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Influence of *Diatraea saccharalis* (Lepidoptera: Crambidae) infestation on sweet sorghum productivity and juice quality

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Ethanol production from sweet sorghum depends on the quality of the biomass and sugars in the juice extracted from the plant. However, quality may be compromised by *Diatraea saccharalis* (Fabricius) (Lepidoptera: Crambidae) or sugarcane borer infestation. This study evaluated the effects of infestation by the pest on sweet sorghum juice productivity and quality. Sorghum variety BRS506 was planted in an experimental area with 4,800 m^2. Samples were harvested at 115 days after planting and the following variables were evaluated: physical injury caused by the pest in the stalk, juice yield, total soluble solids in the juice and chemical composition. Additionally, the presence of *Fusarium* sp. in the stalks was checked. A significant difference was detected for juice yield, with lower values found in bored stalks resulting in a 2.62% decrease in juice yield at an infestation intensity of 4.16%. Infestation of *D. saccharalis* also caused a reduction of 34% in the plant sucrose content and significantly decreased fiber, lignin and ash rates. Infestation by *D. saccharalis* in sweet sorghum caused a significant reduction of plant height, juice productivity, and was associated with the presence of *Fusarium* sp., and sugar and fiber reduction.

Key words: Chemical composition, integrated pest management, juice quality, sugarcane borer.

INTRODUCTION

The sugarcane alcohol and energy industrial sector in Brazil is increasingly seeking profitable and sustainable alternatives to maintain its competitiveness. Sweet sorghum, an alternative feedstock for the production of biomass and ethanol (Durães, 2014; Zegada-Lizarazu and Monti 2012), has important agronomic and industrial

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characteristics for the production of bioenergy (Wu et al., 2010; Monk et al., 1984). Further, ethanol may be produced from the juice of sweet sorghum at the same facilities used for sugarcane processing (Tomaz and Assis 2013; Durães et al., 2012). Sweet sorghum contains fermentable sugars in the juice (sucrose, glucose, and fructose), starch in the grain, and lignocellulose in the bagasse, which may be used in second-generation ethanol plants (Wu et al., 2010).

Since sweet sorghum is characterized by high photosynthetic activity, it may be grown in temperate and tropical environments (Kim et al., 2012), especially if cultivated in summer when there is supply of raw material during the sugarcane offseason (May et al., 2014). However, ethanol production from sweet sorghum may be jeopardized by infestation of *Diatraea saccharalis* (Fabricius) (Lepidoptera: Crambidae), also known as the sugarcane borer (Mendonça 1996), one of the principal insect pests in sweet sorghum production (Waquil et al., 1980). This pest has a polyphagous food habit and causes damage in several economic cultures, among these are, sugar cane, rice, corn and sorghum (Cruz, 2007).

D. saccharalis causes direct and indirect losses to crops due to its feeding on the stalk of plant. In fact, it bores holes in the stalks, reduces the flow of photoassimilates, causes plant lodging and decreases the juice productivity (Fuller et al., 1988). Once it gets into the stalk, its control is difficult. Holes left in the stalk by *D. saccharalis* trigger infection by fungi. Many species of the genus *Fusarium*, including *Fusarium verticillioides* Sacc. (Nirenberg) (synonym *Fusarium moniliform* Sheld.) [teleomorph: *Giberella fujikuroi* (Sawada)], *Fusarium thapsinum* Klittich, Leslie, Nelson & Marasas, and *Fusarium proliferatum* (Matsushima) Nirenberg are capable of infecting stalks. *Colletotrichum falcatum* (Went) is also an important fungus which promotes the inversion of sucrose and reduces juice purity in sugarcane, causing lower sugar yields and contamination during alcoholic fermentation and, consequently, low ethanol yields (Mendes et al., 2012; Tesso et al., 2010; Leslie et al., 2005; Leslie, 1991). However, there are no records of sugar inversion in sweet sorghum as a result of the presence of *D. saccharalis* and the genus, *F. verticillioides*. Nevertheless, it is known that the “red rot” symptom caused by the attack of pests and plant pathogens is due to phytoalexins in sorghum. These substances are the plants defense against pests and plant pathogens. Their accumulation adjacent to the affected spots is marked by a reddish-purple colour (hence the name of the symptom).

