

Efficacy of transgenic maize insecticide treatment to control fall armyworm in late-season maize in São Paulo state, Brazil

Eficácia de milho transgênico tratado com inseticida no controle da lagarta-do-cartucho no milho safrinha no estado de São Paulo, Brasil

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Received in May 17, 2016 and approved in December 5, 2016

ABSTRACT

Several genetically modified maize events expressing insecticidal proteins from *Bacillus thuringiensis* (*Bt*) have been commercially available in Brazil, intended to control of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). The objective of this study was to evaluate the efficiency of transgenic (*Bt*) and conventional (non-*Bt*) hybrids in the control of fall armyworm, treated or not with insecticides throughout three late growing seasons. To this end, trials were conducted at three locations in the state of São Paulo, in a randomized complete block design, in factorial arrangements with 5x4, 5x4 and 8x4 factors, respectively. The first factor consisted of the number of commercial hybrids of different companies. The second factor was represented by the different control managements of insect (non-*Bt* hybrid with and without insecticide; *Bt* hybrid with and without insecticide). The damage caused by fall armyworm was evaluated on a visual 1-9 scale, from score 0 (no damage) to 9 (totally destroyed whorl), and grain yield (kg ha⁻¹). The data were analyzed by analysis of variance and the means compared by the Tukey test at 5% probability for each parameter evaluated at each location. For the *Bt* hybrids, the damage scores attributed to fall armyworm were lower and the proteins Cry 1F, Cry 1A105 and VIP3Aa20 were the most efficient in reducing leaf damage. Insecticide applications proved efficient in reducing leaf damage caused by the pest. Application of insecticides to *Bt* hybrids generally reduced leaf damage, especially for Cry1Ab-producing hybrids, which were the least effective in reducing pest damage without insecticides.

Index terms: *Zea mays*; *Spodoptera frugiperda*; pest management.

RESUMO

Diversas tecnologias de milho geneticamente modificado (*Bt*) foram liberadas comercialmente desde 2007 visando principalmente o controle da lagarta-do-cartucho, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). O objetivo deste trabalho foi avaliar a eficiência de híbridos transgênicos (*Bt*) e convencionais (não *Bt*) no controle lagarta-do-cartucho, submetidas ou não a inseticidas. Para isso, foram conduzidos ensaios em três localidades do estado de São Paulo nas safrinhas de 2009, 2010 e 2011, com delineamento experimental de blocos casualizados, em esquema fatorial 5x4, 5x4 e 8x4, respectivamente. O primeiro fator correspondeu ao número de híbridos comerciais de diferentes empresas. O segundo fator foi constituído pela utilização de diferentes manejos de controle do inseto. Para a avaliação dos danos ocasionados pela lagarta-do-cartucho, foram realizadas amostragens ao acaso de 20 plantas por parcela, aplicando-se uma escala de notas visuais, atribuindo notas que variam de 0 (sem dano) a 9 (cartucho totalmente destruído) e obtido a produtividade de grãos. Os dados foram submetidos à análise de variância e as médias comparadas pelo teste de Tukey a 5% de probabilidade, para cada parâmetro avaliado em cada localidade. Os híbridos transgênicos proporcionaram redução nas notas de danos atribuídas a lagarta-do-cartucho e as proteínas Cry 1F, Cry 1A105 e VIP3Aa20 foram as mais eficientes na redução do dano foliar. A pulverização mostrou-se uma estratégia eficiente em reduzir os danos foliar provocados pela praga. A combinação da pulverização com híbrido transgênico, de modo geral, mostrou ser uma boa estratégia para redução de dano foliar, especialmente quando foi utilizada a proteína Cry 1Ab, comprovadamente de menor eficiência para redução dos danos causados pela praga.

Termos para indexação: *Zea mays*; *Spodoptera frugiperda*; manejo-de-pragas.

INTRODUCTION

Late-season maize in Brazil is characterized by rainfed cultivation, and is sown between January and April,

after the summer crop, usually after early soybean. In the 2015 growing season, the acreage of late-season maize in the state of São Paulo was 370,100 hectares and the mean yield 4494 kg ha⁻¹ (Conab, 2015).

One of the main factors compromising the yield of late-season maize is the incidence of insect pests, whose populations have increased every year, reducing crop yields and thus causing losses to farmers (Fernandes; Carneiro, 2006).

One of the major pests is the fall armyworm, *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae) a polyphagous insect, which is widely distributed in tropical and subtropical regions of the Americas (Andrews, 1988), and is considered the main pest of maize in Brazil (Gallo et al., 2002; Cruz, 2008).

