





# Yield estimation and damage by *Eoreuma loftini* on sorghum genotypes and pearl millet in a warm-humid tropical climate

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## ABSTRACT

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the main forage crops for animal feed, although its productivity is often limited by pest pressure. One strategy to tackle this limitation is the development and adoption of pest-tolerant or resistant genotypes. The objective of this research was to evaluate sorghum genotypes and pearl millet (*Cenchrus americanus* (L.) Morrone) for Mexican rice borer (*Eoreuma loftini*) infestation, intensity of infestation, and forage yield. Larvae of *E. loftini* were detected in all evaluated sorghum genotypes and in pearl millet, with tunnels with horizontal and vertical direction along the stems. ‘Paloma’, ‘Fortuna’, ‘197-1-1’, and ‘197-1’ genotypes, along with pearl millet, showed the lowest infestation rates. Regarding infestation intensity or damage, ‘Proconsul’ and ‘Gobernador’ genotypes had the highest damage rates, with 57.2% and 47.5% respectively, compared to the other treatments, which showed values ranging from 16.8% to 33.9%. Lodging plant values ranged from 0% to 95%, with ‘Proconsul’ genotype showing the highest percentage of lodging plants, compared to genotypes such as ‘197-1-1’, ‘197-1’, ‘195-2’, ‘Fortuna’, ‘Paloma’, ‘Williams’, ‘Arcos’, and pearl millet, which had lodging below 1.2%. In terms of yield, the late genotypes (‘197-1-1’ and ‘197-1’) showed the highest yields, with 73.6 and 63.2 t ha<sup>-1</sup>, respectively. Sorghum genotypes ‘Paloma’, ‘Fortuna’, ‘197-1-1’, and ‘197-1’, as well as pearl millet, showed the lowest infestation rates and intensity by *E. loftini*, indicating that these genotypes may be potentially tolerant to *E. loftini* infestation. This finding could inform the development of an integrated management plan for this pest, including host tolerance.

**Key words:** *Cenchrus americanus*, infestation, infestation intensity, Mexican rice borer, pest management, *Sorghum bicolor*, stem borer, varietal resistance.

## INTRODUCTION

*Sorghum bicolor* (L.) Moench (Poales: Poaceae) is the fifth most important cereal worldwide in terms of production and harvested area, along with other cereals such as maize (*Zea mays* L.), rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.) (Poales: Poaceae) (FAOSTAT, 2025). It is an essential crop for more than 500 million people in Africa, Asia, and Latin America, particularly those living in semiarid and tropical regions (Fontanet-Manzanique et al., 2024), as well as for ruminant feeding, either as a grain or fodder (Guzmán-Ochoa et al., 2026). This crop is highly affected by diseases and pests. One of its main pests is the Mexican rice borer (*Eoreuma loftini* Dyar, 1917) (Lepidoptera: Crambidae), an insect native to Mexico that during the 1980s began to invade northern Mexico and the southern USA. In 2008, it was detected on the US Gulf of Mexico coast

in eastern Louisiana (Wilson et al., 2017), affecting maize, sugarcane (*Saccharum officinarum* L.) (Poales: Poaceae), wheat, and sorghum, causing losses greater than those caused by the corn borer (*Diatraea lineolata* [Walker, 1856]) and the sugarcane borer (*Diatraea saccharalis* Fabricius, 1794) (Lepidoptera: Crambidae) (Showler and Reagan, 2017; Villegas et al., 2024). Its wild hosts are grasses such as Johnson grass (*Sorghum halepense* (L.) Pers.), Vasey grass (*Paspalum urvillei* Steud.), brome (*Bromus secalinus* L.), and ryegrass (*Lolium perenne* L.) (Poales: Poaceae), which play an important role in the seasonality of the population, facilitating its expansion towards crops (Beuzelin et al., 2016; Showler and Reagan, 2017; Kang et al., 2022).