The use of sweet sorghum for ethanol production should considered due the impact of *D. saccharalis* infestation on the quality of the raw material since the infestation of this pest interferes with sucrose content, soluble solids, acidity of juice and fiber content (Clarke and Legendre, 1999). Studies developed by Copersucar® in the 1980s established parameters to determine the effects of *D. saccharalis* on sugar and alcohol production from sugarcane (Téran et al., 1986; Precetti et al., 1988; Arrigoni, 2002). Since the effects caused by the attack of this insect on sweet sorghum have not been established, it is highly relevant to determine the effect of *D. saccharalis* infestation on the agronomic and quality-related components of sweet sorghum production. This study assesses the effect of *D. saccharalis* on production of juice and bagasse from sweet sorghum for ethanol production.

MATERIALS AND METHODS

Experiment site

This study was conducted in sweet sorghum field at the *Embrapa Milho e Sorgo* Research Center in Sete Lagoas MG Brazil (19°28’ S and 44°15’08” W), under field conditions, in the 2013/2014 crop year, using sweet sorghum variety BRS506.

To simulate a realistic field situation as closely as possible, sweet sorghum was grown in a 4800 m^2 field, with 0.70 m spacing between rows and 10 plants per row; the area was divided in two 2400 m^2 fields with and without insecticide treatments. Inside the growing areas, the samples were obtained using completely randomized design, with each stem being considered a repetition. The field plots were not replicated in other years.

The insecticide, chlorantraniliprole was used as chemical insecticide, with spraying at 20, 37 and 42 days after planting, at 60 g per ha. After the last spraying, sweet sorghum yield was high. The other treatment consisted of no-control of *D. saccharalis* and the crop management was made according to May at al. (2012). The soil correction and fertilizing was made follow recommendations of Santos et al. (2014). In each area, three different sorts of 50 samples were collected: the first was used to verify physical injury; the second was used to evaluate juice quality and chemical composition, and the third was used to verify fungus infection.

Physical injury caused by *D. saccharalis* infestation

The injury caused by natural infestation of *D. saccharalis* was evaluated at 115 days after planting, or rather, during the plants physiological maturity. 150 stalks were collected randomly in each area (with or without insecticide). Each stalk was opened lengthwise and data on height, total number of internodes, bored internodes (with symptoms of injury or tunnel formed by the larva) and tunnel lengths were assessed. The number of healthy internodes was calculated as the difference between total and bored internodes.

Determination of juice yield, sugar profile and chemical composition of sweet sorghum stalks

On physiological maturity, additional 400 stalks were collected at random from each treatment and subdivided into four groups: 100

stalks for whole-plant samples; 300 stalks sectioned into 3 parts (basal, middle and apical). Each sample, weighing 500 g, was processed to form replicate samples. The number of samples varied from 6 to 40 (Table 3).

Samples were processed with a hydraulic press to extract the juice and total soluble solids were evaluated with digital refractometer in °Brix. Juice yield (%) was determined as the volume of juice extracted from 500 g of processed stalk (volume/mass). Further, an 80 ml aliquot was collected out of a total volume of juice extracted from each sample, and kept frozen at -4°C in polyethylene bottles for subsequent quantification of fructose, glucose and sucrose contents by HPLC with refractive index detection. A carbohydrate column (Waters Alliance 2695, Waters Corporation, Milford MA USA) was employed to analyze sugars. The mobile phase was a mixture of acetonitrile: water (75:25) with 1 mL per min flow rate. Injection volume was 25 µL. Refractive index (Waters Corporation) was the detector. Standards of fructose, glucose and sucrose sugars with high purity (99% Sigma-Aldrich) were used to construct the calibration curve. The juice samples were diluted, centrifuged and adjusted in the proportion of the mobile phase by comparing retention times of the standards.

Samples of wet bagasse, retrieved from the juice extraction process, were weighed (fresh weight) and dried in an oven at 105°C (AOAC, 1990) to determine dry matter content. After drying, the material was analyzed to measure cellulose, hemicellulose and lignin contents according to the method of Van Soest et al. (1991). Ash rate was determined according to the methodology of AOAC (1990).

Presence of *Fusarium* sp. in stalks

The presence of *Fusarium* sp. in sorghum plants with and without injuries caused by infestation of the *D. saccharalis* was evaluated at physiological maturity using plants from plots treated and untreated with the insecticide. One hundred plants were collected at random in each treatment. Plants were opened lengthwise for symptoms of red rot *Fusarium* sp. by separating the bored from the healthy ones and fragments of internodes were taken from healthy and bored stalks. Fifteen random samples of approximately 1 cm^2 from basal, middle and apical third sections were collected. Samples were taken to the Plant Pathology Laboratory at *Embrapa Milho e Sorgo* for isolation and evaluation for the presence of *Fusarium* sp. Samples were disinfected in 2% sodium hypochlorite for 2 min, transferred to Petri dishes with PDA + antibiotic and kept in a growth chamber at 27 ±2°C, for 7 days. Colonies formed were examined with a magnifying glass and a microscope to detect the colour of the colonies and the fungal morphology, for the identification of the genus.