As an alternative to control this pest, the use of transgenic (containing *Bacillus thuringiensis* - *Bt*) maize resistant to insects of the order Lepidoptera was admitted in Brazil. The first maize event was developed, characterized by expressing the insecticidal protein Cry 1AB, and was released on the market in Brazil in 2007. In the following year, another event expressing the insecticidal protein Cry 1F was launched (Carneiro et al., 2009; Storer et al., 2012). Since then, other maize events with expression of different insecticidal proteins and even events with more than one protein were commercially released for the control of insects of the order Lepidoptera.

Prior to the development of *Bt* hybrids, the main control method was chemical, with synthetic insecticides, although the efficiency was rather variable. However even after the release of transgenic *Bt* maize hybrids in Brazil, insecticide applications were maintained, since initially, the suppression of *S. frugiperda* populations by *Bt* hybrids was merely partial.

Thus, the purpose of this study was to evaluate the effectiveness of these technologies in the control of *S. frugiperda* in three late growing seasons, in comparison with non-*Bt* isoline hybrids, sprayed or not with insecticides, in different regions of São Paulo state.

MATERIAL AND METHODS

The experiments were installed in March in the three regions Northwest of São Paulo, Central North and Mid Paranapanema during three late growing seasons (2009, 2010 and 2011). In the Northwest, the experiment was installed in Votuporanga, in the Central North in the city of Pindorama and in Mid Paranapanema, in the municipality of Maracá in 2009 and 2011 and in Paraguaçu Paulista in 2010. In the experiments carried out in Pindorama the crops were irrigated.

In all experiments, a design with randomized blocks was used in a factorial arrangement of 5 x 4 (2009), 5 x 4 (2010) and 8 x 4 (2011), with four replications. The first factor corresponded to the number of commercial hybrids of different companies; these five were common to all growing seasons while in the last, three additional hybrids were tested. These hybrids were selected because at that time, they were marketed in a conventional and a transgenic version, in isolines with introgression of a gene derived from *B. thuringiensis* that confers resistance to lepidopteran pest species (Table 1).

The second factor consisted of different control managements of Lepidoptera: non-*Bt* hybrid without insecticide; non-*Bt* hybrid + insecticide; *Bt* hybrid without insecticide and *Bt* hybrid + insecticide. Per test, two to four insecticide sprayings (Table 2) were applied to maintain the plants at the lowest possible infestation level on a calendar. Insecticide sprayings of *Bt* and non-*Bt* hybrids were always applied at the same time.

The plots consisted of eight 10-m rows, and the evaluations were carried out in the four middle rows, discarding 1.5 m at either end of the row. The seeding density was between 55 and 57 thousand plants ha⁻¹, for all hybrids in all experiments. The other cultural practices were applied according to the requirements of the no-tillage crop.

For the assessment of damage caused by fall armyworm, samples were randomly taken from 20 plants in the evaluated area of the plot, and assessed on a visual score scale, ranging from score 0 (no damage) to 9 (totally destroyed whorl), as proposed by Davis and Williams (1992), to assess the impact of leaf damage. These evaluations were carried out until flowering of plants began. To check the influence of *S. frugiperda* on the different tested hybrids and management types, analysis of variance was performed in the evaluation with highest scores of visual plant damage of each region.

To determine the yield (kg ha⁻¹) of each treatment, harvest and threshing of maize ears were performed manually in two central rows of eight meters length and estimated by extrapolation of harvested production in 1 ha, with adjustment of the moisture content to 13%.

The data was analyzed by F test (ANOVA), at 5% probability and the means compared by the Tukey test at 5% probability, for meaning leaf damage score and grain yield at each location. All analyzes were carried using the ESTAT statistical software (Barbosa; Malheiros; Banzatto, 1992).

Table 1: Maize events, technology brands, toxins and non-Bt and Bt maize hybrids used in the experiments in the late growing seasons of 2009, 2010 and 2011.

Event	Brand	Toxin	Hybrids		
			2009	2010	2011
MON810	Yieldgard®	Non-Bt Cry1Ab	AG8088 AG8088YG	AG8088 AG8088YG	AG8088 AG8088YG
MON89034	VTpro®	Cry1A105 (1Ab, 1Ac, 1F) + Cry2Ab2			AG8088VTpro
MON810	Yieldgard®	Non-Bt Cry1Ab	DKB350 DKB350YG	DKB350 DKB350YG	DKB350 DKB350YG
TC1 507	Herculex®	Non-Bt Cry1F	2B710 2B710HX	2B710 2B710 HX	2B710 2B710 HX
TC1 507	Herculex®	Non-Bt Cry1F	30F35	30F35	30F35
MON810	Yieldgard®	Cry1Ab	30F35 Y	30F35 Y	30F35Y
SYN -BT011	Total Liberty®	Non-Bt Cry1Ab	Impacto ImpactoTL	Impacto Impacto TL	Impacto Impacto TL
MIR 162	Viptera®	Non-Bt VIP3Aa20			Maximus Maximus Viptera
		Total	5 Bt/5 Non-Bt	5 Bt/5 Non-Bt	8 Bt/ 6 Non-Bt

Table 2: Description of the experiments carried out in the late growing seasons of 2009, 2010 and 2011 at different locations in the state of São Paulo, Brazil.