The main damage consists of the excavation of vertical and horizontal tunnels within the stem, causing lodging plants, weakening, yellowing, and entry points for diseases such as red rot caused by *Colletotrichum falcatum* Went (1893) (Glomerellales: Glomerellaceae) (Showler and Reagan, 2017; Stout et al., 2024), and root and stem rot caused by species of the *Fusarium* sp. complex (Hypocreales: Nectriaceae) (Pérez-Domínguez and Ireta-Moreno, 2017). Yield losses caused by *E. loftini* are related to the phenological stage and location of the lesions. When the larva feeds on the sorghum plant during the vegetative stage, it causes shoot death, preventing panicle development, a phenomenon commonly referred to as dead heart (Stout et al., 2024). When damage occurs during the ripening phase, it interferes with the grain filling process, leading to uneven panicle development (Beuzelin et al., 2016). Although population densities during sampling are typically low (one larva per stem), internode damage has been observed to range from 55% to 88% (Wilson et al., 2015). This is because, during the crop's development cycle, multiple generations occur; they can complete their larval and pupal stages within the stem and subsequently emerge as adults.

The adult typically lays clusters of approximately 100 globular, cream-colored eggs, mainly on the host's senescent leaves, although they can also be found on green leaves and stems (Vanweelden et al., 2017). These eggs hatch in approximately 5 d at 32 °C. The larvae grow up to 2 cm in length, are creamy-white, with four parallel purple-red dorsal stripes, and have an orange-brown head capsule (Beuzelin et al., 2016). There are reports that the larvae can enter diapause during fall and winter months (Villegas et al., 2024). The pupae are yellowish to brown in color and elongated in shape, taking 7 to 21 d at temperatures ranging from 20 to 32 °C to develop into adults. The adult is a nocturnal, straw-beige moth with a conical forehead and grows to 1.5 to 2.0 cm in length; sometimes, a tiny dark spot in the center of each forewing can be observed (Beuzelin et al., 2016; Solis et al., 2020).

Control of this pest is primarily based on adjusting planting dates, crop residue management, cutting height, soil fertility management, crop rotation, biological control with natural enemies (parasitoids or predators), the use of pheromone traps, and insecticides such as chlorantraniliprole as seed treatment or foliar application (Beuzelin et al., 2016; Villegas et al., 2021; Wilson et al., 2024). In this context, research has focused on improving insecticides, developing cultural practices for integrated pest management, and enhancing host resistance mechanisms (Showler and Reagan, 2017). The latter has proven to be an effective and environmentally friendly alternative, reducing dependence on chemical control in food production (Salgado et al., 2022). For this reason, the objective of this study was to evaluate the infestation and infestation intensity of *E. loftini*, as well as forage yield in sorghum genotypes and pearl millet, in a warm-humid tropical climate, to detect genotypes that exhibit some tolerance to the Mexican rice borer.

## MATERIALS AND METHODS

The study was carried out from February to August 2024 at the Aldama Experimental site (22°51'47.38" N, 98°14'14.20" W; 98 m a.s.l.), belonging to the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Tamaulipas, Mexico (INEGI, 2015). The climate is classified as semi-warm sub-humid with summer rains. The average annual precipitation is 657 mm, and the average yearly temperature is 23.4 °C (SMN, 2022).

Seven sorghum (*Sorghum bicolor* (L.) Moench) genotypes from INIFAP ('Arcos', 'Williams', 'Paloma', 'Fortuna', '195-2', '197-1', '197-1-1'), and five from Anzú Genética Seeds ('Proconsul', 'Verde Pacas', 'Gladiador', 'Gobernador', and 'Caramelo') in addition to pearl millet (*Cenchrus americanus* (L.) Morrone) were evaluated. Each experimental plot consisted of four rows, 10 m long, with a distance of 80 cm between rows and an approximate plant density of 287 500 plants ha<sup>-1</sup>.

