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Impact of Fall Armyworm (Lepidoptera: Noctuidae) in the Performance of Corn Crops Associated to Insecticides in Lowland Environment

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Abstract

Brazil, in lowland environment, corn has the potential for crop rotation with irrigated rice to minimizing infestations of red rice. The use of resistant cultivars associated to the use of insecticides are the main methods of control of the fall armyworm, *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae). However, there are lack of field studies that assess the crop's production chain. The objective of this study was to evaluate the performance of corn cultivar, the conventional AG 9045 and the isogenic AG 9045 PRO2 *Bt* on the control of *S. frugiperda*, as well as to analyze the cost of production in the lowland environment. The cultivars were sown in the 2014/2015 and 2015/2016 harvests with adopted spacing of 0.7 meters and length of 5 meters. The application of insecticides was performed when the index of 10% of plants attacked by *S. frugiperda* was reached. Percentage (%) of attacked plants, corn productivity (kg ha^{-1}) and cost of production (US\$ ha^{-1}) were evaluated. In the final analysis, the AG 9045 PRO2 isogenic *Bt* in conjunction to the chlorfenapyr + zeta-cypermethrin treatment show better efficiency on the control of *S. frugiperda* caterpillars, by a combination of two different control methods and active principles in the control of *S. frugiperda*, higher productivity indexes (3,155.58 kg ha^{-1}) and profitability (-112.08 US\$ ha^{-1}).

Keywords: chemical control, varietal control, cultural management, productivity, production cost, biotechnology

1. Introduction

Brazil, although it is the world-renowned in the corn harvested area, presents low levels of productivity and profitability when compared to the world's largest producers, the United States and China (Trindade et al., 2017; CONAB, 2019).

Among the several factors that impair the performance of cultivars, insects are considered one of the most important. On the corn, *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) known as fall armyworm attacks all the phases of the crop development (Cruz et al., 1999). The caterpillars, when young, feed by scraping the plant tissues and along of the development, go into of the cartridge causing severe damage (Campanha et al., 2012; Lima-Junior, 2012).

In Rio Grande do Sul state, in lowland environment, the corn is potentially one of the best alternatives for the crop rotation with irrigated rice because of the economic value it represents to the productive chain and being an alternative to minimize the high infestation rates of red rice (Porto et al., 1998; IRGA, 2019). The lowland areas dominate half of the state of Rio Grande do Sul, corresponding to 300 thousand hectares with significant increase in corn cultivation (Pinto, Miguel, & Pauletto, 2017).

The control of *S. frugiperda* on the corn crop has been carried out through chemical insecticides (Agrofit, 2019). However, inadequate product selection and incorrect equipment regulation have led to an increase in the number of applications and problems on the control of the target insect (Blanco et al., 2016; Pinto, Miguel, & Pauletto, 2017).

The use of resistant cultivars is also an alternative on the control of the fall armyworm. In this context, the transgenic corn that is characterized by the insertion of one or more genes of the bacterium *Bacillus thuringiensis* (Berliner, 1915) (*Bt*) into corn genotypes induces the production of insecticidal proteins in high doses (Moraes, Lourenção, & Paterniani, 2015; Bravo et al., 2017; Jurat-Fuentes, & Crickmore, 2017). However, the continuous use of *Bt* corn for the control of *S. frugiperda* provides selection pressure and may favor the evolution of resistance (Omoto et al., 2016).

The resistance of *S. frugiperda* to *Bt* proteins expressed in corn has caused frequent failures on the pest control in the field. Storer et al. (2010) confirmed the existence of *S. frugiperda* populations resistant to *Bt* Cry1F corn in the region of Puerto Rico. The same was observed by Huang et al. (2014) in the Southeast region of the United States. In Brazil, faults were also observed on the control of *S. frugiperda* in several hybrids of *Bt* Cry1F corn (Farias et al., 2014). Due to this, the use of insecticides in *Bt* growing areas has increased considerably in all the corn producing regions. Therefore, the use of *Bt* corn and the association with insecticides became necessary for a satisfactory control of *S. frugiperda* (Blanco et al., 2016).