Data analyses

Data underwent analysis of variance and means were compared by Scott-Knott test ($P \leq 0.05$), with Sisvar software (Ferreira 2007). Quantities of fructose, glucose and sucrose were determined separately and by grouping averages of each part of the plant.

The intensity of infestation was determined by calculating the proportion (%) of internodes bored by the *D. saccharalis*: (number of bored internodes/number of total internodes) × 100, following Bates (1954) cited by Williams et al. (1969). For variance analysis, the intensity of infestation data and incidence of *Fusarium* sp. in the plant samples were transformed by the square root of rates.

RESULTS

Analysis of structural and physical characteristics associated with infestation of *D. saccharalis* in sweet sorghum revealed significant differences in all variables as compared to the less infested (insecticide-treated) plots (Table 1). The insecticide-treated plants had more internodes, more healthy internodes, lower levels of infestation, fewer infested internodes and a higher number of healthy internodes. Results provide an example of the potential damage that occurs when no action is taken to control *D. saccharalis* on the sweet sorghum crop, although infestation levels vary and the insecticide-treated plots were not completely pest free. It seems that potential benefits of insecticide application are slightly underestimated.

In addition to structural and physical effects associated with insect infestation, significant differences were reported for juice yield (%) between the treatments and the different parts of the plant analyzed (basal, middle and apical segments, and the entire stalk). Highest juice yields were detected in the stalks from insecticide-treated plot and in the basal region of both treatments. The middle third segment showed the largest difference in juice yield between insecticide-treated plants and insecticide-free plants (Table 2).

The concentration of total soluble solids showed significant differences between plant sections, with higher levels for insecticide-treated plots. Significant differences between plant sections were less evident in the untreated plots. The highest concentration of total soluble solids occurred in the apical segment of the plant, whereas the middle third segment displayed the greatest concentration of total soluble solids in no insecticide-treated plots (Table 3).

The concentration of fructose showed significant differences in the basal region between treatments. The only treatment-specific difference was observed in the middle region in the case of glucose concentration (Table 3). Moreover, sucrose concentration in the entire stalk was significantly higher where *D. saccharalis* were controlled (insecticide treatment), as was the sucrose level in the middle and apical third segment of the insecticide-treated plant. In the case of free insecticide plants, no significant differences were detected between plant segments (Table 3).

Few significant differences were observed for dry matter, although the dry matter level of the entire stalk in the insecticide-treated plants was higher than in the basal, middle and apical segments (Table 4).

Significant differences were reported between the treatments for cellulose, hemicellulose and lignin. Differences varied according to the plant segment analyzed for each component, with a greater concentration of cellulose

Table 1. Sweet sorghum plant height (cm), number of internodes per plant, number of undamaged and insect-damaged internodes per plant, proportion of damaged internodes, and proportion of plants that were infested by *D. saccharalis* when sampled from insecticide-treated and untreated plots.

Response variable	Treatment[1]	
	Insecticide	Untreated
Plant height	218.74±1.79[a]	161.85±1.50[b]
Total internodes/plant	12.72±0.10[a]	11.71±0.09[b]
Undamaged internodes/plant	12.65±0.10[a]	11.21±0.12[b]
Insect-damaged internodes/plant	0.07±0.03[b]	0.50±0.08[a]
Bored internodes (%)	0.53±0.21[b]	4.16±0.62[a]
Infested plants (%)	4.70±0.02[b]	31.87±0.04[a]

[1]Means followed by the same letter in the row do not differ significantly by Scott-Knott test ($P > 0.05$).

Table 2. Juice yield (mean % ± SD) from sweet sorghum in insecticide-treated and untreated plots.

Treatment	Stalk portion[1,2]			Entire stalk
	Basal	Middle	Apical	
Insecticide-treated	65.03 ± 0.21[Aa]	63.13 ± 0.47[Ab]	55.45 ± 0.43[Aa]	61.95 ± 0.54[Ab]
No insecticide	61.36 ± 1.09[Ba]	56.76 ± 1.48[Bb]	54.33 ± 2.22[Ab]	59.33 ± 1.00[Ba]

[1]Analyzed segments of plant: basal, middle, apical, and whole plant. [2] Means followed by the same capital letters in the row and small letters in the column, for the same variable, do not differ by Scott-Knott test ($P \leq 0.05$).

