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Article

Damage by *Diatraea* spp. (Lepidoptera: Crambidae) in the Córdoba-Golfo sugarcane region, Veracruz

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Abstract

The stem borer (*Diatraea* spp.) is the primary pest of sugarcane worldwide. In the Córdoba-Golfo sugarcane region, Veracruz, Mexico, the distribution and damage by the *Diatraea* spp. complex has been little studied, which causes biases in the estimation of the impact. The objective of the study was to determine the spatial-temporal damage by *Diatraea* spp. larvae during the production cycle from January 2020 to January 2021. A total of n=21 plots were selected in seven localities, and the number of stems bored by *Diatraea* spp. larvae was determined, with which isodensity maps were generated with the Suprakml software and Google Earth Pro®. The interaction between crop age, studied sites, and bored stems was analyzed with a two-way variance test (α< 0.05) with the Rstudio v3.6 software. The distribution of damage by *Diatraea* spp. larvae showed a clustered spatial arrangement, with the largest number of stems bored in the Actopan site, while in Palmillas, the population behaved as a focus of infestation. The number of bored stems was constant, but from January to April 2020, the damage increased, coinciding with the vegetative development period of the crop. The interaction analysis presented a negative effect since, as the age of the crop increased, the damage decreased, while Palmillas showed statistical differences with respect to the rest of the sites, so it is concluded that this site is the possible nucleus of dispersion of the pest.

Keywords:

percentage of damage, population distribution, spatial-temporal, stem borers.

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Introduction

In Mexico, sugarcane (*Saccharum* spp., hybrid) is one of the five most relevant crops, with 789 996 ha planted in six agroecological zones of the country, processed in 49 sugarcane mills where 5 715 448 t of sugar were obtained in the 2020-2021 harvest (CONADESUCA, 2021a). The larvae of the genus *Diatraea* spp. are the primary pest of sugarcane since they affect crops of economic importance, such as corn, sorghum, and rice (Joyce *et al*., 2014; Barrera *et al*., 2017).

This genus comprises 41 species in the Americas, with *D. saccharalis* being the one with the greatest presence in sugarcane and other crops from the United States of America to Argentina, with economic relevance due to the damages it causes (Solís *et al*., 2015; Francischini *et al*., 2019).

The vagility of *Diatraea* spp. is limited by aspects of locomotion; nevertheless, they are a group of successful species that have colonized 18 mills in various sugarcane-growing areas of Mexico, in which it represented a decrease of 2 to 10 t ha^{-1} of cane in 2020-2021 (Hernández-García *et al*., 2015; CONADESUCA, 2021b).

The larvae bore from the outside to the inside of the stem, which damages the meristematic tissue and decreases yield, juice quality, plant biomass and increases susceptibility to pathogens and consequently, agro-industrial yields of sugarcane decrease (Joyce *et al*., 2014; Pavinato *et al*., 2018; Rossato *et al*., 2019).

In general, sugarcane producers use chemical control as a management measure for the presence of *Diatraea* spp. (Wilson *et al*., 2022). Due to their biological behavior and spatial-temporal population distribution, damage, and management, these strategies are generalized with minimal results, leading to inadequate pest control (Wilson, 2021).

The Córdoba-Golfo sugarcane region is one of the most important areas of Veracruz, Mexico, where there are climatic conditions and crop management that can favor variations in population distribution and incidence of damage of *Diatraea* spp., but the centers of origin of damage in which control strategies should focus are unknown (CONADESUCA, 2021a).

The objective of the study was to determine the spatial-temporal distribution of damage to stems by *Diatraea* spp. larvae in commercial sugarcane crops during the 2020-2021 productive cycle in the Córdoba-Golfo region, which could lead to the application of targeted strategies for the effective management of the pest.

Materials and methods

Study region

The present study was carried out in plots of commercial sugarcane crops belonging to the supply area of the mills Central El Potrero (six plots), Central Progreso (12 plots), and San José de Abajo (three plots), with a monthly sampling per plot for thirteen months, from January 2020 to January 2021, in the Córdoba-Golfo sugarcane region, whose average temperature and precipitation during the study were 22.5 °C and 141.49 mm^3, respectively, and the land use is sugarcane with a soil type mainly vertisol (CONADESUCA, 2021b).