Soil preparation was mechanized (one fallow, two cross-harrow passes, and furrowing). For the irrigation system, 5/8" tape (Aqua Traxx, Toro, El Paso, Texas, USA) was used, with a spacing of 20 cm between emitters. Irrigation was applied every 2 wk during the first cut, giving a total of 230 mm for early-cycle genotypes ('Proconsul', 'Gobernador', pearl millet), 266 mm for intermediate-cycle genotypes ('Verde Pacas', 'Gladiador', 'Caramelo', 'Arcos', 'Williams', 'Paloma', 'Fortuna', '195-2'), and 302 mm for late-cycle genotypes ('197-1', '197-1-1'). In contrast, the second cut (first ratoon crops) was evaluated under rainfed conditions, with accumulated rainfall of 325, 346, and 361 mm, respectively. Fertilization was applied 28 d after sowing (DAS) with a dose of 90-40-00 kg ha<sup>-1</sup> NPK. After the first cut, a uniformity cut was made, and a second fertilization was applied 35 d later with a dose of 50-00-00 kg ha<sup>-1</sup> NPK. Pest control was carried out when the pest population reached its economic threshold. For control of fall armyworm (*Spodoptera frugiperda* J.E. Smith) (Lepidoptera: Noctuidae) spinetoram (12 g ai ha<sup>-1</sup>; Dow Inc., Midland, Michigan, USA) was applied; subsequently, 12 d later, a second application was made with chlorantraniliprole (20 g ai ha<sup>-1</sup>; FMC Corporation, Philadelphia, Pennsylvania, USA) was applied. For the control of the corn flea beetle (*Chaetocnema pulicaria* F.E. Melsheimer) (Coleoptera: Chrysomelidae), an application of imidacloprid (122.5 g ai ha<sup>-1</sup>; Bayer CropScience, Research Triangle Park, North Carolina, USA) was carried out.

#### Evaluation of larvae per plant, infestation, infestation intensity, and total soluble solids

Infestation and infestation intensity (II, %) caused by *Eoreuma loftini* Dyar, 1917 (Lepidoptera: Crambidae) were quantified for each of the evaluated treatments when the sorghum grain reached the soft dough stage during the first and second cutting (first ratoon crops). For this, 20 plants were randomly selected from the two central rows of each experimental unit (10 plants per row). The plants were cut at ground level, the leaves were separated from the stems, the panicle internode was removed, and a longitudinal cut was made in the stem. The damage caused by *E. loftini* was identified by the presence of vertical or horizontal tunnels in the stems, with larvae visible inside (Showler and Reagan, 2017; Stout et al., 2024). The number of larvae present in each stem was counted, and the damaged and healthy internodes were counted. Infestation was defined as the percentage of bored stems, and infestation intensity was defined as the percentage of damaged internodes, estimated from the following formulas:

$$I (\%) = \left( \frac{NDS \times 100}{TS} \right) \quad (1)$$

where, I is Infestation, NDS is number of damaged stems, and TS is total stems,

$$II (\%) = \left( \frac{DIS \times 100}{TES} \right) \quad (2)$$

where, II is infestation intensity, DIS is damaged internodes per stem, and TES is total internodes per stem.

At the same time, juice was extracted from 10 randomly selected stems from each treatment, and total soluble solids (°Brix) were measured separately for each plant using a refractometer.

#### Evaluation of percentage lodging plant, height and forage yield

To estimate the percentage of lodging plants, three replicates of 1 m each were obtained from the intermediate rows of each experimental unit. In each replicate, the total number of plants was counted, and the number of plants with lodging was recorded. These plants were inspected to verify that the lodging was caused by *E. loftini*. The percentage of lodging was obtained using the following formula:

$$L = \left( \frac{LP \times 100}{TP} \right) \quad (3)$$

where, L is lodging (%), LP is lodging plants, and TP is total plants.

When the genotypes reached the soft dough grain stage, plant height (PH), panicle height (PAH), and flag leaf height (FLH) were measured (cm). Forage yield was then determined by cutting the entire forage into 2 m at a height of 20 cm above the ground, weighing it on a digital scale (Rhino, Mexico City, Mexico), and estimating the green matter yield (t ha<sup>-1</sup>).