Experimental location	Sowing date	Insecticide application ¹	Evaluation date of fall armyworm			
			Dates	1 st Ev.	2 nd Ev.	3 rd Ev.
2009						
Mid Paranapanema ³ (22° 36' 39" S, 50° 40' 1" W)	20/Mar	14 and 23/Apr; 02/May	- ²	13/Apr	23/Apr	2/May
Central North ⁴ (21° 11' 9" S, 48° 54' 25" W)	26/Mar	16 and 24/Apr; 18/May	15/Apr	24/Apr	4/May	15/May
Northwest ⁵ (20° 25' 22" S, 49° 58' 22" W)	16/Mar	02 and 08/Apr	8/Apr	17/Apr	27/Apr	7/May
2010						
Mid Paranapanema ⁶ (22° 24' 46" S, 50° 34' 33" W)	13/Mar	05 and 20/Apr; 02/May	22/Apr	03/Mayo	13/Mayo	- ²
Central North ⁴ (21° 11' 9" S, 48° 54' 25" W)	06/May	04 and 14/Jun; 01 and 14/Jul	07/Jun	17/Jun	28/Jun	17/Jul
Northwest ⁵ (20° 25' 22" S, 49° 58' 22" W)	25/Mar	08 and 22/Apr	20/Apr	05/Mayo	19/Mayo	- ²
2011						
Mid Paranapanema ⁷ 22° 40' 23" S, 50° 51' 41" W	25/Mar	20/Apr; 15/May	- ²	26/Apr	10/May	26/May
Central North ⁴ 21° 11' 9" S, 48° 54' 25" W	15/Apr	11 and 30/May	16/May	23/May	31/May	08/Jun
Northwest ⁵ 20° 25' 22" S, 49° 58' 22" W	15/Mar	07 and 26/Apr	- ²	19/May	29/Apr	09/May

¹Insecticide Spinosade (70 mL.ha⁻¹ of the commercial product) in the indicated treatments; ²No evaluation on this date. ³Maracá; ⁴Pindorama; ⁵Votuporanga; ⁶Paraguaçu Paulista; ⁷São José das Laranjeiras.

RESULTS AND DISCUSSION

In the experiments of 2009, the damage caused by fall armyworm in the three regions was significant. However, in the Central North and Mid Paranapanema, the damage scores were initially low and tended to increase until the flowering of the plants, unlike in the Northwest, where the damage was high in the beginning and tended to decline thereafter (Figure 1).

In 2009, the differences between the factors hybrids and managements and the interaction between them in the three regions were significant for the scores of visual symptoms of *S. frugiperda* attack 35 days after emergence (DAE) in the Central North, 16 DAE in the Northwest and 39 DAE in the Mid Paranapanema region (Figure 1; Table 3).

For the scores of *S. frugiperda* symptoms of unsprayed non-*Bt* hybrids, the most severely attacked hybrids were 30F35 in all three regions and 2B710 in the Central North and Mid Paranapanema, while hybrid DKB 350 was least attacked in the three regions (Table 4). Among the *Bt* hybrids, 30F35 Y with the YieldGard technology was the most attacked in the three regions, while the symptom scores of hybrid 2B710 HX (Herculex) were the lowest in all regions (Table 4), indicating differences in the efficiency of *S. frugiperda* control between the technologies YieldGard (Cry1Ab) and Herculex (Cry1F) in this season. It is noteworthy that these results were obtained in the years of early introduction of *Bt* maize, since the first transgenic maize seeds were sold in Brazil in 2008.

