crop management followed the technical practices used in the region developed by Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP 2010).

Insects were sampled using chromatic yellow sticky traps, pitfall traps, and standard sweep netting. Plots were sampled weekly, starting 30 d after planting until 1 wk before harvest.

One 20 $\times$ 20–cm chromatic yellow trap was placed in the middle row of each plot. Individual traps were stapled to a wooden stake parallel to the foliage and adjusted weekly to remain even with plant growth. When changed, traps were immediately placed in clear plastic bags, transported to the laboratory, and stored at −4°C until sorted and counted (Bruck et al. 2006, Rose and Dively 2007).

Pitfall traps were used to capture ground-surface arthropods. These traps were plastic containers, 15 cm diameter and 12 cm deep, buried in the ground so that the top of the trap was level with the ground surface. A soapy liquid (250 ml) was placed in each trap, and a trap was placed at the end of the middle row of each plot. At weekly intervals, trap contents were removed, transported to the laboratory, and filtered for captured arthropods. Those captured were rinsed and placed in vials of 70% ethyl alcohol for eventual identification (Rose and Dively 2007). The liquid in each trap was replaced following the collections.

Plant foliage in the four center rows of each plot also was swept with 10 double sweeps using a 38-cm-diameter sweep net over the plants to collect fast-flying insects that were not attracted to traps. Specimens were placed in vials containing 70% alcohol and returned to the lab for further identification.

Collected predators were identified to family using Borror and White (1970), McAlpine et al. (1981, 1987), White (1987), Schuh and Slater (1995), Triplehorn and Johnson (2005), and Nájera and Souza (2010). Identification to the family level met the objective of the study to establish the effect of the GM technology on beneficial arthropods collectively, regardless of the species.

Once sorted, predator abundance was obtained, and richness, diversity, and uniformity of diversity were estimated and compared. Predator diversity was obtained using the Shannon–Wiener diversity index (H') (Moreno 2001), which shows the diversity value for a population. The Margalef diversity index (D_{mg}) (Magurran 2004, Moreno 2001) was used to calculate predator richness. The uniformity of diversity as a heterogeneity measure of the Shannon–Wiener diversity index was estimated with the Pielou (J') uniformity index that represents the uniformity of a population (Magurran 2004).

Predator abundance within the three types of sampling was analyzed with the Kruskal–Wallis (years 2011, 2013) nonparametric statistical test applied for three or more populations and the Mann–Whitney U test (2012) applied for two populations only, using Minitab18 statistical (Minitab Inc., State College, PA) software. These tests use data ranges of independent samples to test the hypothesis that samples come from populations of equal medians to detect differences between Bt and conventional corn insect populations.

Results

We collected a total of 17,626 predators representing nine taxonomic orders and 30 families. The preponderance of those collected were from orders Coleoptera, Hymenoptera, Hemiptera, and Diptera; our analyses were focused primarily on those groups.

At Oso Viejo in 2011, we collected 2,345 predators, with 834 (35.6%) from Agrisure 3000 GT, 740 (31.6%) from its conventional isoline, 439 (18.7%) from Agrisure Viptera 3110, and 332 (14.1%) from its conventional isoline (Table 1). These represented eight orders and 14 families (13 from Agrisure 3000 GT, 12 from its conventional hybrid, 9 from Agrisure Viptera 3110, 11 from its conventional hybrid). There were no significant differences in predator abundance between Agrisure 3000 GT and its conventional hybrid ($P = 0.661$), or between Agrisure Viptera 3110 and its non-GM hybrid ($P = 0.305$). There also were no statistical differences detected in mean numbers of predators between each GM hybrid and their respective non-GM lines with respect to sampling method (Table 2).

The number of predators collected at Navolato, Sinaloa, in 2012 totaled 4,880 from all plots over the course of the test (Table 3). Of those, 2152 (44.1%) were collected from Agrisure 3000 GT, 585 (12%) from its conventional hybrid, 1,589 (32.6%) from Agrisure Viptera 3111, and 554 (11.3%) from its conventional hybrid. These represented nine taxonomic orders and 20+ families. While more predators were collected from the two GM hybrids in comparison to their corresponding non-GM hybrids, these differences were not statistically significant ($P = 0.749$ for Agrisure 3000GT; $P = 0.461$ for Agrisure Viptera 3111). Mean numbers of predators collected by respective sampling methods provided an indication of the abundance of predators relative to location within the plots (e.g., foliage canopy, ground surface, etc.) (Table 4).