Nevertheless, with the adoption of several control methods, there is an increase in the production cost of the crop. Thus, the knowledge of this parameter can help producers to better adjust their investments and identify both the elements responsible for the good performance of the crop and the bottlenecks of the production process, helping this way the decision making (Richetti, 2017).

Due to the importance of the *S. frugiperda* represents to the corn crop, as well as the lack of field studies evaluating the behavior of the cultivars together with the use of insecticides, the objective of this study was to evaluate the performance of the cultivars corns, AG 9045 conventional and the AG 9045 PRO2 isogenic *Bt* on the control of *S. frugiperda*, as well to analyze the cost of production in lowland conditions.

2. Materials and Methods

2.1 Characterization of the Area

The sowing of corn in the field was performed on 11/29/2014 with emergency on 12/08/2014 (2014/2015 harvest) and 12/11/2015 with emergency on 12/18/2015 (2015/2016 harvest) at the Experimental Station of Embrapa Temperate Climate-RS, Brazil. The area presents alluvial hydromorphic soil, which is characterized as shallow, grayish, clayey texture and the presence of waterproof B horizon (Santos et al., 2013).

The seeds of the conventional corn cultivars AG 9045 and the AG 9045 PRO2 isogenic *Bt* expressing the Cry1A.105/Cry2Ab2 proteins were mechanically seeded (Tatu-T2SI model). In density of 75 thousand plants ha^{-1} (spacing of 0.7 × 5 m × 6 lines) with 4 plots per treatment (Table 1). The irrigation system used was linear pivot driven according to the water requirement of the crop, evaluated daily.

2.2 Chemical Control of S. frugiperda in Cultivars AG 9045 and AG 9045 Pro2

The evaluations were carried out weekly in the plots, from the emergence of the seedlings. The chemical control was only adopted when 10% of the plants were attacked by *S. frugiperda* caterpillars (Hellwig et al., 2017). The infestation was calculated according to the formula:

$$\text{Infestation (\%)} = (\text{PA} \times 100)/\text{PT} \tag{1}$$

where, PA = Number of plants attacked; PT = Total number of plants in the evaluated row.

For the application of the insecticides (Table 1), 24 hours after field evaluation, CO^2 pressurized costal spray (2.5 kgf cm^{-2}) was used. The equipment featured an application bar with fan-tip (Teejet XR 110.02 VS), calibrated at a volume of 200 L ha^{-1}.

Table 1. Treatments used in the field experiment for the control of *Spodoptera frugiperda* in the 2014/2015 and 2015/2016 crop seasons

Commercial name	Active ingredient	Mechanism of action	*Dose	
Premio ™	Chlorantraniliprole	Rannodyne receptor modulators	100	-
Premio ™ + Mustang® 350 EC	Chlorantraniliprole + Zeta-Cypermethrin	Rannodyne receptor modulators + Sodium channel modulators	100	80
Belt®	Flubendiamide	Rannodyne receptor modulators	100	-
Belt® + Mustang® 350 EC	Flubendiamide + Zeta-Cypermethrin	Rannodyne receptor modulators + Sodium channel modulators	100	80
Pirate®	Chlorfenapyr	De-couplers of oxidative phosphorylation via disruption of the proton gradient	500	-
Pirate® + Mustang® 350 EC	Chlorfenapyr + Zeta-Cypermethrin	De-couplers of oxidative phosphorylation via disruption of the proton gradient + Sodium channel modulators	500	80
Mustang® 350 EC	Zeta-Cypermethrin	Sodium channel modulators	80	-
-	Witness	-	-	-

Note. *mL ha^{-1}.

2.3 Experimental Design

The experimental design was a completely randomized block, in a factorial scheme (2 cultivars × 8 inseticides) with four replicates. By means of the Hartley test the data demonstrated heterogeneity in the variances, being transformed into arcsen $\sqrt{p/100}$. The data were submitted to analysis of variance and the means were compared by the Tukey test ($P < 0.05$), paired analyzes were performed by Student's t-test. All analyzes were performed using the statistical program GENES (Cruz, 2019).

2.4 Production Cost

From the technical coefficients, for economic analysis, the partial budget method was applied, according to the formula for the processing of the economic analyzes from the reference data (Agrianual, 2019).

