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Estimating the relationship of sugarcane borer larvae and crop damage based on adult captures and climate variables

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ABSTRACT: Sugarcane borer *Diatraea saccharalis* (F.) is the primary sugarcane pest in Brazil. To estimate the relationship between larvae in sugarcane stalks and captures of male adults of *D. saccharalis*, we collected samples weekly: (1) adults with one delta trap with three virgin females and three female pupae and (2) larvae in 120 stalks per plot of 12.6 hectares (355 × 355 m). The study was conducted in two sites with five plots each, in the municipalities of Nova Ponte and Tupaciguara, Minas Gerais State, Brazil, from July 2016 to May 2017. Relationships between (1) males trapped per week and the number of larvae outside of stalks (LOS) were estimated and (2) we evaluated climate variables, namely average temperature, average relative air humidity, hours with relative air humidity below 30 %, rainfall and number of rainy days, and adults and larvae of *D. saccharalis*. We obtained generalized linear models for LOS in autumn and for larvae inside the stalks (LIS) in spring and autumn and trapped males in both sites. A significant and direct relationship between LIS and males trapped allows predicting larvae density based on captures of males. In addition, plant damage can be estimated based on accumulated captures of males. There was a negative relationship between hours of air humidity < 30 % and larvae outside of stalks. Densities of LIS can be estimated from male captures and by the humidity variables in the trapping week. Nevertheless, the models require validation in the field.

Keywords: *Diatraea saccharalis*, sampling, virgin female traps, temperature, relative humidity

Introduction

Sugarcane borer *Diatraea saccharalis* (F.) is widely distributed in tropical and sub-tropical regions of the Americas (Long and Hensley, 1972; Joyce et al., 2014). In Brazil, it occurs in all regions and is considered one of the major pests of sugarcane crops (Dinardo-Miranda et al., 2013). The larvae cause the damage by opening galleries inside the cane stalks, causing the death of tillers in young plants, and reducing crop yield sharply. More recently, it has been estimated that for 1% damage in plants of 16 new sugarcane varieties, losses average 2.9 % in stalk yield and 3.3 % in sugar production (Dinardo-Miranda et al., 2013).

The parasitoid *Cotesia flavipes* (Cameron) has been used for decades in an attempt to reduce damages caused by the sugarcane borer in Brazil. Nevertheless, damages caused by sugarcane borer continue to increase. Then other control tactics are needed, including the application of insecticides to control newly hatched larvae that have not yet penetrated the stalk and the release of egg parasitoid *Trichogramma galloi* Zucchi. However, estimates of the adult population have become necessary for the success of these measures.

There are limitations to estimate the adult population of *D. saccharalis*. The lack of complete characterization of pheromone components and their mixture (Palacio-Cortés et al., 2010), as well as the genetic variability among populations (Lopes et al., 2014; Silva-Brandão et al., 2015) and the possible occurrence of cryptic species (Joyce et al., 2014), hinder the development of a synthetic product of high attractiveness to the insect pest. Other authors have reported difficulty in identifying components of the sex pheromone in other *Diatraea* species, *D. considerata* (Gries et al., 1998) and *D. flavipenella* (Kalinová et al., 2012). Therefore, traps with virgin females of *D. saccharalis* are the only method available to sample adults today. In addition, it is not easy to find newly hatched larvae of *D. saccharalis* before they enter the sugarcane stalks because they are small and generally occur at low densities. Sampling these phases is time-consuming and expensive (Schexnayder et al., 2001).

Adult population estimates from captures in sticky traps with virgin females of *D. saccharalis* have been regularly used (Nava et al., 2009). However, it is unknown if there is a relationship between the number of males captured and egg densities or neonate larvae, parameters that could support the measures to release *T. galloi* or apply insecticide, respectively. Likewise, it is unknown if there is a relationship between the population of males captured and the larvae inside the stalks, which could help the control by *C. flavipes* release. Thus, this study investigated if there is a relationship between male captures in traps with virgin females of *D. saccharalis* and young larvae outside of stalk, larvae inside the stalk, and stalk injuries as well as to predict larvae density and plant damage, considering male captures in traps and climate variables.

Materials and Methods

The assays were performed in two sugarcane crops in the state of Minas Gerais. In Nova Ponte (19°13′39.70″ S, 47°49′23.59″ W, altitude 948 m), the assay was installed in July 2016 in an area cultivated with the sugarcane variety CTC9, planted in Apr 2014 and harvested in May 2016. In Tupaciguara (18°51′01.71″ S, 48°36′14.99″ W, altitude 913 m), the assay started in July 2016 in an area cropped with the sugarcane variety RB965902, planted in Mar 2016 and harvested in May 2017. The climate in the regions is Aw type with warm and rainy periods from Oct to Mar and a dry season with mild temperatures from Apr to Sept.

Each site comprised five plots of 12.6 ha each (355 m × 355 m) with one trap in the plot center (five traps). In each trap (delta type, white, 10 cm height, 14 cm width, 20 cm depth, and coated internally with glue), a plastic cage (5 cm length, 3 cm diameter) was placed with three newly emerged virgin females (< 3 h) and three female pupae (Butt and Cantu, 1962). The traps were installed in a wooden rod, kept at the plant height, and raised according to their growth. Seven days after installation, males of *D. saccharalis* captured were counted, the trap was discarded and replaced by another one. This procedure occurred between July 2016 and May 2017 in both sites.