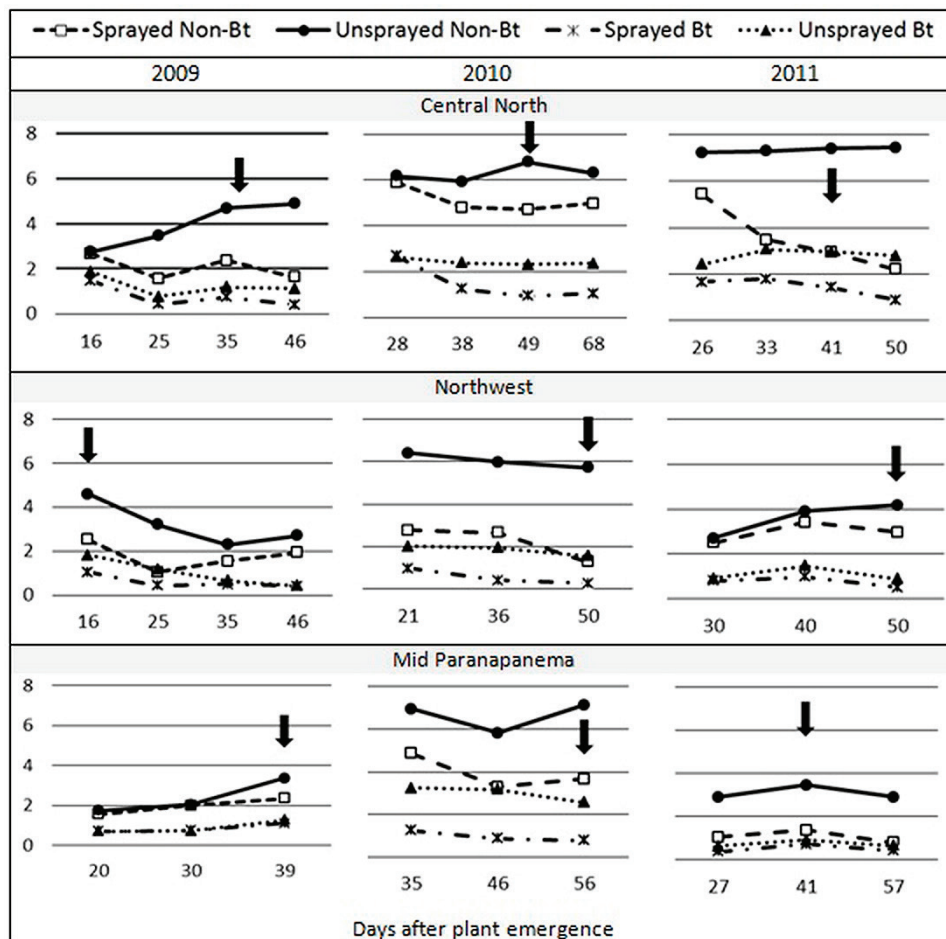


Figure 1: Symptom scores of visible damage (Davis Scale) of non-*Bt* and *Bt* maize hybrids with or without insecticide in three late growing seasons (2009, 2010 and 2011) in three regions of the state of São Paulo. The arrow indicates the evaluation used for analysis of variance.

According to the Seed Producers Association of São Paulo (APPS), the proportion of *Bt* maize seeds planted in the state of São Paulo was 52%, 69% and 73% in 2009, 2010 and 2011, respectively. Therefore, it is unlikely that the differences in results between the technologies were related to the development of genetic resistance by the pest.

In an experiment carried out in Georgia, United States, Buntin (2008) found that both events MON810 (Cry1Ab) and TC1507 (Cry1F) provided similar levels of protection against damage on the whorls of maize plants caused by *S. frugiperda* at low infestation levels and moderate infestation. However, at high infestation levels, hybrids with the insecticidal protein Cry1Ab were more attacked than those with Cry1F.

With regard to the management types, it was found that depending on the region, insecticide application significantly reduced the scores of *S. frugiperda* attack on non-*Bt* as well as *Bt* hybrids (Table 4). Insecticide application influenced the pest attack on *Bt* hybrids only in the Northwest region and specifically of hybrid 30F35Y. In the Mid Paranapanema and Central North, there were no differences between sprayed and unsprayed *Bt* hybrids due to the low armyworm infestation.

In the experiments of 2010, the intensity of *S. frugiperda* attack was higher than in the other years (Figure 1). In the Central North, there was a major *S. frugiperda* attack 49 DAE, in the Northwest 21 DAE, and in Mid Paranapanema, the attack rate was highest in the evaluation 56 DAE. In the case of the Northwest region, we decided to

Table 3: Results of the F test for separate effects of maize hybrids and management types and of their interactions on the different parameters evaluated.

Region	Evaluated parameters	F test				CV (%)
		Hybrids	Management	Interaction		
2009 ¹						
Mid Paranapanema	Symptom score	10.65**	85.70**	2.87**		25.21
	Yield ²	9.60**	0.6ns	0.8ns		12.22
Central North	Symptom score	13.97**	102.59**	2.80**		34.84
	Yield	9.21**	0.8ns	2.5*		8.13
Northwest	Symptom score	6.59**	128.84**	2.76**		23.74
	Yield	19.35**	4.8**	2.5*		8.31
2010						
Mid Paranapanema	Symptom score	6.2**	348.3**	9.3**		8.61
	Yield	14.1**	3.6*	3.6**		4.61
Central North	Symptom score	9.2**	223.4**	4.9**		10.54
	Yield	2.5*	1.2 ^{ns}	0.9 ^{ns}		9.64
Northwest	Symptom score	1.5ns	119.6**	5.3**		18.63
	Yield	4.5**	2.2 ^{ns}	1.7 ^{ns}		7.90
2011						
Mid Paranapanema	Symptom score	2.0 ^{ns}	116.3**	1.8*		16.69
	Yield	- ³	-	-		-
Central North	Symptom score	32.2**	396.4**	14.7**		9.52
	Yield	5.0**	10.3**	1.6 ^{ns}		9.98
Northwest	Symptom score	0.9 ^{ns}	228.4**	3.1**		14.02
	Yield	23.2**	3.6*	2.3*		10.85