We collected a total of 1,418 predators, representing seven orders and 20 families, at El Dorado in 2012, with 800 (56.4%) from the Agrisure Viptera 3111 plots and 618 (43.6%) from its conventional hybrid (Table 5). No significant differences were observed between the two hybrids in terms of overall predator abundance and abundance within each of the three sampling methods (Table 4) ($P = 0.869$).

In 2013, we collected a total of 4,541 predators at El Camalote (Table 6) and a total of 4,442 at Oso Viejo (Table 7). As in previous years, we saw no statistical significance among the treatments at either El Camalote ($P = 0.863$) or Oso Viejo ($P = 0.999$). Slightly higher numbers of predators were collected from Agrisure Viptera 3111 with sweep nets, pitfall traps, and sticky traps at El Camalote and with sweep

Table 1. Total number of predators collected on genetically modified (GM) corn events Agrisure 3000 GT, Agrisure Viptera 3110, and their conventional non-GM hybrids, Oso Viejo, Culiacán, Sinaloa, 2011.

Order	Family	Agrisure 3000 GT	Conventional Hybrid	Agrisure Viptera 3110	Conventional Hybrid
Araneae	Miturgidae	1	0	0	1
	Salticidae	19	12	13	10
	Sicariidae	2	5	0	0
Ephemeroptera	Ephemeridae	12	1	9	4
Hemiptera	Anthocoridae	19	12	15	15
	Geocoridae	1	1	0	0
Thysanoptera	Aeolothripidae	1	201	11	14
Coleoptera	Carabidae	1	3	0	4
	Coccinellidae	42	29	22	26
	Melyridae	0	2	0	0
	Staphylinidae	293	101	122	82
Neuroptera	Chrysopidae	2	0	1	2
Hymenoptera	Formicidae	294	264	131	166
Diptera	Dolichopodidae	147	109	115	8
Total		834	740	439	332

Table 2. Mean number of predators collected from genetically modified (GM) corn Agrisure 3000 GT, Agrisure Viptera 3110, and their conventional non-GM hybrids by different sampling methods in Oso Viejo, Sinaloa, 2011.

Corn Hybrid	Sampling Methods		
	Sweep Net	Pitfall Traps	Sticky Traps
Agrisure 3000 GT	5.4	43.5	42.0
Conventional Hybrid	5.4	36.7	43.4
Agrisure Viptera 3110	4.1	22.8	20.0
Conventional Hybrid	6.7	22.5	8.4

Table 3. Number of predators collected from genetically modified (GM) corn Agrisure 3000 GT, Agrisure Viptera 3111, and their conventional non-GM hybrids, Navolato, Sinaloa, 2012.

Order	Family	Agrisure 3000 GT	Conventional Hybrid	Agrisure Viptera 3111	Conventional Hybrid
Araneae	—*	38	51	55	51
Ephemeroptera	Ephemeridae	0	1	1	0
Dermaptera	Labiduridae	1	0	1	0
Hemiptera	Anthocoridae	198	270	210	185
	Nabidae	5	0	3	2
	Reduviidae	1	0	4	1
Thysanoptera	Aeolothripidae	84	5	2	67
Coleoptera	Carabidae	1	1	3	0
	Coccinellidae	172	82	109	75
	Malachiidae	0	1	0	0
	Melyridae	1	0	0	0
	Staphylinidae	31	19	26	25
	Trogossitidae	1	7	2	9
Neuroptera	Chrysopidae	4	3	4	5
	Hemerobiidae	0	1	0	0
Hymenoptera	Formicidae	1491	44	1074	55
Diptera	Dolichopodidae	53	61	54	31
	Empididae	28	29	18	25
	Micropezidae	0	0	0	1
	Syrphidae	43	10	22	22
	Trichoceridae	0	0	1	0
Total		2,152	585	1,589	554

* Not identified to taxonomic family level.

nets and sticky traps at Oso Viejo (Table 8); however, these differences were not statistically significant.

The population diversity, richness, and uniformity indices derived from our data from all tests conducted over the 3-yr period are listed in Table 9. The Shannon–Weaver diversity index (H′) value ranged from 1.20 in the Agrisure 3000 GT planting at Navolato in 2011 to 2.06 in the plantings of Agrisure Viptera 3111 at El

Table 4. Mean number of predators from genetically modified (GM) corn Agrisure 3000 GT, Agrisure Viptera 3111, and their conventional non-GM hybrids using different sampling methods, Navolato and El Dorado, Sinaloa, 2012.