Based on the information collected in a diagnostic monitoring, a transect of 59.73 linear km was established with an area of influence of 53 073 ha, estimated by measuring the pixels generated after the isodensity analysis and its visualization in Google Earth Pro®. Quadrants of 1 ha were established in the transect, which consisted of seven sites with three replications (n= 21 plots) (Figure 1).

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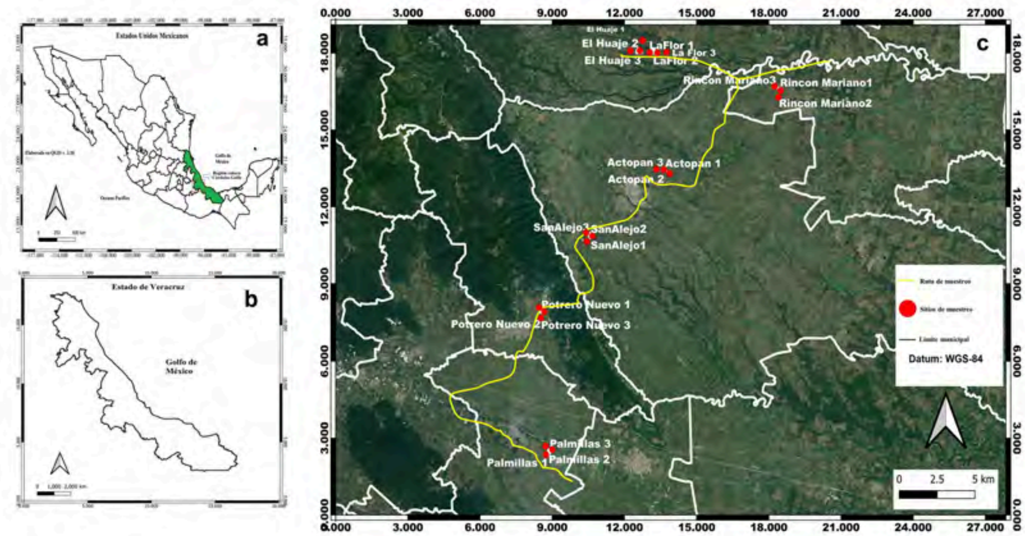
Figure 1. Study area. a) Mexico; b) Veracruz; and c) 21 study sites.



In the quadrants, systematic and random samplings were carried out to detect the direct presence of larvae or feeding tunnels caused by *Diatraea* spp. species, which is characterized by the presence of holes with feeding residues called 'frass' (Flores, 2007; Joyce *et al*., 2016).

Quantification of stems bored by larvae of the *Diatraea* spp. complex.

One hectare per site was delimited, where healthy and bored (with entrance holes or feeding tunnels) stems were counted in a 10 ml transect at five points, that is, a point for each of the four corners and a fifth point in the center of the quadrant. A different transect was selected in each count to avoid counting the areas evaluated in the previous count (Flores, 2007).

Only stems damaged by larvae of *Diatraea* spp. were counted, characterized by having central perforations that start from the apical part of the stems between the internodes and accumulate residues in the entrance hole, called frass (Dinardo-Miranda *et al*., 2013; Joyce *et al*., 2016).

Analysis of the spatial-temporal distribution of stems bored by larvae of the *Diatraea* spp. complex

With the records of the presence of *Diatraea* spp. larvae and the geographical coordinates of the sampling plots, maps of damage distribution in the studied sites were generated, the population isodensity was calculated, and inverse linear interpolation was carried out.

The analyses were performed with Supra KML® Windows® version, with a fixed significance level of 1%, which is based on a nonparametric continuous distribution (inverse-distance weighting) that analyzes data with negative binomial or Poisson distribution and which has been used in species with clustered spatial-temporal dynamics Response Surface (López-Collado, 2004; Flota-Bañuelos *et al*., 2013).