The standard cost of inputs and services in the implantation of the corn crop, conventional cultivars and *Bt* isogenic was used to the following formula:

$$VF = VU \times Q \tag{2}$$

where, VF = final value; VU = unit value; Q = quantity used of each input or service.

The cost of production and the economic indexes were elaborated according to Scorvo-Filho, Martin, & Ayroza (1998). The total cost per sack of 60 kg of corn, revenue (US\$ ha^{-1}), average price (US\$ sc^{-1} 60 kg) and the corn profitability (US\$ ha^{-1}) were calculated (Brazilian Central Bank, 2019).

3. Results and Discussion

3.1 Chemical Control of S. frugiperda in Cultivars AG 9045 and AG 9045 Pro2

In the 2014/2015 crop season to the cultivar, chemical control and their interaction, did not present significant difference in the vegetative stage V.3, V.5 and V.7 of the corn. Throughout the development of the seedlings, the cultivar factor responded significantly in the stages V.9, V.10 and VT to the attack of fall armyworm. In the chemical control parameter, differences were noted only in stage V.9, and not being verified interaction between the factors in subsequent evaluations (Table 2).

Therefore, due to the field conditions, it was observed that the intensity of the damage caused by the feeding of the insect was higher in the conventional cultivar than the isogenic *Bt*. In the results obtained in the 2008/2009 crop season, variability was observed in the protection level of the *Bt* plants against the attack of the fall armyworm. Plants with genes that contained insecticidal properties protected at least three applications of the insecticides in conventional cultivars (Carneiro et al., 2009; Bravo et al., 2017).

Table 2. Summary of the variance analysis of the chemical control of *Spodoptera frugiperda* in the corn crop (2014/2015 crop season)

Sources of Variation	DF	28/12/2014 V.3	13/01/2015 V.5	23/01/2015 V.7	29/01/2015 V.9	05/02/2015 V.10	11/02/2015 VT
		Average squares					
Cultivar	1	7.39^{ns}	94.60 ^{ns}	161.23 ^{ns}	1,147.85 *	18,434.17 **	17,036.12 **
Chemical control	7	1.50^{ns}	295.96 ^{ns}	250.18 ^{ns}	109.39 ^{ns}	599.47 *	90.12 ^{ns}
Cultivar × Chemical control	7	3.57^{ns}	108.23 ^{ns}	85.65 ^{ns}	313.34 ^{ns}	250.56 ^{ns}	92.47 ^{ns}
Block	3	8.40	178.64	157.78	205.06	203.03	93.68
Residue	45	2.00	48.83	105.52	253.55	437.41	507.58
Average		1.27	49.99	19.35	65.92	70.05	79.84
CV%		98.09	26.74	64.91	21.72	20.34	12.12

Note. DF = Degrees of freedom. NS = Not significant. CV% = Coefficient of variation. * 5% of probability by F test. **1% of probability by F test. V = Vegetative stage. VT = reproductive stage.

The cultivars, both conventional and transgenic, showed similar behavior up to the stage V.7 of development, from that, the population of *S. frugiperda* in the cultivar AG 9045 had an increase of 33.99% (V.9) and 32. 63% (VT) compared to the isogenic *Bt* (Table 3).

The results show that from 01/13/2015 (V.5) the two cultivars, especially the conventional cultivar, reached the control level (10% of the infested plants). To the conventional cultivar AG 9045 by not presented resistance genes to the fall armyworm, it was necessary to carry out 6 applications and for the isogenic *Bt* AG 9045 PRO2 it was necessary 5 applications of insecticides. In the field, it was also observed that the seedlings that had the *Bt* gene had less symptoms of scraped leaves and easily recovered themselves from the attack of the fall armyworm. Factor attributed to the genetic technology that contributes to insect-pest control (Mendes et al., 2011; Bravo et al., 2017).

In the 2011/2012 crop season, Shioga et al. (2012) reported high levels of infestation of the fall armyworm, with rates of 97.00% and 50.00% of attack in conventional and *Bt* isogenic cultivars, respectively, the same as in this study. The 2014/2015 crop season characterized a period of water stress, occurrence of diseases in corn, lodging and breakage caused by strong winds (Shioga et al., 2015; 2016).