Table 3. Concentration of total soluble solids (°Brix) and sugars (mg mL^{-1}) in healthy and *D. saccharalis*-bored sweet sorghum stalks.

Characteristics of the juice	Stalk segment[1]	Treatment[2]	
		Control[3]	Bored
Total soluble solids	Basal	14.50±0.24[Ac] (40)[4]	13.90±0.29[Bb] (22)
	Middle	15.50±0.20[Ab] (40)	14.60±0.30[Ba] (21)
	Apical	16.50±0.12[Aa] (40)	13.40±0.43[Bb] (6)
	Entire stalk	16.40±0.22[Aa] (37)	14.80±0.16[Ba] (18)
Fructose	Basal	28.39±2.22[Ab]	17.93±1.07[B]
	Middle	28.83±2.82[b]	24.95±1.81
	Apical	35.39±2.50[a]	27.44±4.96
	Entire stalk	23.97±2.11[Ab]	16.15±0.82
Glucose	Basal	24.50±0.67[b]	24.84±1.35
	Middle	22.67±0.67[Bb]	28.18±1.13[A]
	Apical	27.08±1.58[a]	29.00±2.80
	Entire stalk	25.08±0.91[b]	24.98±1.08
Sucrose	Basal	56.14±4.68[b]	52.42±3.29
	Middle	76.10±3.98[Aa]	44.16±6.20[B]
	Apical	77.46±5.00[Aa]	35.86±11.51[B]
	Entire stalk	85.78±2.52[Aa]	56.25±4.04[B]

[1]Analyzed segments of plant: basal, middle, apical, and whole plant. [2] Means followed by the same capital letters in the row and small letters in the column, for the same variable, do not differ by Scott-Knott test ($P \leq 0.05$). [3] Control: insecticide treatment. [4]n: sample number.

Table 4. Percentages of dry matter, cellulose, hemicellulose, lignin and ash in the basal, middle, and apical segments and the entire stalk of sweet sorghum sampled from insecticide-treated and untreated plots.

Characteristic (%)	Stalk segment[1]	Treatment[2]	
		Control	Bored
Dry matter	Basal	93.90±0.06^{b} (40)[3]	93.90±0.15 (22)
	Middle	93.90±0.06^{b} (40)	94.00±0.03 (21)
	Apical	93.80±0.02^{b} (40)	93.90±0.06 (6)
	Entire stalk	94.10±0.08^{a} (37)	94.10±0.11 (18)
Cellulose	Basal	37.61±0.34^{a}	37.57±0.55^{a}
	Middle	36.20±0.43^{b}	35.74±0.65^{b}
	Apical	34.21±0.21^{c}	35.71±0.91c
	Entire stalk	37.22±0.34^{Aa}	34.16±0.39^{Bb}
Hemicellulose	Basal	33.28±0.24^{Bb}	35.34±0.33^{A}
	Middle	34.10±0.17^{a}	34.85±0.51
	Apical	34.47±0.27^{a}	35.68±0.67
	Entire stalk	34.36±0.28^{a}	34.08±0.31
Lignin	Basal	4.10±0.15^{B}	4.6±0.22^{Ab}
	Middle	4.00±0.15	4.40±0.23^{b}
	Apical	4.40±0.17^{B}	5.90±0.47^{Aa}
	Entire stalk	4.40±0.14	4.00±0.13^{b}
Ash	Basal	2.21±0.06^{b}	2.32±0.03^{a}
	Middle	2.03±0.05c	2.02±0.03^{b}
	Apical	2.38±0.02^{a}	2.30±0.09^{a}
	Entire stalk	2.30±0.04^{a}	2.16±0.09^{b}

[1] Analyzed segments of plant: basal, middle, apical, and whole plant. [2] Means followed by the same capital letters in the row and small letters in the column, for the same variable, do not differ by Scott-Knott test ($P \leq 0.05$). [3] n: sample number.

Table 5. Percentage of sweet sorghum stalks (mean ± SD) from insecticide-treated (control), without borer symptoms and untreated plots (with bored symptoms) with *Fusarium* sp. in the basal, middle or apical segment of the plants.

Treatment	Plant segment[1]		
	Basal	Middle	Apical
Control	93.3 ± 6.7^{a}	100.0 ± 0.0^{a}	86.7 ± 8.2^{b}
Bored	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}

[1]Means followed by the same letters in the column for the same variable do not differ by Scott-Knott test ($P > 0.05$).

observed in the entire stalk in the insecticide-treated plants. However, higher concen-trations of hemicellulose and lignin were reported in the insecticide-free treatment, the former in the basal segment and the latter in the basal and apical segments. Significant differences of ash were detected among the different regions of the stalk and in the entire stalk for each treatment (Table 4), but not between treatments.