¹Means followed by the same letter in a column and capital letter in a row do not differ by Tukey test at 5% probability. ns = not significant; *, ** = Significant at 5 and 1% probability. ²Yield in Kg ha⁻¹. ³Experiment not harvested due to frost.

perform analysis of variance with plants 50 DAE for 21 DAE due to technical problems, since the treatments had not been sprayed with insecticide and therefore the damage caused by the larvae in these treatments was overestimated (Figure 1). For this parameter, significant differences were observed for the factors hybrids and managements separately and the interaction between both in all three regions, with exception of the Northwest region, where there was no significant difference within the factor hybrids (Table 3).

In the regions Mid Paranapanema and Central North, the lowest score attributed to *S. frugiperda* attack of unsprayed non-*Bt* hybrids was 6.53, however, no significant difference were observed between the scores of hybrids of this group (Table 5). In the Northwest region however, 30F35 was the most attacked (7.41) and DKB 350 the least attacked (3.89). Insecticide spraying caused a significant

reduction in symptom scores in all regions and hybrids, except on 2B710 and Impacto in the Central North.

The scores attributed to *Bt* hybrids differed in all studied regions, indicating the control efficiency of the different technologies used in Brazil. The hybrids expressing the insecticidal protein Cry1Ab (DKB 350 YG and AG8088 YG) were the most attacked and hybrids expressing Cry1F (2B710 HX and 30F35 M) were significantly less attacked in all regions (Table 5).

Regarding the damage scores of sprayed transgenic hybrids, all *Bt* hybrids except those with the Herculex® technology, had lower scores when sprayed with insecticides, reinforcing the differences in efficiency of fall armyworm control between technologies the Yieldgard® and Agrisure TL (hybrids with insecticidal protein Cry1Ab) and Herculex® (with Cry1F) (Table 5). Although after insecticide

Table 4: Partitioning of interactions for the visual symptoms of *Spodoptera frugiperda* between the hybrids and fall armyworm managements at four locations in the state of São Paulo.

Hybrids	Fall armyworm management ¹			
	Non- <i>Bt</i>		<i>Bt</i>	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Mid Paranapanema				
AG 8088/AG8088 YG	3.34ab A	2.08 c B	1.26ab BC	1.03a C
2B710/2B710 HX	3.94a A	2.21 bc B	0.83 b C	0.73a C
DKB 350/DKB 350 YG	2.34 b A	1.85 c AB	1.09ab B	1.09a B
30F35/30F35 Y	4.10a A	3.19ab A	2.06a B	1.59a B
IMPACTO/IMPACTO TL	3.13ab A	3.41a A	1.09ab B	1.09a B
Mean	3.37	2.55	1.27	1.11
Central North				
AG 8088/AG8088 YG	4.08 bc A	2.20ab B	0.65 b C	0.59a C
2B710/2B710 HX	5.21ab A	2.24ab B	0.65 b C	0.50a C
DKB 350/DKB 350 YG	2.60 c A	1.28 b AB	1.14ab B	0.60a B
30F35/30F35 Y	6.59a A	3.01a B	2.43a BC	1.43a C
IMPACTO/IMPACTO TL	4.94 b A	3.11a B	1.04ab C	1.04ab C
Mean	4.68	2.37	1.18	0.83
Northwest				
AG 8088/AG8088 YG	4.25ab A	1.65 b B	1.85ab B	1.03a B
2B710/2B710 HX	5.43a A	2.80ab B	1.25 b C	1.00a C
DKB 350/DKB 350 YG	3.60 b A	2.13ab B	1.95ab B	0.80a C
30F35/30F35 Y	4.98a A	3.00a B	2.78a B	1.55a C
IMPACTO/IMPACTO TL	4.75ab A	3.10a B	1.38 b C	1.38b C
Mean	4.60	2.54	1.84	1.15

¹Means followed by the same letter in a column and capital letters in a row do not differ by the Tukey test at 5% probability.

spraying the damage scores of hybrids with protein Cry1Ab were similar to those with Cry1F technology, this type of management increases production costs (Table 5).

The fact that the hybrid expressing protein Cry1F is more effective in reducing *S. frugiperda* damage than hybrids expressing protein Cry1Ab was also reported by Siebert et al. (2008a, 2008b) and Hardke et al. (2011).