		Sampling Methods		
Locality	**Hybrid**	**Sweep Net**	**Pitfall Traps**	**Sticky Traps**
Navolato	Agrisure 3000 GT	4.1	120.2	41.0
	Conventional Hybrid	2.0	9.5	35.0
	Agrisure Viptera 3111	3.5	86.0	33.5
	Conventional Hybrid	3.5	11.8	28.0
El Dorado	Agrisure Viptera 3111	8.1	37.5	27.4
	Conventional Hybrid	14.6	20.7	18.8

Dorado (2012) and its conventional non-GM hybrid at Navolato (2012). No significant differences among the various hybrids, locations, and year were observed.

The Margalef diversity index (D_{mg}) values for the GM hybrids and their conventional non-GM isolines at each location and with each year of the study were similar and did not differ significantly. The highest D_{mg} value was observed in Agrisure Viptera 3111 ($D_{mg} = 2.59$) at El Dorado in 2012, while the lowest was recorded on Agrisure Viptera 3111 ($D_{mg} = 1.31$) at Oso Viejo in 2011. The lowest population uniformity, as indicated by the Pielou uniformity (J') value of 0.43 was observed at Navolato in 2012 in both GM hybrids (Agrisure 3000 GT and Agrisure Viptera 3111). Highest uniformity values occurred plantings of Agrisure Viptera 3111 isoline ($J' = 0.78$) at Navolato (2012), Agrisure Viptera 3110 ($J' = 0.74$) at Oso Viejo (2011), and Agrisure Viptera 3111($J' = 0.71$) at El Dorado (2012). The index values varied among the 3 yr of the study, with the higher values in 2012 and the lowest in 2011.

Discussion

Given that there were no differences between hybrids at each location and within each year of this study, it is apparent that predator populations in corn may differ with time and location, but that there is no evidence that GM corn has a negative or positive effect on predator population abundance, diversity, richness, or uniformity in the crop production area of Sinaloa, Mexico. Our results further demonstrated that GM corn and its isolines support diverse predator communities with generally low richness, which is frequently characteristic of agroecosystems (Gliessman 2002).

The groups of predators that were more frequently collected from GM hybrids over the 3-yr study were spiders (Araneae), lady beetles (Coleoptera: Coccinelli-

Table 5. Number of predators collected from genetically modified (GM) corn Agrisure Viptera 3111 and its conventional non-GM hybrid, El Dorado, Sinaloa, 2012.

Order	Family	Agrisure Viptera 3111	Conventional Hybrid
Araneae	—*	94	97
Dermaptera	Forficulidae	0	1
Hemiptera	Anthocoridae	125	104
	Geocoridae	3	3
	Nabidae	2	0
	Reduviidae	5	2
Coleoptera	Cantharidae	1	4
	Carabidae	17	6
	Coccinellidae	171	223
	Staphylinidae	1	27
	Trogossitidae	22	22
Neuroptera	Chrysopidae	0	2
	Hemerobiidae	1	2
Hymenoptera	Formicidae	182	46
	Sphecidae	4	0
Diptera	Asilidae	2	0
	Dolichopodidae	74	40
	Empididae	77	30
	Syrphidae	18	8
	Therevidae	1	1
Total		800	618

* Not identified to taxonomic family level.

dae), pirate bugs (Hemiptera: Anthocoridae), rove beetles (Coleoptera: Staphylinidae), ants (Hymenoptera: Formicidae), long-legged flies (Diptera: Dolichopodidae), and dagger flies (Diptera: Empididae). There were no significant differences in predator occurrence among the GM and non-GM hybrids, further supporting our conclusion that the Cry proteins from *B. thuringiensis* had no adverse effects on predator abundance in GM corn in our study.

Our conclusions are similar to the findings of a number of other studies conducted in a variety of geographic locations. Dively and Rose (2002) and Dively (2005) reported a wide range of arthropods associated with Bt corn. They also

Table 6. Number of predators collected from genetically modified (GM) corn Agrisure Viptera 3111 and its conventional non-GM hybrid with and without insecticide, El Camalote, Sinaloa, 2013.