On the exact dates of trap evaluations, we conducted samplings to estimate larva and pupa densities of *D. saccharalis* in plants. We cut and evaluated 120 stalks in each plot, collecting randomly 12 continuous stalks in 10 points. We obtained: (1) the number of *D. saccharalis* larvae outside the stalk (LOS), (2) the number of larvae inside the stalk (LIS), and (3) the number of pupae inside the stalk (PIS). We evaluated LOS carefully to remove the leaves and count the neonate larvae. For the evaluation of LIS and PIS, each stalk was cut transversely with a pruning knife observing for larvae, pupae, and damage by associated microorganisms, especially fungi, which cause red rot. The assays were conducted until the crop allowed the evaluator to enter the plantation in May 2017. In this month, it was estimated the injury caused by borer in the stalks, counting the total internodes and those damaged by the sugarcane borer and fungi in the 120 stalks per plot. This study assumed that the larvae needed up to 14 days to enter the stalk; therefore, LOS was estimated in weeks zero + one + two while LIS in weeks three + four + five, based on captures in week zero.

The experiment was divided into four periods, as seasons: "winter" – July to Sept 2016; "spring" – Oct to Dec 2016; "summer" – Jan to Mar 2017, and "autumn" – Mar to May 2017. The regression analyses using generalized linear models and binomial distribution were used to evaluate the relationship between the number of *D. saccharalis* males trapped per week (MTW) as an independent variable, and the number of LIS as a dependent variable, for each period and for the entire year. We estimated the relationship between LOS and MTW, considering the total number of larvae in weeks zero + one + two after male captures and LIS in weeks three + four + five after male captures considering the insect life cycle at constant temperatures (Melo and Parra, 1988). In addition, the relationship between trapped males accumulated in the year (from July 2016 to May 2017) and the percentage and number of internodes damaged (PID, NID) were estimated in May 2017.

The regression analyses were tested to relate the number of MTW and LOS (dependent variables) with climate variables (independent variables) in the week of capturing males and prior to larvae sampling: (1) temperature average (T), (2) relative humidity (RH), (3) number of hours with relative humidity below 30 % (RH < 30 %), (4) rainfall (R), and (5) number of rainy days (NRD). Data on T and RH were obtained from a meteorological station in the municipality of Uberlandia, Minas Gerais State (18°55′01.46″ S, 48°15′51.1″ W, altitude 874 m). Daily precipitation data were obtained in a pluviometer located approximately 1 km away from the experiment sites. The variables T, RH, and RH < 30 % were calculated from the hourly data for each day during the period of exposure to the trap and prior to LOS sampling. In RH < 30 %, *D. saccharalis* eggs are not viable (Parra et al., 1999). Rainfall was obtained by total precipitation in the period of trap exposure and the rainy days.

The generalized linear model function of software R (R Core team, 2018) and the most appropriate probability distribution were used for each variable: Poisson distribution for the number of larvae, pupae, damaged internodes, and climate variables and Gamma distribution for the percentage of damaged internodes. The Akaike information criteria (AIC) was adopted to measure the adjustment quality and models with the lowest AIC were selected.

Results

In the Nova Ponte experiment, there was no significant correlation between MTW in week zero and total LOS in the trapping week (zero) and in the following two weeks (one and two) (Table 1). However, this relationship was significant in the Tupaciguara experiment. On the other hand, relations were significant and the occurrence of LIS in weeks three, four, and five after the capture depended on MTW (week zero) (Table 1).

Although trap captures did not relate to the LOS densities of *D. saccharalis* in all seasons, there was a significant relationship between LOS and MTW in "autumn" in Nova Ponte and Tupaciguara (Table 2). The relationship between LIS and MTW of *D. saccharalis* was also significant in "spring" and "autumn" in both sites (Figures 2A, 2B, 2C and 2D). Thus, the results of both experiments allow estimating LIS based on MTW in "spring", as well as LOS and LIS in "autumn" (Table 2).

There was a positive relationship between damage in sugarcane stalks (PID, NID) and MTW accumulated, with a better adjustment to the model with the variable PID, as it presented lower AIC (Table 1). Despite the

Table 1 – Generalized linear models adjusted for estimating larvae outside the stalks (LOS) (weeks zero+one+two), larvae inside the stalks (LIS) (weeks three+four+five) based on the captures of males of *Diatraea saccharalis* in traps (MTW) with virgin females in week zero; proportion (PID) and number of internodes damaged (NID) by larvae and fungi in May 2017 based on accumulated captures of males in the period of July 2016 to May 2017 in Nova Ponte and Tupaciguara, Minas Gerais State, Brazil.

Relationship between male captures and:	Test site	t test	z teste[2]	AIC[3]	Equation[4]
Larvae outside the stalks[1]	Nova Ponte	-	–1.206 ns	1858.3	-
	Tupaciguara	-	9.946***	1834.8	$\hat{Y} = e^{0.896593+0.001683^{***}X}$
Larvae inside the stalks	Nova Ponte	-	3.692***	11451	$\hat{Y} = e^{0.8412696+0.0021671^{***}X}$
	Tupaciguara	-	17.653***	1665.5	$\hat{Y} = e^{0.558546+0.02767^{***}X}$
Damaged internode proportion (%)	Nova Ponte	4.864***	-	–38.955	$\hat{Y} = e^{-5.3559849+0.0026177^{**}X}$
	Tupaciguara				
Number of damaged internode (%)	Nova Ponte	-	22.42***	302.49	$\hat{Y} = e^{2.621318+0.0024234^{***}X}$
	Tupaciguara				

[1]Dependent variables; [2]ns and ***not significant and significant at 0.1 %, respectively, for the t test (variable internodes damaged with Gamma distribution) and z test (variables larvae and damaged internodes with Poisson distribution); [3]Alkaike Information Criterion: measurement of the quality of the adjusted regression models; [4]Adjusted model where Ŷ is the dependent variable larvae or damaged internodes and X is the independent variable males captured.