The high incidence of the fall armyworm may be related to the instability of the climatic conditions that affected the recommended corn planting window. Another relevant factor is the nocturnal temperature that has reached higher means compared to the previous year, favoring the development and the increase of generations in the field (Wangen, Pereira-Junior, & Santana, 2015; Viana, Faria, & Bairros, 2016).

Table 3. Percentage of conventional corn plants AG 9045 and isolate *Bt* AG 9045 PRO2 attacked by *Spodoptera frugiperda* the field (2014/2015 crop season)

Cultivar	28/12/2014 V.3	13/01/2015 V.5	23/01/2015 V.7	29/01/2015 V.9	05/02/2015 V.10	11/02/2015 VT
AG 9045	2.34 a[1]	51.21 a	66.49 a	70.16 a	87.02 a	96.16 a
AG 9045 PRO2	1.32 a	48.77 a	63.32 a	61.69 b	53.08 b	63.53 b

Note. [1]Means followed by the same tiny letter in the column do not differ significantly from each other by the T test at the 5% probability level. V = Vegetative stage. VT = reproductive stage.

The percentage of plants attacked after the control of the fall armyworm, was only significant in the stage V.10, with the treatment chlorfenapyr + zeta-cypermethrin the lowest level of infestation, in relation to flubendiamide + zeta-cypermethrin and zeta-cypermethrin (Table 4). However, no treatments allowed an expressive reduction on the number of plants attacked, presenting a lower efficiency of 65.07% in insect-pest control.

With the adoption of the chemical control, there was no reduction in the insect-pest infestation at the non-action level, however, the performance involves several factors that influence the efficiency of chemical control. One possible factor involved is the active principle by itself and the difference between populations. Studies evaluating the control of *S. frugiperda* with chlorfenapyr showed different mortalities between the populations from Pelotas-RS (88.01%) and Cascavel-PR (54.00%) evidencing differences in susceptibility among populations (Gobbi et al., 2017).

Insecticides have often presented control failures, due in part to the increase of resistant individuals in the field, as a consequence of the spraying of insecticides with the same mechanism of action (Omoto et al., 2013).

The low efficiency in the control in the 2014/2015 crop season may also be related to the conditions of high rainfall that provided the product washing after application (Belay, Huckaba, & Foster, 2012).

Table 4. Percentage of conventional corn plants AG 9045 and isogenic *Bt* AG 9045 PRO2 attacked by *Spodoptera frugiperda* in the field subjected to the chemical control (2014/2015 crop season)

Treatments	28/12/2014 V.3	13/01/2015 V.5	23/01/2015 V.7	29/01/2015 V.9	05/02/2015 V.10	11/02/2015 VT
Chlorantraniliprole	0.00 a[1]	52.75 a	63.70 a	69.90 a	72.22 ab	81.09 a
Chlorantraniliprole + Zeta-Cypermethrin	0.00 a	58.08 a	73.28 a	69.61 a	76.40 ab	82.93 a
Flubendiamide	0.00 a	56.27 a	56.33 a	58.92 a	62.68 ab	74.71 a
Flubendiamide + Zeta-Cypermethrin	0.83 a	53.17 a	71.34 a	67.76 a	78.18 a	81.19 a
Chlorfenapyr	0.34 a	48.02 a	64.43 a	68.13 a	65.20 ab	76.48 a
Chlorfenapyr + Zeta-Cypermethrin	1.49 a	43.08 a	66.06 a	64.90 a	53.77 b	78.89 a
Zeta-Cypermethrin	1.05 a	47.35 a	64.74 a	64.81 a	76.49 a	78.51 a
Witness	1.01 a	41.18 a	59.35 a	63.32 a	75.42 ab	84.91 a

Note. [1]Means followed by the same tiny letter in the column do not differ significantly from each other by the Tukey test at the 5% probability level. V = Vegetative stage. VT = reproductive stage.

In the 2015/2016 crop season there was no significance in the stage V.3 to cultivars, products and the interaction between both. In the V.5 and V.10 stages, differences were observed for the cultivar, with effect on V.10 of the chemical control (Table 5).

Accordingly, to the crop development and favorable climatic conditions, there was an increase in the number of damages in both cultivars and crops. However, in the 2015/2016 crop season, the caterpillar pressure was lower, probably due to the fact that the population of *S. frugiperda* was reduced in the area due winter. With the emergence of the first adults from pupae that were in the area or from adults migrating from other regions, they oviposited and the caterpillars hatched, using crop leaf as food for development and future damage (Melo et al., 2014; Trindade et al., 2017).