The presence of *Fusarium* sp. was observed in all the bored stalks retrieved from insecticide-untreated plots (Table 5). In the case of samples from treatment with insecticides and in samples without bores by *D. saccharalis*, the presence of *Fusarium* was observed in 93.30, 100 and 86.70% of the basal, middle and apical

Figure 1. Samples of stalks (A), wet bagasse (B) and juice (C) from sweet sorghum in non-bored (1) and in the bored stalks (2).

segments, respectively (Table 5).

However, a statistically significant difference was only observed in the apical third segment. Moreover, the presence of the fungus changed the color of the extracted juice. A purple colour was observed in the wet bagasse of bored stalks. No red or purple colour was reported in samples of healthy stalks (Figure 1). *Fusarium* sp. was isolated from the two samples containing red, symptomatic (red rot) and asymptomatic segments (stalk with a normal colour).

DISCUSSION

Results of natural infestation and attack by *D. saccharalis* observed in sweet sorghum stalks demonstrate that the

pest has a significant role in altering the quantity and quality of the extracted juice. The attack of the pest directly reduced productivity-related variables, since plant height and average number of internodes decreased, perhaps due to the reduction of the translocation of nutrients and photosynthates in the bored internodes and, consequently, reduction of juice yield, a product of industrial interest. Losses have also been reported in commercial production of other host plants of the insect, e.g. corn, where the attack of the borer directly affects grain production and yield (Cruz et al., 2010) and sugarcane, where plant height is reduced, among other issues (Souza et al., 2008).

In this study, 31.87% of plants were infested, with infestation intensity (considering total of internodes) of 4.16%, and a reduction of 2.62% in juice yield. This is the first study to show yield parameter reductions, from *D. saccharalis* injury in sweet sorghum cultivars. Studies conducted in the 1980s with sugarcane and published by Arrigoni (2002) demonstrated the borer´s capacity to decrease sugarcane production. According to the author, a 1% intensity of borer infestation causes 1.50% reduction in stalk production, 0.49% reduction in sugar production and 0.28% reduction in alcohol production. The relationship between juice reduction and occurrence of pest in the current study was higher than that demonstrated for sugarcane. These results demonstrated the need for improving integrated pest management (IPM) strategies, aiming at the maximization of juice and bagasse production.

In addition to quantitative effects, the borer also causes loss of juice quality in sugarcane (Dinardo-Miranda et al., 2012). This study reveals that high quality may be observed with the concentration of total soluble solids and sugars in the juice, influencing the production of ethanol. As a rule, the occurrence of tunnels in all parts of the plant reduced the concentration of total soluble solids. In the whole plant, a reduction of 1.6 °Brix units was observed when symptoms of damage were detectable. This corroborates data published by Gomes (2014), who used bored materials of sweet sorghum (CVSW80007) and obtained total soluble solids below 16 °Brix, whereas the rate was higher in healthy materials.

Fuller et al. (1988) obtained a significant negative correlation between the percentage of internodes bored by *D. saccharalis* and the concentration of total soluble solids in sweet sorghum, demonstrating the same impact on sugar reduction. Likewise, Rossato Júnior (2009) detected a significant difference of 1.58 °Brix units in total soluble solids in sugarcane between healthy materials and materials attacked by *D. saccharalis*. Consequently, the reduction of sorghum juice quality parameters demonstrates the pest´s effects.

Gomes (2014) showed that sweet sorghum has similar technological characteristics as unripe sugarcane, which include soluble sugars, reduced sugars, total reduced sugars and others. However, according to the above author, the end product will depend on the concentration of sugars available in the medium; thus, at higher concentrations of sugar (16 °Brix), yeast will transform sugar into ethanol and CO_2 (fermentation) more efficiently.

According to this study, infestation of *D. saccharalis* reduced significantly total soluble solids. Due to significant Brix reduction, there was a 34% sucrose reduction in the plant. Dinardo-Miranda et al. (2012) observed that the infestation of the pest in sugarcane reduced sucrose and increased the amount of reduced sugars (fructose and glucose), also reported in the current study, in which the glucose content increased in bored stalks as compared to stalks from control treatment.