Table 2 – Generalized linear models adjusted for estimating larvae outside the stalks (LOS) (weeks zero+one+two), larvae inside the stalks (LIS) (weeks three+four+five), in each season of the year based on the captures of males of *Diatraea saccharalis* (MTW) (week zero) in traps with virgin females in Nova Ponte and Tupaciguara, Minas Gerais State, Brazil.

Relationship between male captured and:	Season[2]	Test site	z teste[3]	AIC[4]	Equation[5]
Larvae outside the stalks[1]	"winter"	Nova Ponte	–1.681 ns	384.49	-
	"spring"		0.316 ns	171.20	-
	"summer"		–0.367 ns	659.59	-
	"autumn"		2.086*	241.82	$\hat{Y} = e^{0.159703+0.013174^{*}X}$
Larvae outside the stalks	"winter"	Tupaciguara	1.424 ns	39.749	-
	"spring"		0.882 ns	201.13	-
	"summer"		–4.80 ns	484.62	-
	"autumn"		6.212***	305.56	$\hat{Y} = e^{2.067651+0.017252^{***}X}$
Larvae inside the stalks	"winter"	Nova Ponte	–1.225 ns	50.475	-
	"spring"		6.119***	501.08	$\hat{Y} = e^{1.162677+0.012162^{**}X}$
	"summer"		–7.233 ns	4701.20	-
	"autumn"		3.718***	659.59	$\hat{Y} = e^{1.242729+0.013505^{***}X}$
Larvae inside the stalks	"winter"	Tupaciguara	0.000 ns	4.00	-
	"spring"		3.078**	195.95	$\hat{Y} = e^{-0.265756+0.018431^{**}X}$
	"summer"		1.192 ns	579.63	-
	"autumn"		7.353***	357.40	$\hat{Y} = e^{0.864403+0.029568^{**}X}$

[1]Dependent variables; [2]"winter" (July to Sept 2016), "spring" (Oct to Dec 2016), "summer" (Jan to Mar 2017) and "autumn" (Apr and May 2017); [3]ns, *, ** and *** not significant, significant at 5 %, significant at 1 % and significant at 0.1 %, respectively, for the z test (variable larvae with Poisson distribution); [4]Alkaike Information Criterion: measurement of the quality of the adjusted regression models; [5]Adjusted model where Ŷ is the dependent variable larvae and X is the independent variable males captured.

great data dispersion, the adjusted models allow predicting and estimating LOS based on the captures of males considering the results of "autumn" in both sites (Figures 1A and 1B). Likewise, considering the annual data of Tupaciguara, there was a significant relationship between MTW and LOS of *D. saccharalis* and the relationship between MTW and LIS in the year (Table 1), as well as in "spring" and "autumn", in both sites (Figures 3A and 3B). The lowest AIC values were observed in the adjusted models of LOS in Nova Ponte in "autumn" (241.82) and LIS in Tupaciguara in "spring" (195.95) (Figures 1B and 2A).

Considering the models with smaller AIC: the model for LOS in Nova Ponte in "autumn" ($\hat{Y} = e^{0.159703+0.013174^{*}X}$), the model for LIS in Tupaciguara in "spring" ($\hat{Y} = e^{-0.265756+0.018431^{**}X}$), and the model for PID in both sites ($\hat{Y} = e^{-5.3559849+0.0026177^{**}X}$), ten MTW generated the following estimates: 1.34 LOS, 0.92 LIS in 120 stalks, and 1.5 % of PID. Similarly, with 20 MTW, the LOS, LIS and PID were 1.5, 1.1, and 4.7 %.

For both sites and both sampling methods [one delta trap with three virgin females and three female pupae exposed for one week, and 120 sugarcane stalks (ten points in the area and 12 continuous stalks) in 12.6 hectares], the trap method was more effective to detect *D. saccharalis*. Adult capture was more effective than larval sampling. There were male captures in traps in 91.4 % of the samplings (192/210) in Nova Ponte, and

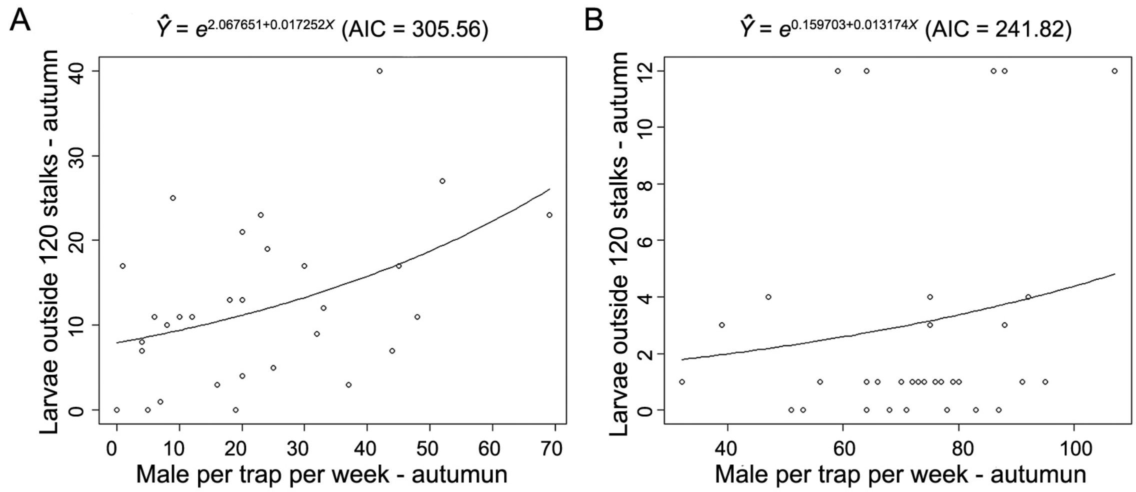

Figure 1 – Estimation of larvae of *Diatraea saccharalis* outside the stalks in weeks zero+one+two based on the capture of males in week zero in traps with virgin females during the "autumn" (Apr to May 2017) in Tupaciguara (A) and Nova Ponte (B), Minas Gerais State, Brazil.