Order	Family	Agrisure Viptera 3111	Conventional Hybrid	Conventional Hybrid + Insecticide*
Araneae	—**	119	81	48
Dermaptera	Labiduridae	1	15	33
Hemiptera	Anthocoridae	80	115	99
	Geocoridae	1	0	1
	Nabidae	0	1	3
	Reduviidae	3	15	16
Coleoptera	Cantharidae	2	2	0
	Carabidae	8	14	4
	Coccinellidae	125	44	43
	Lampyridae	1	7	1
	Melyridae	66	111	102
	Staphylinidae	17	17	15
Neuroptera	Chrysopidae	7	15	6
Hymenoptera	Formicidae	302	25	45
Diptera	Dolichopodidae	311	359	416
	Empididae	1016	471	357
	Syrphidae	0	0	1
Total		2,059	1,292	1,190

* Emamectine benzoate (Denim 19 CE) applied for fall armyworm larval control at V4 and V8 corn growth stages.
** Not identified to taxonomic family level.

found no significant differences in abundance and diversity of natural enemies between GM and non-GM hybrids, noting that changes occurred in some taxa, but these changes were indirectly due to the plant, either by the lack of food or as a response to less damage in the GM maize, which provides a higher density of nontarget prey for natural enemies.

Candolfi et al. (2004) reported no significant differences in the densities of predators in Bt versus non-GM corn. De la Poza et al. (2005), using pitfall traps and visual sampling, reported that Anthocoridae, Coccinellidae, Araneae, and Carabidae predators were more abundant in Bt corn than in non-GM corn and concluded that this GM technology is compatible with natural enemies in the agroecosystem.

Table 7. Number of predators collected from genetically modified (GM) corn Agrisure Viptera 3111 and its non-GM hybrid with and without insecticide treatment, Oso Viejo, Sinaloa, 2013.

Order	Family	Agrisure Viptera 3111	Conventional Hybrid	Conventional Hybrid + Insecticide*
Araneae	—**	97	160	119
Ephemeroptera	Ephemeridae	1	2	1
Dermaptera	Labiduridae	248	37	227
Hemiptera	Anthocoridae	100	100	77
	Geocoridae	3	0	4
	Nabidae	0	2	0
	Reduviidae	14	15	26
Coleoptera	Carabidae	3	12	10
	Coccinellidae	24	54	23
	Melyridae	44	50	45
	Staphylinidae	21	27	30
Neuroptera	Chrysopidae	1	2	2
Hymenoptera	Formicidae	29	9	5
Diptera	Dolichopodidae	531	444	418
	Empididae	726	325	374
Total		1,842	1,239	1,361

* Emamectine benzoate (Denim 19 CE) applied for fall armyworm larval control at V4 and V8 corn growth stages.
** Not identified to taxonomic family level.

Pilcher et al. (2005) observed slight differences in predator abundance between Bt corn hybrids (e.g., 76 and Bt 11) expressing the Cry1Ab toxin and their corresponding conventional non-GM hybrids. They concluded that these results should not be unexpected, given the feeding and searching behaviors of the species examined. Daly and Buntin (2005) did not find consistent differences in predator abundance between GM and conventional corn. Higgins et al. (2009), sampling during a 3-yr period on Bt corn expressing the Cry1F toxin, did not find significant negative effects on nontarget arthropods. Fernandes et al. (2007), testing the GM (7590-Bt11 and Avant-ICP4) with the Cry1Ab and VIP3A proteins, reported no adverse effect of these hybrids on populations of Forficulidae, Reduviidae, Anthocoridae, Coccinellidae, Araneae, Carabidae, and Cicindellidae (=Cicindellinae), concluding that Bt hybrids did not cause a reduction in densities of natural enemies.

Table 8. Mean number of predators collected from genetically modified (GM) corn Agrisure Viptera 3111 and its conventional non-GM hybrid with and without insecticide treatment with different sampling methods, El Camalote and Oso Viejo, Sinaloa, 2013.

		Sampling Methods		
Locality	Hybrid	Sweep Net	Pitfall Traps	Sticky Traps
El Camalote	Agrisure Viptera 3111	26.1	50.8	153.5
	Conventional hybrid	19.5	20.1	106.2
	Conventional hybrid + insecticide*	18.7	19.4	95.4
Oso Viejo	Agrisure Viptera 3111	57.5	41.1	112.2
	Conventional hybrid	22.1	25.8	99.5
	Conventional hybrid + insecticide*	21.6	45.0	87.0

* Emamectine benzoate (Denim 19 CE) applied for fall armyworm larval control at V4 and V8 corn growth stages.

Any observed greater abundance of natural enemies on the GM versus non-GM hybrids is probably due to GM plants having less foliar damage from target pests, while remaining more attractive to nontarget natural enemies (Aguirre et al. 2015, 2016). Indeed, numerous phytophagous insects have been reported on Bt corn. Pons et al. (2005) observed that GM plants had a direct correlation of insect abundance with foliar biomass. This has resulted in natural enemies being attracted to the GM corn to search for prey in a conducive habitat based on their spatial distribution within the agroecosystem (Rose and Dively 2007).