However, the best strategy for industries is the maintenance of juice quality, that is, a higher concentration of sucrose relative to the concentration of glucose and fructose (Wu et al., 2010), as observed in the current study. The above emphasizes the need for stalks free of infestations by *D. saccharalis*. Thus, constant monitoring of the pest in the production of sweet sorghum and the adoption of appropriate IPM strategies are recommended regardless of the development of plant development.

Insoluble materials such as cellulose, a fraction of the plant´s fiber, may be transformed into glucose through physical and chemical treatments. Ethanol obtained from this process, or second-generation ethanol (Pereira Jr. et al., 2008), may be produced from agro-industrial materials such as sweet sorghum bagasse. However, in this study, differences were detected between healthy stalks and stalks with symptoms of infestation only for cellulose when the whole plant was evaluated. This corroborates observations by Milano (2012) who isolated bacteria that degraded cellulose in the digestive tract of the species. Although, Saldarriaga (2009) and Dantur et al. (2015) reported that bacteria isolated from the intestinal tract of *D. saccharalis* showed a positive response in *in vitro* degradation tests for cellulose, hemicellulose and lignin in sugarcane bagasse, they showed a greater efficiency in cellulose degradation.

Reduction in the quality of sweet sorghum juice was related to the presence of fungi of the genus *Fusarium*, which cause the red rot disease that infects stalks and reduces sugar content in the juice due to the inversion of the sucrose stored in the plant and its transformation into glucose and fructose, as described by Botelho and Macedo (2002) and Stupiello (2005). Furthermore, the contamination of the juice by the fungus inhibits fermentation, compromising industrial processes. Dinardo-Miranda et al. (2012) suggested that the infestation of opportunist and secondary fungi in

sugarcane stalks reduces juice quality. The presence of *Fusarium* sp. in healthy sorghum tissues is common (Waniska et al., 2001) and indicates that the occurrence of *D. saccharalis* pest is not a *sine qua non* condition for the incidence of the pathogen in the plant. However, Schulthess et al. (2002) suggested that in maize, some Lepidoptera and Coleoptera were attracted or survived for a longer period in plants infected by *Fusarium verticillioides*. This relationship between the presence of *F. verticillioides* and insects was also reported by Cardwel et al. (2000). Rossato et al. (2013) demonstrated that juice quality decreased as the infestation intensity increased. Consequently, the effect of the borer-stalk rot complex on juice quality must be further elucidated to improve agro-industrial processes for ethanol production from sweet sorghum.

Results demonstrate that measures to ensure maximum growth and production of high quality raw material for ethanol production should be started by striving to keep pest damage at a minimal. Although studies such as that of Wu et al. (2010) were undertaken to understand the influence of the characteristics of sweet sorghum juice on fermentation for ethanol production, these authors focused their analysis on the end of the production chain. On the contrary, the quality of the raw material may be compromised from the beginning of the production cycle due to inadequate management of pests in the crop. As demonstrated in this study, infestation by *D. saccharalis* in sweet sorghum causes a significant decrease in plant height and juice yield, including a decrease in sugar content and fiber.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Arrigoni EB (2002). Broca da cana: importância econômica e situação atual. *In* Pragas da cana-de-açúcar: importância econômica e enfoques atuais. *Edited by* Arrigoni E.B., Dinardo-Miranda L.L., Rossetto R. STAB/IAC/CTC Piracicaba, São Paulo, Brazil. pp. 1-4.

Association of Analytical Chemists (AOAC) (1990). Official Methods of Analysis, 15th edition. AOAC Inc., Arlington, Virginia, United States of America.

Botelho PSM, Macedo N (2002). *Cotesia flavipes* para o controle de *Diatraea saccharalis*. *In* Controle biológico no Brasil: Parasitoides e predadores. *Edited by* Parra JRP, Botelho PSM, Correa-Ferreira BS, Bento JMS, Manole, São Paulo, São Paulo, Brazil pp. 409-425.

Cardwell KF, Kling JG, Maziya-Dixon B, Bosque-Pérez NA (2000). Interactions between *Fusarium verticillioides*, *Aspergillus flavus*, and insect infestation in four maize genotypes in lowland Africa. Phytopathology 90:276-284.

Clarke MA, Legendre BR (1999). Qualidade de cana-de-açúcar: Impactos no rendimento de açúcar e fatores de qualidade. STAB – Açúcar, Álcool e Subprodutos, Piracicaba, São Paulo, Brazil.

Cruz I (2007). A broca da cana-de-açùcar, *Diatraea saccharalis,* em milho, no Brasil. Circular Técnica 90:12.