The generated layers were visualized using Google Earth Pro® (Serna-Lagunes *et al*., 2022). To explain the phenomenon of the presence of bored stems during the research, the meteorological conditions during the crop cycle were studied, for which the region was subdivided into three

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subregions from which statistical data related to average monthly temperature and precipitation were obtained (CONADESUCA, 2021b) (Table 1).

Table 1. Classification used to obtain meteorological data.

Subregion	Sites associated
1	Potrero Nuevo, Actopan and Palmillas
2	Rincón Mariano, La Flor and El Huaje
3	San Alejo

Determination of the interaction between the age of the crop and the stems bored by larvae of the *Diatraea* spp. complex, and the sites studied

The relationship between the presence of the borer and the age of the crop was calculated from the date of harvest (December 2019 to January 2020) and the count of the stems bored monthly. To determine the interaction between the studied sites, the age of the crop, and the damage caused by the feeding of *Diatraea* spp. larvae, a two-way analysis of variance with a significance value of #< 0.05, and a Tukey HSD multiple comparison test were performed in the statistical package RStudio version 3.6 for Windows (Core Team, 2022).

Results and discussion

Analysis of the spatial-temporal distribution of stems bored by larvae of the *Diatraea* spp. complex.

At the Potrero Nuevo site (Figure 2a), the highest activity of stem borer larvae was observed in January 2020, with a percentage of bored stems between 14 and 29%, which resulted in areas of damage grouped into halos or circumferences that merge at the sites Palmillas and Actopan, which presented 5.24 to 13.83% of bored stems. In contrast, from September, the damage by larvae was the opposite, with a decrease from 10.78 to 7.19%, with an area of influence of 1 857 ha in which different crops are found, in addition to sugarcane (Figure 2a).

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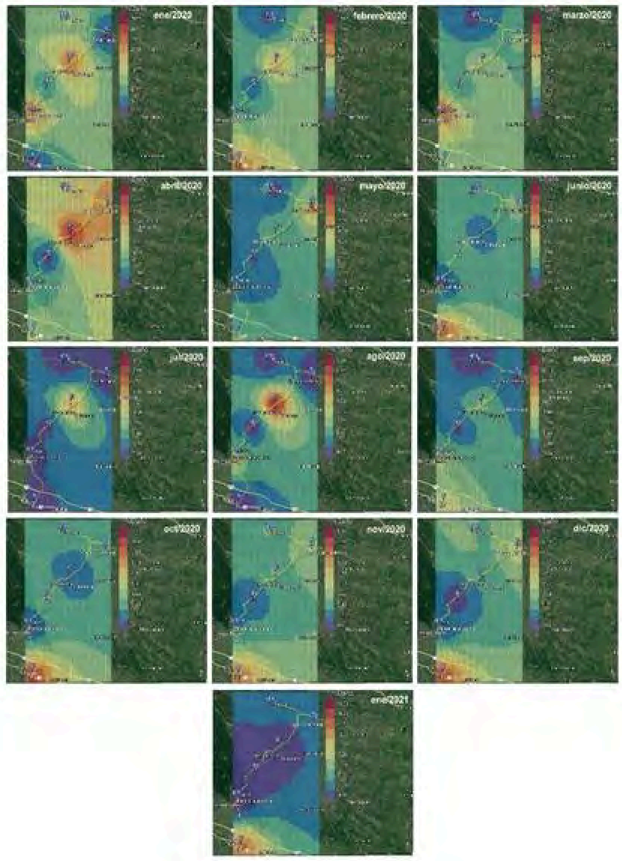
Figure 2. Spatial distribution of damage caused by larvae of the Diatraea spp. complex in sugarcane stems in the mills of southeastern Mexico. a) Potrero Nuevo, Atoyac; b) San Alejo, Paso del Macho; c) Actopan, Pasodel Macho; d) Rincón Mariano, Paso del Macho; e) La Flor, Zentla; f) El Huaje, Zentla; and g) Palmillas, Yanga, Veracruz.



The number of stems bored by *Diatraea* spp. showed aggregate distribution patterns with a tendency to damage peaks at recurrent sites. Previous reports have associated aggregate populations of *Diatraea* spp. with habitats suitable for reproduction and survival (Dinardo-Miranda *et al*., 2011; Leyton-Flor *et al*., 2018).