Romeis et al. (2006) added that the higher abundance of natural enemies in Bt corn is due to reductions in applications of chemical insecticides to control key lepidopteran pests (e.g., *S. frugiperda*). In Mexico, an average of 2,360 metric tons of insecticidal active ingredients are applied annually to approximately 4.8 million ha to control fall armyworm with two or three applications needed each crop cycle (Blanco et al. 2010, 2014). In our study, we made two applications of insecticide to the conventional non-GM hybrids at El Camalote and Oso Viejo to control *S. frugiperda* larvae. We saw no impact of these applications and the subsequent management of the larvae in the non-GM hybrid planting versus plantings of Agrisure Viptera 3111, although slightly higher numbers of natural enemies were observed in the GM corn.

Similar results were reported by Dively and Rose (2002) on Bt corn using a pyramidal event hybrid (VIP3A and Cry1Ab) and a conventional non-GM hybrid treated with λ-cyhalothrin. They concluded that the insecticide showed negative effects over nontarget insects. Later, Dively (2005), using the same GM hybrid, reported that the insecticide-treated non-GM hybrid showed both positive and negative changes in the abundance of different predatory taxa; however, the negative effects of the insecticide application were greater than those associated

Table 9. Diversity, richness, and uniformity index values for predator populations collected from genetically modified (GM) corn and conventional non-GM hybrids, Sinaloa, 2011–2013.

Year	Locality	Hybrid	H′ (mean ± SD)*	D_{mg}	J′
2011	Oso Viejo	Agrisure 3000 GT	1.49 ± 0.14	1.78	0.58
		Conventional hybrid	1.63 ± 0.14	1.66	0.65
		Agrisure Viptera 3110	1.62 ± 0.14	1.31	0.74
		Conventional hybrid	1.51 ± 0.11	1.72	0.63
2012	Navolato	Agrisure 3000 GT	1.20 ± 0.08	1.95	0.43
		Conventional hybrid	1.77 ± 0.11	2.20	0.65
		Agrisure Viptera 3111	1.21 ± 0.09	2.17	0.43
		Conventional hybrid	2.06 ± 0.11	2.06	0.78
	El Dorado	Agrisure Viptera 3111	2.06 ± 0.12	2.59	0.71
		Conventional hybrid	1.97 ± 0.11	2.44	0.69
2013	El Camalote	Agrisure Viptera 3111	1.60 ± 0.12	1.83	0.59
		Conventional hybrid	1.82 ± 0.12	1.95	0.67
		Conventional hybrid + insecticide**	1.81 ± 0.12	2.12	0.65
	Oso Viejo	Agrisure Viptera 3111	1.64 ± 0.13	1.73	0.62
		Conventional hybrid	1.80 ± 0.12	1.82	0.68
		Conventional hybrid + insecticide**	1.82 ± 0.13	1.80	0.69

* H′ = Shannon–Wiener diversity index, D_{mg} = Margalef diversity index, J′ = Pielou uniformity index.
** Emamectine benzoate (Denim 19 CE) applied for fall armyworm larval control at V4 and V8 corn growth stages.

with the GM hybrid. The impact of a multitrophic negative event in the corn agroecosystem will likely reduce populations of beneficial natural enemies. Such an event which might occur following the application of insecticides (Bruck et al. 2006, Rose and Dively 2007). Insecticide applications in conventional non-GM corn crops negatively impact on the abundance of all nontarget insect species (Benamú 2010, Chaves et al. 2016). Zenner and Alvarez (2008) postulated that low densities of beneficial insects in Bt and conventional non-GM crops are likely due to low densities of insect prey resulting from insecticide applications (non-GM crops) or GM technology (GM crops). In the latter case, the reduction in abundance of nontarget species cannot be directly attributed to the Cry toxins (Zenner and Álvarez 2008).

As with any other insect control measure, GM plants expressing the Bt toxins could have unanticipated risks to the arthropod complex in the cropping system. In our 3-yr study, however, the results obtained in Sinaloa showed that Bt corn did not cause a reduction to the predator densities associated with the GM corn. GM technology appears to be an acceptable tool in pest management in corn systems in Mexico.

To date, no commercial or experimental GM corn planting has been authorized in Mexico; however, we suggest that field testing of these materials is important in order to gather information under the Mexican agroecosystem conditions to provide science-based data to the scientific community and policymakers regarding any environmental risks associated with the use of GM crop technology. This will aid policymakers in deciding what role GM corn may play in the future in pest management that also conserves biodiversity in agroecosystems.

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