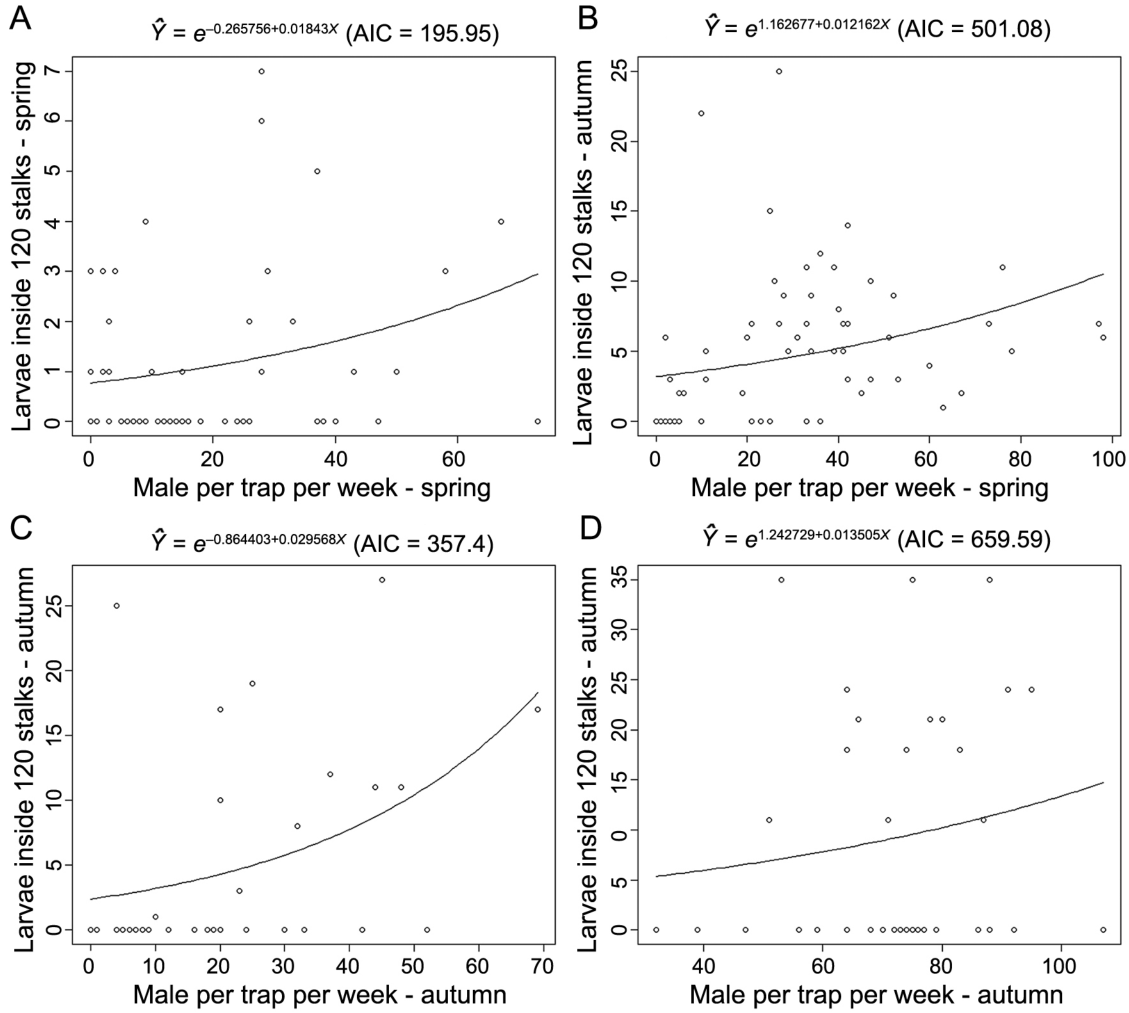

Figure 2 – Estimation of larvae inside the stalks in weeks three+four+five based on the capture of males of *Diatraea saccharalis* in traps with virgin females in week zero during the "spring" (Oct to Dec 2016) and "autumn" (Apr and May 2017) seasons in Tupaciguara (A and C) and Nova Ponte (B and D), Minas Gerais State, Brazil.

91.1 % (173/190) in Tupaciguara. LOS were found in 28.6 % of the samplings (60/210) in Nova Ponte and 24.7 % (47/190) in Tupaciguara. LIS were observed in 35.2 % (74/210) and 31.6 % (60/190) of samplings in Nova Ponte and Tupaciguara, respectively.

Considering the data from both sites, PID correlated positively with the total number of males captured from July 2016 to May 2017 (Table 1, Figure 3A). Thus, it is possible to estimate the damage caused by the sugarcane borer and fungi associated to MTW accumulated in the 11 months before.