Table 5. Overview of the variance analysis of the chemical control of *Spodoptera frugiperda* in the corn crop (2015/2016 Crop season)

Sources of Variation	DF	12/01/2016 V.3	18/01/2016 V.5	03/02/2016 V.9	11/02/2016 V.10	16/02/2016 VT
		Average squares				
Cultivar	1	7.31^{ns}	89.67 **	0.34^{ns}	8,470.90 **	33.01^{ns}
Chemical control	7	1.06^{ns}	155.60^{ns}	0.14^{ns}	235.22 **	7.52^{ns}
Cultivate × Chemical control	7	4.59^{ns}	219.74^{ns}	0.14^{ns}	133.06^{ns}	16.22^{ns}
Block	3	8.35	31.18	0.17	64.49	35.22
Residue	45	2.73	21,657.53	0.11	67.48	26.81
Average		1.20	34.08	0.07	23.50	4.21
CV%		177.92	43.49	571.97	34.17	122.85

Note. DF = Degrees of freedom. NS = Not significant. CV% = Coefficient of variation. * 5% of probability. **1% of probability. V = Vegetative stage. VT = reproductive stage.

The percentages of attack of *S. frugiperda* had higher values in the cultivar AG 9045 in comparison to the isogenic *Bt* in all the vegetative stages and harvests (Table 6). The results are expected because of the conventional cultivar does not present genes that condition protection against the target insect. Another interesting factor is the early occurrence of the fall armyworm in the 2014/2015 crop season, possibly due to factors such as temperature, relative humidity and rainfall determined to the presence or absence of the insect (Waquil, Vilela, & Foster, 2002).

In the regions of Campinas and Mococa, the results of damages caused by the fall armyworm, according to the Davis scale, were more severe in conventional crop cultivars P30F35, DKB 390 and DAS2B710 than in their transgenic versions at 60 days after the sowing of corn (Moraes, Lourenção, & Paterniani, 2015). The cultivars AG 9010 and DKB 390 also presented lesions and holes in several leaves, whereas the *Bt* isogenic plants were verified with little damage in the region of Sete Lagoas-MG, Brazil (Mendes et al., 2008).

The increase of the percentage of the insect-pests was recorded to the phenological stage V.5 for both the 2014/2015 and 2015/2016 crops, 36 and 31 days after the emergence of the plants in the field, respectively. The phase characterizes the complete formation of the cartridge, associated to a period with favorable climatic conditions. This gives the crop a high susceptibility of the attack of the fall armyworm, lacking a constant monitoring (Polato & Oliveira, 2011; Mendes et al., 2011).

Table 6. Percentage of conventional corn plants AG 9045 and isogenic *Bt* AG 9045 PRO2 attacked by *Spodoptera frugiperda* in the field (2015/2016 crop season)

Cultivate	12/01/2016 V.3	18/01/2016 V.5	03/02/2016 V.9	11/02/2016 V.10	16/02/2016 VT
AG 9045	1.41 a[1]	52.48 a	0.14 a	35.01 a	4.96 a
AG 9045 PRO2	0.99 a	15.69 b	0.00 a	11.99 b	3.47 a

Note. [1]Means followed by the same tiny letter in the column do not differ significantly from each other by the T test at the 5% probability level. V = Vegetative stage. VT = reproductive stage.

The chemical control in the stage V.10 presented a significant difference between the treatments flubendiamide + zeta-cypermethrin (16.95%) differing from the chlorantraniliprole (29.74%) and witness (30.97%) (Table 7). The efficiency of all treatments remained between 53.40% and 84.28%, with three applications in the conventional cultivar AG 9045 and two applications in the isogenic *Bt* AG 9045 PRO2 throughout the crop cycle. In the 2014/2015 crop season, there was also a difference in the treatment, however, with a lower response to the efficiency of the control of the fall arwyworm caterpillar and a larger amount in the use of the chemical method.