In the 2011 late growing season, hybrids expressing new insecticidal proteins were released on the market (Table 2). In this growing season, only the Central North region continued under intensive fall armyworm attack (Figure 1).

Analysis of variance indicated significant differences in *S. frugiperda* infestation for the factors management and management x hybrid interaction in all three regions, but the factor hybrid was only significant in the Central North,

where symptom scores were highest (Table 3). Partitioning the interaction indicated significant differences between non-*Bt* hybrids: in the Mid Paranapanema region the most attacked hybrid was Impacto (4.42) and the least Maximus (1.83) in the Northwest the most attacked was Maximus (5.51) and the least 30F35 (3.18) (Table 6).

With regard to the unsprayed *Bt* hybrids, the lowest levels of infestation were found in Maximus Viptera hybrids in all regions, and in AG8088 VTpro in the Mid Paranapanema and Central North regions. In the Central North, a highly infested region, the symptom scores of some *Bt* hybrids exceeded those of the non-*Bt* sprayed isolines, namely 30F35 Y, AG8088 YG and DKB 350 YG (Table 6). This fact indicates that the technology with *Bt* event YG was insufficient to protect plants from armyworm infestation.

Table 5: Partitioning of the effect of interactions between maize hybrids and management systems used on the scores ascribed to the symptoms of fall armyworm infestation on plants.

Hybrids	Fall armyworm management ¹			
	Non- <i>Bt</i>		<i>Bt</i>	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Mid Paranapanema				
30F35/30F35H	7.41A	4.81a B	1.04 c C	0.65C
2B710/ 2B710HX	7.49A	3.51ab B	1.14 c C	0.75C
Impacto/ImpactoTL	7.18A	3.94ab B	4.23a B	1.05C
AG 8088/AG8088YG	6.53A	3.30 b B	3.76ab B	0.59C
DKB 350/DKB350YG	7.01A	2.71 b B	2.63ab B	0.85C
Mean	7.12	3.65	2.56	0.78
Central North				
30F35/30F35H	7.28A	4.80 B	1.13 b C	0.51 c C
2B710/ 2B710HX	6.66A	4.85 A	1.04 b B	0.10 c C
Impacto/ImpactoTL	6.61A	5.39 A	2.51 a B	1.08ab C
AG 8088/AG8088YG	6.74A	4.78 B	3.74 a B	2.00a C
DKB 350/DKB350YG	6.70A	3.80 B	3.18 a B	0.94ab C
Mean	6.80	4.72	2.32	0.93
Northwest				
30F35/30F35H	7.41a A	1.98a B	0.29 b C	0.25C
2B710/ 2B710HX	6.14ab A	1.66ab B	0.36 b C	0.33C
Impacto/ImpactoTL	5.08ab A	0.50 b BC	1.53ab B	0.14C
AG 8088/AG8088YG	6.06ab A	1.25ab BC	2.56a B	0.15C
DKB 350/DKB350YG	3.89 b A	1.01ab B	3.01a A	0.45B
Mean	5.72	1.28	1.55	0.26

¹Means followed by the same letter in a column and capital letters in a row do not differ by the Tukey test at 5% probability.

This was the only region where spraying reduced the attack intensity on non-Bt hybrids, and specifically on the Bt hybrids expressing the insecticidal protein Cry1Ab (Table 6).

In relation to the variable grain yield, differences were significant in 2009 for the factors hybrids in the

three regions, for managements in the Northwest and for hybrid x management interaction in the Central North and Northwest (Table 3).

The mean yield was highest in the Central North, mainly due to the use of irrigation. In this region, hybrid

Table 6: Partitioning of the effect of interaction between the late season maize hybrids and fall armyworm managements on the scores for visual symptoms of pest attack.