Both sugarcane varieties, CTC9 and RB965902, are susceptible to larvae and fungi, showing that the differences observed in the internodes average damage ($\pm$ standard error mean) from Nova Ponte (13.0 $\pm$ 1.9 %) and Tupaciguara (3.3 $\pm$ 0.8 %) are attributed to differences in *D. saccharalis* population size, notably larvae density. The densities of LOS and LIS were 6.1 $\pm$ 1.2 and 1.2 $\pm$ 0.2, and 1.2 $\pm$ 0.2 and 0.6 $\pm$ 0.1 in Nova Ponte and Tupaciguara, respectively.

The most significant number of male captures of *D. saccharalis* in Tupaciguara occurred in mid-Nov, in the second half of Jan, and in Mar and Apr 2017. In Nova Ponte, most captures occurred in Oct and Nov and Apr (Figure 4B). LOS were observed between Jan and May in Tupaciguara and between Jan and Mar in Nova Ponte. LIS showed higher densities from Feb to May in Tupaciguara and in Feb in Nova Ponte (Figure 4B). The most significant number of occurrences of larvae were registered in the warm and rainy period between Oct and May (Figures 4A and 4B).

All climate variables significantly affected MTW in both sites (Table 3). The variables RH, R, and NRD positively affected the captures; however, RH < 30 % had a negative effect. The adjusted models estimated increases of 4-5 % MTW for every 1 % increase in RH (Table 3). For RH, the AIC was lower in Tupaciguara (1581.40) than in Nova Ponte (3312.50), indicating a better adjustment for the first site. Thus, the model obtained in Tupaciguara allows estimating MTW based on RH. The T directly affected MTW in Tupaciguara, but an opposite effect in Nova Ponte (Table 3).

The T had no influence on LOS in Tupaciguara. However, in Nova Ponte, the increase of T reduced LOS (Table 3). The variables RH < 30 % and RH had opposite effects in LOS. The first correlated negatively, while the second correlated positively with LOS (Table 3). Thus, greater RH or lower RH < 30 % favor the occurrence of LOS. As LIS had a specific microclimatic condition, this insect phase was not correlated with climate variables.

The variables R and NRD in the week of captures had a significant effect on MTW (Table 3). Thus, rainfall increased the capture of *D. saccharalis*. For LOS, R was not significant; however, LOS increased with NRD. In both sites, RH was important in the occurrence of LOS. There was an increase of LOS with the increase of RH and reduction in LOS with increasing RH < 30 % (Table 3).

Discussion

The use of traps with virgin females of *D. saccharalis* is recommended in the management of this pest. Nava et al. (2009) suggested the use of traps with two females, installed every 500 m, on the sugarcane crop perimeter to sample adults and thus start the release of egg parasitoids when the first males are captured.

The period between the larvae emergence until they enter the cane stalk varies from days, two to five days, to weeks, one to two weeks. If the larva penetrates the stalk after its first ecdysis, it spends approximately

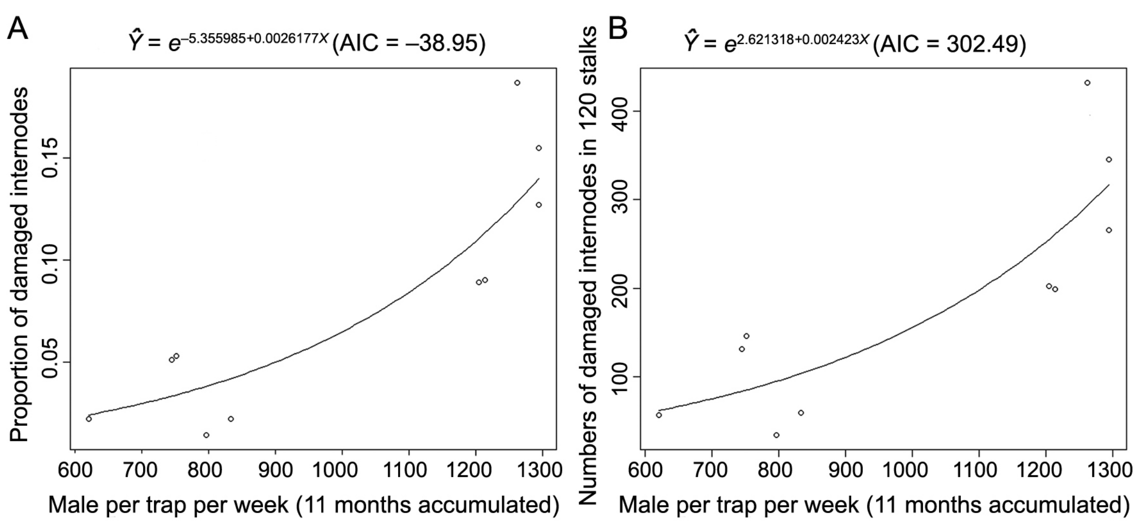

Figure 3 – Estimate of the proportion of internodes damaged (A), number of internodes damaged by sugarcane borer and fungi (B) in May 2017 based on accumulated captures of males in traps with virgin females in the period from July 2016 to May 2017 in Nova Ponte and Tupaciguara, Minas Gerais State, Brazil.