For the San Alejo site, the percentage of bored stems ranged from 0.55 to 8.86%, with an average of 1.38% on the periphery of this site during February, March, May, June, July, August, November, December 2020, and January 2021, even though it is located between sites of higher incidence such as Potrero Nuevo and Actopan (Figure 2b). Thus, populations of *Diatraea* spp. larvae remained constant and intermittent in the studied area, which can be attributed to their dispersion behavior and the search for sites to complete their reproductive cycle (Beuzelin *et al*., 2011; Pavinato *et al*., 2018).

Regarding Actopan, the highest number of bored stems occurred in January 2020, with 4.77 to 29.55% (Figure 2c). In contrast, in February, April, July, August, and September, the greatest damage was 2.87 to 12.55% (Figure 2c). During April 2020, there was a percentage of bored stems between 5.24 and 10.49%, which resulted in a halo that merges geographically with the sites La Flor, El Huaje, and Rincón Mariano, which generated an area of influence of 32 270 ha, which reached 10.49% (Figure 2c, d and f).

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The results of this study indicate that the greatest damage caused by sugarcane borers occurs at 70 days of crop development (January to March) under the understanding that the crop has been harvested in January, while for this study, it was extended until April 2020, which coincides with the initial period of vegetative development described as the stage most susceptible to damage with generations of development stages of *Diatraea* spp. overlapping with continuous peaks as a result of water-moisture stress and successively during the year (Vargas *et al*., 2015).

Concerning the Rincón Mariano site, the highest incidence was observed during May, with a percentage of bored stems of 5.28 to 10.57% (Figure 2d). In contrast, in April, the halo generated by this site merged with the areas of influence of the sites Actopan, El Huaje, and La Flor, which resulted in the largest recorded area, with percentages of damaged stems between 5.24 and 10.49%, equivalent to 32 270 ha (Figure 2c, f and e). In addition, the highest number of stems damaged by *Diatraea* spp. larvae was counted from January to March 2020 when intermittent drought occurred at the sites Actopan, Potrero Nuevo, and Rincón Mariano, which differs from previous findings that relate high borer infestations with the rainy season (CONADESUCA, 2021b; Joyce *et al*., 2016).

With respect to the harvest period, it was from December 15, 2019, to March 16, 2020, in the Central Progreso mill, from December 15, 2019, to May 07, 2020, in Central El Potrero, and from December 28, 2019, to May 30, 2020, in San José de Abajo, which coincides with the period of greatest damage by *Diatraea* spp. larvae reported in the present study (CONADESUCA, 2021a).

For the La Flor site, the highest incidence occurred during January 2020, with 17.73% of stems damaged, and the rest of the study period ranged from 0.87 to 7.34% (Figure 2e). Concerning the El Huaje site, the peak of damage took place in January 2020, when 11.82% of bored stems were recorded and subsequently gradually decreased to 0.87%, generally influenced by the halos formed by the sites Actopan and Rincón Mariano (Figure 2f).

What was observed in the La Flor site is closely related to the planting period called 'great cultivation' (from September to October), when 7-10 month-old stems are usually cut, which are used as seed, which gives rise to crop areas with stems that are young (pelillos) and succulent for the consumption of borers from October to January, as analyzed on this site and some others such as Actopan, Palmillas, and Rincón Mariano.

At the Palmillas site, the percentage of bored stems was greater than 5% (Figure 2g) during the study period, which ranged from 2.34 to 18.57%, with a fluctuation of bored stems during the monitoring period and peaks of activity in February 2020. On the other hand, in September of the same year, a tendency to increase was observed, and the area of influence merged with the sites Potrero and Actopan, with a percentage between 5.39 and 10.78%, which gave rise to the second area of greatest influence of 30 299 ha. In contrast, in January 2021, the highest incidence peak with 5.55 to 18.57% and an area of influence of 10 311 ha were observed.