Populations of *S. frugiperda* evaluated in Puerto Rico, submitted to the treatment with flubendiamide required a longer time (≥ 96 hours) to achieve considerable levels of mortality. The fact is attributed to the resistance acquired due to the excessive use of the active principle that ends up selecting resistant individuals (Storer et al., 2010; Omoto, 2016).

The occurrence of *S. frugiperda* biotypes may be another limiting factor, since they may present different behaviors in relation to the susceptibility to insecticides (Pashley, Pawar, & Bhatnagar, 1987; Adamczyk et al., 1997). Busato et al. (2006) evaluating *S. frugiperda* in the corn and rice crops, demonstrated that the *S. frugiperda* corn biotype was less susceptible to lambda-cyhalothrin, lufenuron and methoxifenozide insecticides.

Table 7. Percentage of the conventional corn plants AG 9045 and isogenic *Bt* AG 9045 PRO2 attacked by *Spodoptera frugiperda* in the field subjected to chemical control (2015/2016 crop season)

Treatments	12/01/2016 V.3	18/01/2016 V.5	03/02/2016 V.9	11/02/2016 V.10	16/02/2016 VT
Chlorantraniliprole	0.00 a[1]	31.58 a	0.00 a	29.74 a	6.61 a
Chlorantraniliprole + Zeta-Cypermethrin	0.53 a	36.12 a	0.00 a	22.14 ab	1.29 a
Flubendiamide	0.00 a	36.07 a	0.29 a	19.51 ab	3.48 a
Flubendiamide + Zeta-Cypermethrin	1.53 a	31.18 a	0.00 a	16.95 b	5.88 a
Chlorfenapyr	0.76 a	34.46 a	0.00 a	18.33 ab	2.55 a
Chlorfenapyr + Zeta-Cypermethrin	2.49 a	34.70 a	0.29 a	22.17 ab	3.47 a
Zeta-Cypermethrin	2.45 a	32.86 a	0.00 a	28.16 ab	6.93 a
Witness	1.86 a	35.67 a	0.00 a	30.97 a	3.48 a

Note. [1]Means followed by the same tiny letter in the column do not differ significantly from each other by the Tukey test at the 5% probability level. V = Vegetative stage. VT = reproductive stage.

In the 2014/2015 crop season, it was not possible to perform a productivity evaluation (Kg ha^{-1}), due to adverse climatic factors that prevented the harvest. However, in the 2015/2016 crop season, there was significance for the cultivar factor, with no effect of the products or interaction between the factors (Table 8).

Table 8. Overview of the variance analysis of the chemical control of *Spodoptera frugiperda* in the corn crop (2015/2016 harvest)

Sources of Variation	DF	Productivity
Cultivate	7	12,242,003.80 **
Treatments	7	427,573.58 ^{ns}
Cultivate × Treatments	3	167,109.92 ^{ns}
Block	1	253,959.79
Residue	45	35,454.86
Average		2,718.12
CV%		18.54

Note. DF = Degrees of freedom. NS = Not significant. CV% = Coefficient of variation. * 5% of probability. **1% of probability.

3.2 Productivity

The isogenic *Bt* AG 9045 PRO2 reached the highest value with 3,155.48 kg ha^{-1}, followed by the conventional one with 2,280.76 kg ha^{-1} (Table 9). The difference is attributed to the cultivar presenting *Bt* genes that provides less damage and interference on the photosynthetic capacity of the plant, responding significantly to grain yield (Moraes, Lourenção, & Paterniani, 2015).

The low productivity reported in all treatments of the present work is attributed to the averages that the State presents from 1,413.18 to 5,457.61 Kg ha^{-1}, however, climatic conditions may have influenced the development of the corn crop (SPGG, 2019).

Table 9. Productivity (Kg ha^{-1}) between cultivars AG 9045 conventional and AG 9045 PRO2 isogenic *Bt* in the crop season 2015/2016

Cultivate	Productivity (Kg ha^{-1})
AG 9045	2,280.76 b[1]
AG 9045 PRO2	3,155.48 a

Note. [1]Means followed by the same tiny letter in the column do not differ significantly from each other by the T test at the 5% probability level.

3.3 Production Cost

The profitability in the 2015/2016 crop season, taking into account chemical control, was not observed. The result is direct interference in the grain yield. However, for the conventional and transgenic cultivars, chlorfenapyr + zeta-cypermethrin provided better control of the fall armyworm, contributing to better productivity index (Table 10).