Hybrids	Fall armyworm management ¹			
	Non-Bt		Bt	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Mid Paranapanema				
30F35/30F35 H	3.78ab A	1.03ab B	0.40ab B	0.45B
30F35/30F35 Y	3.78ab A	1.03ab B	1.08ab B	0.78B
2B 710/2B710 HX	3.73ab A	1.97a B	0.40ab C	0.30C
Impacto/Impacto TL	4.42a A	0.67ab B	0.43ab B	0.27B
AG8088/AG8088 YG	3.57ab A	1.07ab B	1.45a B	0.32C
AG8088/AG8088 VT Pro	3.57ab A	1.07ab BC	0.30 b B	0.24B
DKB 350/DKB 350YG	3.72ab A	1.22ab B	0.85ab B	0.40B
Maximus/Maximus Vip	1.83 b A	0.43 b BC	0.22 b C	0.28B
Mean	3.55	1.06	0.64	0.38
Central North				
30F35/30F35 H	7.24A	2.78B	2.09 bc BC	1.14 bcd C
30F35/30F35 Y	7.24A	2.78B	5.69a A	3.10a B
2B 710/2B710 HX	7.89A	3.13B	1.04 cd C	0.68 cd C
Impacto/Impacto TL	7.14A	3.30B	3.64 b B	1.58abcd C
AG8088/AG8088 YG	7.65A	2.54C	5.25a B	2.04abc C
AG8088/AG8088 VT Pro	7.65A	2.54B	0.42 d C	0.63 d C
DKB 350/DKB 350YG	7.61A	2.81C	5.36a B	2.36ab C
Maximus/Maximus Vip	8.09A	3.08B	0.19 d C	0.16 d C
Mean	7.67	2.86	2.96	1.46
Northwest				
30F35/30F35 H	3.18 b A	3.06ab A	0.68ab B	0.53B
30F35/30F35 Y	3.18 b A	3.06ab A	0.81ab B	0.63B
2B 710/2B710 HX	5.13ab A	3.94a A	0.64ab B	0.44B
Impacto/Impacto TL	4.50ab A	2.40ab B	1.25ab BC	0.48C
AG8088/AG8088 YG	4.79ab A	3.09ab B	1.08ab C	0.35C
AG8088/AG8088 VT Pro	4.79ab A	3.09ab B	0.63ab C	0.40C
DKB 350/DKB 350YG	4.61ab A	3.73a B	1.80a B	0.78B
Maximus/Maximus Vip	5.51a A	1.89 b B	0.39 b C	0.13C
Mean	4.46	3.03	0.91	0.47

¹Means followed by the same letter in a column and capital letters in a row do not differ by the Tukey test at 5% probability.

30F35 was the most productive, regardless of the management (sprayed or unsprayed). Of the sprayed *Bt* hybrids, 30F35 Y was the most productive and DKB350 YG and Impacto TL were the least productive hybrids (Table 7).

Among conventional hybrids in the Northwest, hybrid AG8088 was also the highest-yielding, irrespective of the management (sprayed or unsprayed) and hybrid AG8088 YG (sprayed or unsprayed) was also the *Bt* hybrid with highest mean yield (Table 7).

For the management type in the Central North region, no significant differences were observed, while in the Northwest curiously the mean yield of unsprayed non-*Bt* hybrids was higher (6,065 kg ha⁻¹), while the unsprayed *Bt* hybrids had lower mean yield (5,489 kg ha⁻¹) (Table 7). In other words, the hybrid yield was not correlated with spraying, or with the tested pest control managements. The reason may have been that the scores indicated an insufficient level of leaf damage to cause a loss of grain yield.

In the late growing season of 2010, the differences for the factor hybrids were significant in all three regions, while for the factor managements and hybrid x management interaction, differences were only significant in the Mid Paranapanema region (Table 3).

Among the non-*Bt* hybrids without spraying, no significant differences were observed, however with spraying, hybrid 2B710 was the highest yielding (mean yield of 4.150 kg ha⁻¹), and among the *Bt* hybrids (sprayed or unsprayed), Impacto TL, 2B710 HX, AG8088 YG and DKB350 YG were the most productive (Table 8).

With regard to yield in Mid Paranapanema in the late season of 2011, the crop could not be harvested, due to frost damage. In the Central North, the differences between the factors hybrids and managements were significant, however there was no significant interaction between the two factors, since in the Northwest the factors hybrids and managements differed and there was a significant interaction between the factors as well (Table 3).

In the split analysis for the interaction between hybrids and managements, hybrid AG8088 was the most productive (5.343 kg ha⁻¹) of the unsprayed non-*Bt* hybrids, and in response to spraying, the hybrids 2B710, AG8088 and Maximus were the most productive (approximately 4.942, 4.854 and 4.869 kg ha⁻¹, respectively) (Table 9).

Regardless of the hybrids, to observe the adopted managements types, different from what occurred in 2009 and 2010, the combination of *Bt* hybrid plus spraying

Table 7: Partitioning of interactions for grain yield (Kg ha⁻¹) between late season maize hybrids and fall armyworm managements at two locations in the state of São Paulo.

Hybrids	Fall armyworm management ¹			
	Non- <i>Bt</i>		<i>Bt</i>	
	Unsprayed	Sprayed	Unsprayed	Sprayed
	Central North			
30F35/30F35Y	8,326a A	8,599a A	8,127a A	8,356a A
2B710/2B710HX	7,809ab A	6,913 b A	8,005a A	7,780ab A
DKB350/DKB350YG	7,431ab A	7,040 b A	7,709a A	6,827 b A
Impacto/ImpactoTL	7,150ab A	8,058ab A	7,090a A	6,916 b A
AG8088/AG8088YG	6,679 b A	6,935 b A	7,767a A	7,734ab A
Mean	7,479	7,509	7,740	7,523
	Northwest			
AG8088/AG8088YG	7,019a A	6,835a A	6,492a A	6,363a A
2B710/2B710HX	6,535ab A	6,121ab A	5,737ab AB	5,041 b B
Impacto/ImpactoTL	5,882 bc A	5,431 b A	6,190a A	5,275 b A
30F35/30F35Y	5,458 c AB	5,282 b B	5,536ab A	5,071 b B
DKB350/DKB350YG	5,432 c A	5,431 b A	5,147 b A	5,697ab A
Mean	6,065	5,821	5,821	5,489