Cruz I, Coelho AM, Figueiredo LC, Silva RB, Redoan AC (2010). Suscetibilidade de Cultivares de Milho (*Zea mays* L.) à *Diatraea saccharalis* Fabr. (Lepidoptera: Crambidae). *In* Congresso Nacional de Milho e Sorgo, 28° Simpósio Brasileiro sobre a Lagarta do Cartucho, 4, Goiânia. Potencialidades, desafios e sustentabilidade: Resumos Expandidos. Associação Brasileira de Milho e Sorgo, Goiânia, Brazil. pp. 652-657.

Dantur KI, Enrique R, Welin B, Castagnaro AP (2015). Isolation of cellulolytic bacteria from the intestine of *Diatraea saccharalis* larvae and evaluation of their capacity to degrade sugarcane biomass [online]. AMB Express 5(15).

Dinardo-Miranda LL, Fracasso JV, Anjos IA, Garcia J, Costa V (2012). Influência da infestação de *Diatraea saccharalis* (Fabr.) sobre parâmetros tecnológicos da cana-de-açúcar. Bragantia 71:342.

Durães FOM (2014). Sorgo-energia: Inovações e negócios de base tecnológica. Informe Agropec. 35:100-101.

Durães FOM, May A, Parrella RA da C (2012). Seminário agroindustrial do sorgo sacarino no Brasil e a participação público-privada: oportunidades, perspectivas e desafios. Embrapa Milho e Sorgo, Sete Lagoas, Minas Gerais, Brazil.

Ferreira DF (2007). Sisvar: programa estatístico: versão 5.0. Software. Universidade Federal de Lavras, Lavras, Minas Gerais, Brazil.

Fuller BW, Reagan TE, Flynn JL (1988). Economic injury level of the sugarcane borer (Lepidoptera: Pyralidae) on sweet sorghum, *Sorghum bicolor* (L.) Moench. J. Econ. Entomol. 81:349-353.

Gomes SCMP (2014). Produção de etanol utilizando mix de sorgo sacarino e cana-de-açúcar em processo de maturação, MS. Thesis– Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, São Paulo, Brazil.

Kim M, Kun-Jun H, Jeong Y, Day DF (2012). Utilization of whole sweet sorghum containing juice, leaves, and bagasse for bio-ethanol production. Food Sci. Biotechnol. 21:1075-1080.

Leslie JF (1991). Mating populations in *Gibberella fujikuroi* (Fusarium section Liseola). Phytopathology 81:1058–1060.

Leslie JF, Zeller KA, Lamprecht SC, Rheeder JP, Marasas FO (2005). Toxicity, pathogenicity and genetic differentiation of five species of *Fusarium* from sorghum and millet. Phytopathology 95:275-283.

May A, Durães FOM, Filho IAP, Schaffert RE, Parrela RA, da C (2012). Sistema Embrapa de Produção Agroindustrial de Sorgo Sacarino para Bioetanol Sistema BRS1G – Tecnologia Qualidade Embrapa. Embrapa Milho e Sorgo, Sete Lagoas, Minas Gerais, Brazil.

May A, Parrella RA da C, Damasceno CMB, Simeone MLF (2014). Sorgo como matéria-prima para produção de bioenergia: etanol e cogeração. Informe Agropecu. 35:14-20.

Mendes SM, Viana PA, Cruz I, Waquil JM (2012). Controle de pragas. *In* Seminário Embrapa de produção agroindustrial de sorgo sacarino para bioetanol. Sistema BRS1G – Tecnologia Qualidade Embrapa. *Edited by* May A, Durães FOM, Pereira Filho IA, Schaffert RE, Parrella RA, da C. Embrapa Milho e Sorgo, Sete Lagoas, Minas Gerais, Brazil pp. 57-67.

Mendonça AF (1996). Pragas da cana-de-açúcar. Insetos & Cia, Maceió, Alagoas, Brasil.