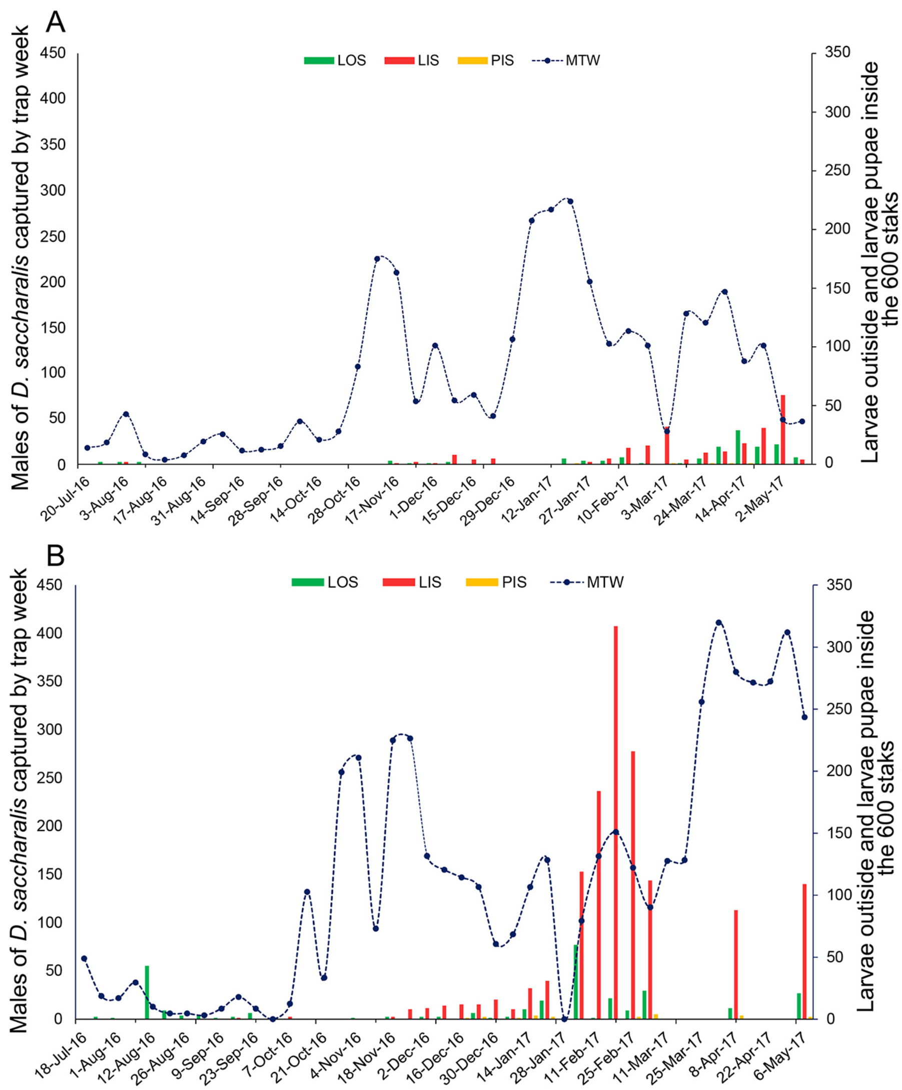

Figure 4 – Number of males of *Diatraea saccharalis* captured in five traps with virgin females per week (MTW), larvae outside the stalks (LOS), larvae inside the stalks (LIS) and pupae inside the stalks (PIS) in 120 sugarcane stalks, from July 2016 to Apr 2017, in Tupaciguara (A) and Nova Ponte (B), Minas Gerais State, Brazil.

six days at 25 °C (Melo and Parra, 1988). However, if the larva enters the stalk only after its second ecdysis, it stays approximately nine days outside the stalk, considering the thermal requirements for the insect (Melo and Parra, 1988).

It may be challenging to relate larvae density with the damage that they cause, as the insect damage occurs over time and accumulated in the stalks. The relationship between larvae infestation in stalks and internodes damaged before the harvest depends on numerous and unpredictable factors (White et al., 2008), such as the host plant susceptibility to herbivory and, in the case of sugarcane, the fungi associated with the borer damage. In addition, the damage can vary from year to year and be dependent on agricultural practices (Pannuti et al., 2015).

With another Crambidae insect, *Eureuma loftini* (Dyar), Wilson et al. (2012) suggested an action threshold to insecticide applications of 20 males captured per week. Applying this control threshold suggested to the models obtained in our study (20 MTW), the result shows 1.5 LOS in 120 stalks in the first two weeks and 1.1 LIS in the following weeks (three + four + five) after the capture. Considering 20 MTW, we obtain 880 insects in 44 weeks (11 months) and an estimate of damage (PID) of 4.7 %.

Traps with three to four virgin females were used (Nava et al., 2009) to assist the decision of control of *D. saccharalis*. As male captures in traps occurred from July 2016 to May 2017, control measures are possibly needed throughout the year, which is impractical and economically unfeasible. Although *D. saccharalis* is

Table 3 – Generalized linear models adjusted for estimating males of *Diatraea saccharalis* captured in traps (MTW) with virgin females, larvae outside the stalks (LOS) of sugarcane and climate variables: average temperature (T), hours with relative humidity of the air less than 30 % (RH < 30 %), relative humidity (RH), rainfall (R) and number of rainy days (NRD) in the week of exposure of the trap and prior to sampling of larvae in the Tupaciguara and Nova Ponte, Minas Gerais State, Brazil.