¹Means followed by the same letter in a column and capital letters in a row do not differ by the Tukey test at 5% probability.

resulted in the highest mean yield (4,811 kg ha⁻¹), while the management non-*Bt* hybrid + spraying induced the lowest mean yield (4,407 kg ha⁻¹) (Table 9).

In field experiments, Lourenção and Fernandes (2013) obtained results similar to those of this study, that the management of insecticide application plus use of *Bt* plants significantly reduced the damage caused by *S. frugiperda*. However, in relation to yield in the late growing seasons of 2009 and 2010, the results differ from those of Lourenção and Fernandes (2013). In the late growing season of 2010, in experiments in Mato Grosso do Sul, these authors found that the combination

of *Bt* hybrid with insecticide spraying induced the highest yields, exceeding those obtained in other tested management types.

This fact was observed by Gurian-Sherman (2009), who reported that the yield gains in *Bt* plants are not significant when compared to conventional plants. In studies the United States, these authors also estimated that *Bt* maize resistant to *Ostrinia nubilalis* produced a 7.0 to 12% higher yield than non-*Bt* lines during periods of high infestation, but offers little or no advantage when infestation is low or moderate.

Table 8: Partitioning of the effect of interactions between maize hybrids and management systems on yield.

Hybrids	Fall armyworm management ¹			
	Non- <i>Bt</i>		<i>Bt</i>	
	Unsprayed	Sprayed	Unsprayed	Sprayed
	Mid Paranapanema			
30F35/30F35 YG	3,142.5a A	3,411.5 b A	2,842.0 b AB	2,539.3 b B
2B710/2B710 HX	3,499.0a B	4,150.8a A	3,564.0a AB	3,567.3a AB
Impacto/Impacto TL	3,227.5a B	3,787.0ab AB	3,843.3a A	3,868.5a A
AG 8088/AG 8088 YG	3,227.5a	3,231.5 b	3,634.3a	3,683.5a
DKB 350/DKB 350 YG	3,378.0a	3,567.0ab	3,248.5ab	3,761.0a
Mean	3,294.9	3,629.6	3,426.4	3,483.9

¹Means followed by the same letter in a column and capital letters in a row do not differ by the Tukey test at 5% probability.

Table 9: Partitioning of the effect of interactions between late season maize hybrids and fall armyworm managements on grain yield (kg ha⁻¹) in Votuporanga, SP.

Hybrids	Fall armyworm management ¹			
	Non- <i>Bt</i>		<i>Bt</i>	
	Unsprayed	Sprayed	Unsprayed	Sprayed
	Northwest			
30F35/30F35 H	3,924.0 b A	3,436.8 b A	3,211.8 d A	3,801.8 d A
30F35/30F35 Y	3,924.0 b AB	3,436.8 b B	4,330.8bc B	4,377.0 cd A
2B 710/2B710 HX	4,623.3ab AB	4,942.3a A	4,072.8 cd B	4,123.0 d AB
Impacto/Impacto TL	4,870.0ab AB	4,491.3ab B	5,436.3a A	4,621.3bcd AB
AG8088/AG8088 YG	5,343.3a AB	4,854.5a B	4,767.5abc B	6,006.8a A
AG8088/AG8088 VT Pro	5,343.3a A	4,854.5a A	5,420.5ab A	5,581.3ab A
DKB 350/DKB 350YG	4,771.5ab A	4,373.5ab A	4,561.3abc A	4,570.0 bcd A
Maximus/Maximus Vip	4,677.5ab A	4,869.0a	5,388.3ab A	5,409.3abc A
Mean	4,684.6	4,407.3	4,648.6	4,811.3

¹Means followed by the same lowercase letter in a column and capital letter in a row do not differ from each other by the Tukey test at 5% probability.

CONCLUSIONS

Transgenic hybrids reduced the damage scores attributed to fall armyworm and those expressing the proteins Cry1F, Cry1A105, and VIP3Aa20 were the most efficient in reducing leaf damage. Spraying was an effective strategy in reducing leaf damage caused by the pest. In general, the combination of spraying with a *Bt* hybrid, proved a good strategy to reduce leaf damage, especially when using protein Cry 1ab, which is known to be less efficient in reducing the damage caused by the pest.

ACKNOWLEDGEMENT

The authors thank Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, Proc. No. 2010/02666-8) for their financial support.

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