Given that the Palmillas site presents a focus of infestation with a constant number of stems bored by larvae of the *Diatraea* spp. complex, possibly the lack of geographical barriers that separate the different areas in the study region and the constant movement of plant material (seed) with intermittent and high presence in sites such as Palmillas, which represents potential foci that can lead to sites of widespread dispersal, which could indicate that a greater distribution of stem borers is only a matter of time (Vargas *et al*., 2018).

According to the sugarcane stems bored by *Diatraea* spp. larvae, three blocks were defined: block 1: Potrero Nuevo, Actopan, and Palmillas, with greater activity between January and April (greater than 8%); block 2: sites Rincón Mariano, La Flor, and El Huaje, which had a number of damaged stems greater than 3.9%; and block 3: the San Alejo site, which maintained an average of < 1.9%.

The intermittent presence of *Diatraea* spp. larvae in the sites of block 1 is attributable to the climatic and orographic characteristics in the study area, that is, due to the optimal conditions for the development of species of the *Diatraea* spp. complex, such as temperatures of 20-23 °C, annual precipitation of 1 200-1 500 mm^3, precipitation of 50 mm^3 in the driest months, orography

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with slopes < 0.05 degrees, and heterogeneity of crops (Valencia *et al*., 2021; CONADESUCA, 2021b).

In block 2, the Rincón Mariano site (Figure 2d) showed intermittent behavior. In January 2020, 2.43% of bored stems were observed, which increased during the following months, with a maximum peak of 6.29% in May and a decrease of 0.25% in August. Where the number of bored stems increased until January 2021 with 2.14%, similar to that observed in January 2020. El Huaje (Figure 2f) and La Flor (Figure 2e) showed similar behaviors, with peaks of 10 and 5% during January and April 2020, respectively, and a decrease during the second quarter, which could be attributed to the fact that these sites have similar agroclimatic characteristics (CONADESUCA, 2021b).

In contrast, for block 3, the San Alejo site (Figure 2b) showed a number of bored stems less than 5% in 2020, except in January and October of that same year, despite being a transition site between Actopan and Potrero Nuevo, where a number of bored stems greater than 10% were counted. However, at all sites, except for Palmillas, a decrease in the number of stems damaged by *Diatraea* spp. larvae was observed during June and July, which coincided with the dog days (July 12 to August 20, 2020), characterized by a sudden increase in temperature with a tendency to periods of low moisture and subsequently an increase in precipitation in the region of study (CONADESUCA, 2021b).

Climatic conditions can be influenced by phenomena such as El Niño/Southern Oscillation (ENSO) (Valencia *et al*., 2021). Several studies have reported that interannual climate variability is largely related to the ENSO phenomenon in its warm phase and its cold phase, known as 'La Niña'; in Mexico, the variability of precipitation is largely modulated by this phenomenon (Tejeda-Martínez *et al*., 2011; Báez-González *et al*., 2018).

From April to September 2020, there was an increase in temperature and precipitation variations with slight peaks during June and September of the same year, a period in which the fluctuation of damage by *Diatraea* spp. larvae was between 7 and 17%, with a maximum peak during September 2020 in most of the sites studied. These distribution patterns tend to be repetitive and dependent on climatic conditions in the study area, which may be influenced by the increase or variations in precipitation periods attributed mainly to the climatic phenomenon called ENSO.

This is because the presence of ENSO causes anomalous distributions of variables such as temperature, air humidity, cloudiness, and precipitation on a seasonal scale above normal (Díaz and Markgraf, 2000). Also, in the winter season, 'El Niño' induces an increase in precipitation patterns and a decrease in temperatures (Conde *et al*., 2006; Ponnette-González *et al*., 2010).

In contrast, 'La Niña' is characterized by the absence of rainfall, which makes the pre-summer drought (dog days) more pronounced and causes stress to the plant, leaving it vulnerable to damage caused by the feeding of *Diatraea* spp. larvae as in Actopan, Potrero Nuevo, El Huaje, La Flor, Rincón Mariano and San Alejo (Magaña *et al*., 2003).