Climate variables[1]	Test site	z test[2]	AIC[3]	Equation[4]
Males of *D. saccharalis*				
Average temperature	Tupaciguara	6.481***	2734.40	$\hat{Y} = e^{2.5454+0.0852^{***}X}$
Hours of relative humidity < 30 %		–29.03***	1281.00	$\hat{Y} = e^{4.984255-0.042703^{***}X}$
Relative humidity		32.21***	1581.40	$\hat{Y} = e^{1.582592+0.047554^{***}X}$
Rainfall		23.72***	2273.00	$\hat{Y} = e^{4.210521+0.008588^{***}X}$
Number of rainy days		24.49***	2140.40	$\hat{Y} = e^{3.991728+0.157084^{***}X}$
Average temperature	Nova Ponte	–3.547***	4927.70	$\hat{Y} = e^{5.852129-0.035419^{***}X}$
Hours of relative humidity < 30 %		–36.26***	2466.20	$\hat{Y} = e^{5.374710-0.047642^{***}X}$
Relative humidity		37.99***	3312.50	$\hat{Y} = e^{2.373828+0.041597^{***}X}$
Rainfall		8.81***	4866.60	$\hat{Y} = e^{4.9149805+0.0026908^{***}X}$
Number of rainy days		11.6***	4810.20	$\hat{Y} = e^{4.828561+0.0174672^{***}X}$
Larvae of *D. saccharalis*				
Average temperature	Tupaciguara	–1.947 ns	349.39	-
Hours of relative humidity < 30 %		–5.35***	283.71	$\hat{Y} = e^{1.60731-0.06305^{***}X}$
Relative humidity		5.784***	314.60	$\hat{Y} = e^{-1.8963+0.048^{***}X}$
Rainfall		0.798 ns	352.58	-
Number of rainy days		2.230*	348.32	$\hat{Y} = e^{0.86370+0.07837^{*}X}$
Average temperature	Nova Ponte	–5.462***	569.81	$\hat{Y} = e^{8.52515-0.2787^{***}X}$
Hours of relative humidity < 30 %		–5.259***	566.14	$\hat{Y} = e^{2.207748-0.019978^{***}X}$
Relative humidity		–4.640***	578.61	$\hat{Y} = e^{0.610148+0.021879^{***}X}$
Rainfall		–1.254 ns	599.29	-
Number of rainy days		6.475***	561.69	$\hat{Y} = e^{1.43388+0.18764^{***}X}$

[1]Independent variables; [2]ns, * and ***not significant, significant at 5 % and significant at 0.1 %, respectively, for the z test (with Poisson distribution); [3]Akaike Information Criterion: measurement of the quality of the adjusted regression models; [4]Adjusted model where $\hat{Y}$ is the dependent variable, moths captured per trap per week and X represent the independent variable.

an insect quite common and apparently abundant in sugarcane crops, the damage can vary considerably between the cultivars and be influenced by cultural practices. Thus, the control measures should focus on occurrence periods of LOS chemical control (Wilson et al., 2012; Wilson et al., 2017) and presence of LIS for biological control with *C. flavipes* (Dinardo-Miranda and Fracasso, 2013).

The use of traps with virgin females of *D. saccharalis* in sugarcane crops in Brazil can support pest management since it allows estimating LOS and LIS based on male captures, and the damage caused by the insect. Wilson et al. (2012) obtained a positive and direct relationship between captures of *E. loftini* in traps baited with synthetic pheromone and the sugarcane stalks with larvae. The authors found a relationship of 20 males of *E. loftini* per trap per week and stalk infestation of 5 %. We found similar results in this study, at 20 MTW (44 weeks) the estimation of PID was 4.7 %. Additionally, the increase in captures could be used as an indication to start the larvae sampling in the stalks (Wilson et al., 2012).

Although adults of *D. saccharalis* occurred throughout the year in both sites, the larvae were observed predominantly from Oct 2016 to May 2017, during the warm and rainy period of the year. Therefore, dry periods limited the oviposition or egg viability of this insect (Parra et al., 1999). The rainfall increases soil moisture, favoring plant development and indirectly LIS. However, air humidity affects *D. saccharalis* LOS (eggs, larvae and adults). Rainfall may have hindered the neonate larvae by falling or drowning. However, more rainy days in the week prior to sampling increases the number of LOS in sugarcane. Therefore, estimation of LOS should take into account the humidity conditions in the week prior to larvae sampling. Low RH average or many hours of RH < 30 % reduces the possibility of finding LOS even with male captures.

In Brazil, new control strategies of *D. saccharalis* in sugarcane have been adopted. In 2017, it was released the first genetically modified variety with an expression of Cry1Ab toxin from *Bacillus thuringiensis*. The variability in susceptibility of this insect population to this toxin requires proper management of insect resistance (Girón-Pérez et al., 2014). The effectiveness of egg parasitoid *T. galloi* and chemical control with insect growth regulators and diamides requires an adequate estimation of the population of *D. saccharalis* larvae and the action threshold for each strategy adopted. Thus, the models estimated in our study may contribute to the control of sugarcane borer. Nevertheless, these models should be validated in the field. The biological and chemical control of the *D. saccharalis*, eggs by *T. galloi* and LOS by insecticides should be measured with different levels of male captures under suitable climatic conditions for the insect, correlating with damaged internodes.

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References

Butt, B.A.; Cantu, E. 1962. Sex Determination of Lepidopterous Pupae. USDA-ARS, Washington, DC, USA. https://doi.org/10.5962/bhl.title.67261

Dinardo-Miranda, L.L.; Fracasso, J.V. 2013. Sugarcane straw and the populations of pests and nematodes. Scientia Agricola 70: 305-310. https://doi.org/10.1590/S0103-90162013000500012

Dinardo-Miranda, L.L.; Fracasso, J.V.; Costa, V.P.; Anjos, I.A.; Lopes, D.O.P. 2013. Reaction of sugarcane cultivars to sugarcane borer. Bragantia 72: 29-34 (in Portuguese, with abstract in English). https://doi.org/10.1590/S0006-87052013005000012