Milano HS (2012). Identificação de microorganismos do trato digestivo de pragas de cana-de-açúcar com atividade enzimática para degradação de substratos lignocelulósicos e potencial de

bioconversão de D-xilose em xilitol. MS thesis Universidade de São Paulo, Piracicaba, Brasil pp. 51-57.
Monk RL, Miller FR, McBee GG (1984). Sorghum improvement for energy production. Biomass 6:145-153.
Pereira Jr N, Couto MAPG, Santa Anna LMM (2008). Biomass of lignocellulosic composition for fuel ethanol production and the context of biorefinery. Series on Biotechnology. Biblioteca Nacional, Rio de Janeiro, Rio de Janeiro, Brazil.
Precetti AACM, Terán FO, Sánchez AG (1988). Alterações nas características tecnológicas de algumas variedades de cana-de-açúcar, devidas ao dano da broca *Diatraea saccharalis*. Boletim Técnico Copersucar 41:3-8.
Rossato Júnior JAS, Costa GHG, Madaleno LL, Mutton MJR, Higley LG, Fernandes OA (2013). Characterization and impact of the sugarcane borer on sugarcane yield and quality. Agron. J. 105:643-648.
Rossato Júnior JAS (2009). Influência dos estressores bióticos *Diatraea saccharalis* (Fabr.) (Lepidoptera: Crambidae) e *Mahanarva fimbriolata* (Stal) (Hemiptera: Cercopidae) na produtividade e qualidade tecnológica da cana-de-açúcar. MS Thesis Universidade Estadual Paulista, Jaboticabal, São Paulo, Brazil.
Saldarriaga AJJ (2009). Caracterização das comunidades de microorganismos associados ao mesêntero de *Diatraea saccharalis* e *Spodoptera frugiperda* (Lepidoptera: Crambidae e Noctuidae). MS Thesis Universidade de São Paulo, Piracicaba, São Paulo, Brazil.
Santos FC, Coelho AM, Resende AV (2014). Correção do solo e adubação na cultura do sorgo. Informe Agropecu. 35:76-88.
Schulthess F, Cardwell KF, Gounou S (2002). The effect of endophytic *Fusarium verticillioides* on infestation of two maize varieties by lepidopterous stalk borers and coleopteran grain feeders. Phytopathology 92:120-128.
Stupiello JP (2005). O complexo broca-podridão vermelha. Sociedade dos técnicos açucareiros e alcooleiros do Brasil – Açúcar, Álcool e Subprodutos 24:14-14.
Souza ZM, Paixão A, Prado R, Cesarin LG, Souza SR, Montanari R (2008). Produtividade agrícola de variedades de cana-de-açúcar e incidência de broca-comum e cigarrinha da raiz em canavial colhido sem queima. Bragantia 67:413-419.
Téran FO, Precetti AACM, Sánchez AG (1986). Importância econômica, aspectos bioecológicos e manejo populacional da broca da cana-de-açúcar, *Diatraea saccharalis,*. Seminário de Tecnologia Agronômica, 3, *Edited by* Copersucar, Piracicaba, São Paulo, Brazil pp. 153-167.
Tomaz HVQ, Assis RQ (2013). Sorgo sacarino - rendimento extra na entressafra da cana-de-açúcar. *In* Sustentabilidade e inovações no campo. Edited by Silva, J.C., Silva, A.A.S., Assis, R.T. Composer Gráfica e Editora, Uberlândia, Minas Gerais, Brazil pp. 73-84.
Tesso TT, Ochandaa N, Little CR, Claflinb L, Tuinstrac MR (2010). Analysis of host plant resistance to multiple *Fusarium* species associated with stalk rot disease in sorghum [*Sorghum bicolor* (L.) Moench]. Field Crop Res. 118:177-182.
Van Soest PJ, Robertson JB, Lewis BA (1991). Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.
Waniska RD, Venkatesha RT, Chandrashekar A, Krishnaveni S, Bejosano FP, Jeoung J, Jayaraj J, Muthukrishnan S, Liang GH (2001). Antifungal proteins and other mechanisms in the control of sorghum stalk rot and grain mold. J. Agric. Food Chem. 49:4732-4742.
Waquil JM, Santos JP, Lordello AIL, Schaffert RE, Giacomini FS, Vencovsky R, Oliveira AC (1980). Comportamento de cultivares de sorgo sacarino em relação à broca da cana-de-açúcar, *Diatraea saccharalis* (Fabricius, 1794) em condições de campo. *In* Congresso Brasileiro de Entomologia, 6, CATI, Campinas, São Paulo, Brazil pp. 151-151.
Williams JR, Metcalfe JR, Mungomery RW, Mathes R (1969). Pests of sugar cane, Elsevier Publishing Company, Amsterdam, The Netherlands.
Wu X, Staggenborg S, Propheter JL, Rooney WL, Yu J, Wang D (2010). Features of sweet sorghum juice and their performance in ethanol fermentation. Ind. Crops Prod. 31:164-170.
Zegada-Lizarazu W, Monti A (2012). Are we ready to cultivate sweet sorghum as a bioenergy feedstock? A review on field management practices. Biomass Bioenergy 40:1-12.