The seed factor had a large participation on the final cost, representing a higher cost for AG9045 PRO2, representing an investment of 17.31% compared to the conventional seed. The same was observed on the conventional cultivars (2B604) and transgenic (2B604Hx) (Miguel et al., 2014). However, reductions of 10.00% and 7.20% in operating costs were observed with the adoption of *Bt* technology (Miguel et al., 2013; Silva et al., 2015).

Thus, the implantation of transgenic corn meant a saving of 66.60% in comparison to the conventional one due to the reduction in the use of the chemical control. The use of the cultivar AG 9045 PRO2 contributed to the reduction of labor cost, fuel use, depreciation of agricultural machinery and even grain losses (Padilha et al., 2015; Richetti, 2017).

Table 10. Economic evaluation of the corn crop (2015/2016 crop season)

Treatments	Parameters	Technology	
		AG 9045	AG 9045 PRO2
Chlorantraniliprole	Total cost (US$ ha^{-1})	439.00[1]	513.65
	Total cost (US$ sc^{-1} 50 Kg)	11.26	9.90
	Revenue (US$ ha^{-1})	273.92	364.55
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-187.53	-149.10
Chlorantraniliprole + Zeta-Cypermethrin	Total cost (US$ ha^{-1})	433.71	513.28
	Total cost (US$ sc^{-1} 50 Kg)	14.60	10.02
	Revenue (US$ ha^{-1})	208.83	360.04
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-247.33	-153.24
Flubendiamide	Total cost (US$ ha^{-1})	437.49	513.31
	Total cost (US$ sc^{-1} 50 Kg)	12.05	10.02
	Revenue (US$ ha^{-1})	255.33	360.33
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-204.60	-152.97
Flubendiamide + Zeta-Cypermethrin	Total cost (US$ ha^{-1})	441.45	512.72
	Total cost (US$ sc^{-1} 50 Kg)	10.21	10.21
	Revenue (US$ ha^{-1})	303.97	353.14
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-159.92	-159.58
Chlorfenapyr	Total cost (US$ ha^{-1})	435.71	513.18
	Total cost (US$ sc^{-1} 50 Kg)	13.12	10.06
	Revenue (US$ ha^{-1})	233.43	358.74
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-224.73	-154.43
Chlorfenapyr + Zeta-Cypermethrin	Total cost (US$ ha^{-1})	444.37	516.93
	Total cost (US$ sc^{-1} 50 Kg)	9.20	8.98
	Revenue (US$ ha^{-1})	339.80	404.84
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-127.02	-112.09
Zeta-Cypermethrin	Total cost (US$ ha^{-1})	436.37	514.19
	Total cost (US$ sc^{-1} 50 Kg)	12.70	9.74
	Revenue (US$ ha^{-1})	241.56	371.29
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-217.25	-142.91
Witness	Total cost (US$ ha^{-1})	413.57	502.88
	Total cost (US$ sc^{-1} 50 Kg)	10.34	9.18
	Revenue (US$ ha^{-1})	281.28	385.18
	Average price (US$ sc^{-1} 50 kg)	7.03	7.03
	Profit (US$ ha^{-1})	-154.73	-117.69

Note. [1]Brazilian Central Bank-US$ 0.2608 sale. Updated in April 10, 2019.

4. Conclusion

In the final analysis, the AG 9045 PRO2 isogenic *Bt* in conjunction to the chlorfenapyr + zeta-cypermethrin treatment show better efficiency on the control of *S. frugiperda* caterpillars, by a combination of two different control methods and active principles in the control of *S. frugiperda*, higher productivity indexes (3,155.58 kg ha^{-1}) and profitability (-112.08 US$ ha^{-1}). As such, this study did not consider natural enemies, whose interactions with the pest may negatively influence the pest population abundance from the adoption of conservative techniques. However, current results show the influence of different environmental factors on *S. frugiperda* population abundance, in particular, the month, condition of the plant, temperature and relative humidity, as the main drivers to *S. frugiperda* spatio-temporal population trends in lowland environment. This provides a significant step towards simple, localized *S. frugiperda* pest outbreak prediction to aid sustainable management.

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