Girón-Pérez, K.; Oliveira, A.L.; Teixeira, A.F.; Guedes, R.N.C.; Pereira, E.J.G. 2014. Susceptibility of Brazilian populations of *Diatraea saccharalis* to Cry1Ab and response to selection for resistance. Crop Protection 62: 124-128. http://dx.doi.org/10.1016/j.cropro.2014.04.004

Gries, R.; Dunkelbum, E.; Gries, G.; Baldilla, F.; Hernandez, C.; Alvarez, F.; Perez, A.; Velasco, J.; Oehlschlager, A.C. 1998. Sex pheromone components of *Diatraea considerata* (Heinrich) (Lep., Pyralidae). Journal of Applied Entomology 122: 265-268. http://dx.doi.org/10.1111/j.1439-0418.1998.tb01494.x

Joyce, A.L.; White, W.H.; Nuessly, G.S.; Solis, M.A.; Scheffer, S.J.; Lewis, M.L.; Medina, R.F. 2014. Geographic population structure of the sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), in the southern United States. PLoS One 9: e110036. http://dx.doi.org/10.1371/journal.pone.0110036

Kalinová, B.; Nascimento, R.R.; Hoskovec, M.; Mendonça, A.L.; Silva, E.L.; Freitas, M.R.T.; Cabral Jr, C.R.; Silva, C.E.; Sant'Ana, A.E.G.; Svatoš, A. 2012. Identification of two components of the female sex pheromone of the sugarcane-borer *Diatraea flavipennella* (Lepidoptera: Crambidae). Journal of Applied Entomology 136: 203-211. https://doi.org/10.1111/j.1439-0418.2011.01625.x

Long, W.H.; Hensley, S.D. 1972. Insect pests of sugar cane. Annual Review of Entomology 17: 149-176. https://doi.org/10.1146/annurev.en.17.010172.001053

Lopes, D.A.; Cantagalli, L.B.; Stuchi, A.L.P.B.; Mangolin, C.A.; Ruvolo-Takasusuki. M.C.C. 2014. Population genetics of the sugarcane borer *Diatraea saccharalis* (Fabr.) (Lepidoptera: Crambidae). Acta Scientiarum Agronomy 36: 189-194. https://doi.org/10.4025/actasciagron.v36i2.16211

Melo, A.B.P.; Parra, J.R.P. 1988. Biology of *Diatraea saccharalis* under different temperatures. Pesquisa Agropecuária Brasileira 23: 663-680 (in Portuguese, with abstract in English).

Nava, D.E.; Pinto, A.S.; Anjos, S.D.S. 2009. Biological control of sugarcane borer = Controle biológico da broca da cana-de-açúcar. Embrapa Clima Temperado, Pelotas, RS, Brazil (in Portuguese).

Palacio-Cortés, A.M.; Zarbin, P.H.G.; Takiya, D.M.; Bento, J.M.S.; Guidolin, A.S.; Consoli, F.L. 2010. Geographic variation of sex pheromone and mitochondrial DNA in *Diatraea saccharalis* (Fab., 1794) (Lepidoptera: Crambidae). Journal of Insect Physiology 56: 1624-1630. https://doi.org/10.1016/j.jinsphys.2010.06.005

Pannuti, L.E.R.; Baldin, E.L.L.; Gava, G.J.C.; Silva, J.P.G.F.; Souza, E.S.; Kölln. O.T. 2015. Interaction between N-fertilizer and water availability on borer-rot complex in sugarcane. Bragantia 74: 75-83. https://doi.org/10.1590/1678-4499.0258

Parra, J.R.P.; Milano, P.; Consoli, F.L.; Zerio, N.G.; Haddad, M.L. 1999. Effects of adult nutrition and humidity on the fecundity of *Diatraea saccharalis* (Fabr.) (Lepidoptera: Crambidae). Anais da Sociedade Entomológica do Brasil 28: 49-57 (in Portuguese, with abstract in English). https://doi.org/10.1590/S0301-80591999000100005

Schexnayder, H.P.; Reagan, T.E.; Ring, D.R. 2001. Sampling for the sugarcane borer (Lepidoptera: Crambidae) on sugarcane in Louisiana. Journal of Economic Entomology 94: 766-771. https://doi.org/10.1603/0022-0493-94.3.766

Silva-Brandão, K.L.; Santos, T.V.; Consoli, F.L.; Omoto, C. 2015. Genetic diversity and structure of Brazilian populations of *Diatraea saccharalis* (Lepidoptera: Crambidae): Implications for pest management. Journal of Economic Entomology 108: 307-316. https://doi.org/10.1093/jee/tou040

White, W.H.; Viator, R.P.; Dufrene, E.O.; Dalley, C.D.; Richard, E.P.; Tew, T.L. 2008. Re-evaluation of sugarcane borer (Lepidoptera: Crambidae) bioeconomics in Louisiana. Crop Protection 27: 1256-1261. https://doi.org/10.1016/j.cropro.2008.03.011

Wilson, B.E.; Showler, A.T.; Reagan, T.E.; Beuzelin, J.M. 2012. Improved chemical control for the mexican rice borer (Lepidoptera: Crambidae) in sugarcane: larval exposure, a novel scouting method, and efficacy of a single aerial insecticide application. Journal of Economic Entomology 105: 1998-2006. https://doi.org/10.1603/EC11271

Wilson, B.E.; VanWeelden, M.T.; Beuzelin, J.M.; Reagan, T.E.; Prado, J.A. 2017. Efficacy of insect growth regulators and diamide insecticides for control of stalk borers (Lepidoptera: Crambidae) in sugarcane. Journal of Economic Entomology 110: 453-463. https://doi.org/10.1093/jee/tow305