This, as a consequence of the excess of water derived from the increase in rainfall, negatively affects the development of the crop and increases the possibility of the presence of pathogenic fungi in the feeding holes of borer larvae, with effects on the quality of cane juice. In addition, if the humidity condition is maintained at the beginning of spring, the excess could favor the spread of populations of the *Diatraea* spp. complex and diseases such as those associated with fungal pathogens related to the deterioration of the quality of sugarcane juice (White *et al*., 2008; Vargas *et al*., 2015; Rossato *et al*., 2019).

Therefore, this study is the first to establish the patterns of population distribution in the Córdoba-Golfo sugarcane region, and the results obtained establish the bases that will allow the optimization of resources and effective management with a lower bias of the damage caused by *Diatraea* spp. larvae, since the possible centers of population origin, the adjacent areas of influence, and the critical period for the management of stem borer in sugarcane were identified (Pérez *et al*., 2022).

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Determination of the interaction between the crop age, stems bored by *Diatraea* spp. larvae and the sites studied

No significant differences were observed in the interaction between the site and the month of sampling (which coincides with the age of the crop by the date of harvest) (Table 2). Nevertheless, significant differences were observed between the factors separately, such as the sites studied in the response variable number of stems damaged by borer and the months with respect to this variable.

Table 2. Relationship between crop age and stems damaged by *Diatraea* spp. larvae in the sugarcane cultivation cycle 2020-2021.

Interaction	*Pr(>F)*	*Mean*	*df*
Site	<0.0001	93.52	6
Month of sampling	<0.0001	68.27	11
Interaction (site: month of sampling)	0.698	14.59	61

Significance value ($p \leq 0.05$).

Regarding the sites, the results observed in Palmillas show significant differences compared to the rest of the sites, with damages that reached an average of 6.31% during the study period (Table 3).

Table 3. Multiple comparison of the means of the number of damages with respect to the month of sampling (Tukey HSD).

Month of sampling	Mean	Groups of the Tukey test
January -20	10.321408	a
February -20	5.054624	b
March -20	4.270402	bc
April -20	4.716927	bc
May -20	2.34154	bcd
June. -20	2.182517	bcd
July -20	1.122116	d
August -20	1.960166	cd
September -20	3.76381	bcd
October -20	3.296356	bcd
November -20	2.542599	bcd
December -20	1.86356	cd
January -21	3.037898	bcd

Significance value ($p \leq 0.05$). Treatments with the same letter have no significance.

The highest number of bored stems was observed from January to May 2020 and in January 2021, with distribution patterns that tend to be repetitive and dependent on climatic conditions, which indicates a negative correlation between the abundance of larvae of the *Diatraea* spp. complex and the age of the crop, which is an important finding since, generally, the increase in damage by larvae of *Diatraea* spp. complex is usually related to the beginning of the maturity stage of the crop (Srikanth and Kurup, 2011).

In addition, it was observed that this condition could vary because it is closely related to the cut date because the harvest is not simultaneous but is distributed over a period of five to six months, called zafra (CONADESUCA, 2021a). It is a relative event that depends on the physiological maturity of the crop, determined with periodic measurements until reaching the sucrose values required by the industry, based on a maturity curve by variety (Rossato *et al*., 2019).

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This was reflected in the results of the statistical test, which indicated differences between the Palmillas site and the rest of the sites studied due to the overlapping presence of all stages of development of larvae of the *Diatraea* spp. complex, possibly influenced by the agroecological characteristics of the site (Zhang *et al*., 2019).

Conclusions

Variations in population distribution and incidence of damage of larvae of the *Diatraea* spp. complex were identified, which change according to the environmental characteristics of the region and the phenological development of sugarcane. This phenomenon was evident in the Actopan site, where there was the most significant damage in the study area, and the Palmillas site was observed as a focus of infestation or center of population origin since the population fluctuation varies with occasional peaks that obey the phenological development of the crop.

For their part, the temporality of the distribution of damage caused by larvae of the *Diatraea* spp. complex, and the populations remain constant over time, with a critical period in the first months of the development of the crop, which is due to the negative correlation observed between the number of bored stems and the age of the crop. Finally, this study provided the basis for the design of a program of integrated management of sugarcane borers of the genus *Diatraea* based on the knowledge of the most affected sites and possible centers of origin.

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