#### Experimental design and statistical analysis

To analyze the data for each variable, an ANOVA was performed using a randomized complete block design with 13 treatments and three replicates. A comparison of means was then conducted using the Tukey test ( $\alpha =$

0.05) in the SAS 9.0 statistical program (SAS Institute, Cary, North Carolina, USA). Prior to the ANOVA, the assumptions of normality and homogeneity of variances were verified. Normality of residuals was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated using Levene's test, following standard statistical procedures (Montgomery, 2017). Since all variables fulfilled these assumptions, no data transformation was required. A multivariate analysis was applied to evaluate the relationship between *E. loftini* infestation variables and agronomic characteristics in sorghum genotypes. The data were standardized using z-scores to eliminate scale effects. Subsequently, a principal components analysis (PCA) was performed to reduce dimensionality and visualize the variability between genotypes (Jolliffe and Cadima, 2016). Based on the coordinates obtained from the PCA, a K-means clustering was implemented to classify the genotypes into four distinct groups (Dana et al., 2021). The results were represented in a biplot, which showed the variable loadings and the distribution of genotypes according to the identified groups.

## RESULTS AND DISCUSSION

### Evaluation of larvae per plant, infestation, infestation intensity, lodging, and total soluble solids

*Eoreuma loftini* larvae were observed in all sorghum genotypes and pearl millet evaluated, in the plant stage (first cut). The tunnels examined were horizontal and vertical in the stems. The average number of larvae in the infested stems did not exceed two individuals per plant; however, there were significant differences between 'Proconsul' and 'Gobernador' compared with pearl millet, with 1.25, 1.23 and 0.15 larvae per plant, respectively ( $p = 0.008$ ; Table 1). 'Paloma', 'Fortuna', '197-1-1', and '197-1' genotypes and pearl millet showed the lowest infestation rates, with 23.3%, 38.0%, 45.0%, 46.6%, and 46.6%, respectively, while 'Proconsul', 'Verde Pacas', 'Gobernador', 'Gladiador', 'Caramelo', 'Williams', 'Arcos', and '195-2' had the highest infestation rates ( $p = 0.001$ ), with values ranging from 61.6% to 95.0% (Table 1). Regarding the variable of infestation intensity or damage, the 'Proconsul' and 'Gobernador' genotypes showed the highest damage rates, at 57.2% and 47.5%, respectively. In contrast, the remaining treatments showed values ranging from 16.8% to 33.9% (Table 1).

**Table 1.** Infestation and damage caused by *Eoreuma loftini* on sorghum and pearl millet during the first forage cutting. Different letters indicate differences between treatments (Tukey;  $\alpha = 0.05$ ). <sup>1</sup>The number of larvae per plant presented in the tables are averages of stems that had larvae; stems that did not have larvae were excluded.

Genotype	Larvae per plant <sup>1</sup>	Infestation	Intensity of infestation	Lodging plants	Total soluble solids
	Nr plant <sup>-1</sup>	%	%	%	%
Proconsul	1.25 <sup>a</sup>	95.0 <sup>a</sup>	57.2 <sup>a</sup>	95.2 <sup>a</sup>	5.7 <sup>ef</sup>
Verde Pacas	1.17 <sup>ab</sup>	88.3 <sup>a</sup>	33.9 <sup>bc</sup>	23.9 <sup>b</sup>	4.0 <sup>f</sup>
Gladiador	1.17 <sup>ab</sup>	83.3 <sup>a</sup>	30.9 <sup>bc</sup>	13.8 <sup>c</sup>	12.7 <sup>bc</sup>
Gobernador	1.23 <sup>a</sup>	88.3 <sup>a</sup>	47.5 <sup>ab</sup>	12.1 <sup>c</sup>	8.3 <sup>de</sup>
Caramelo	0.98 <sup>ab</sup>	81.6 <sup>a</sup>	31.9 <sup>bc</sup>	11.6 <sup>c</sup>	17.9 <sup>a</sup>
Pearl Millet	0.15 <sup>b</sup>	23.3 <sup>d</sup>	19.8 <sup>c</sup>	0.8 <sup>d</sup>	7.8 <sup>de</sup>
Arcos	0.65 <sup>ab</sup>	70.0 <sup>a-c</sup>	22.4 <sup>c</sup>	1.1 <sup>d</sup>	7.7 <sup>de</sup>
Williams	0.88 <sup>ab</sup>	80.0 <sup>ab</sup>	25.7 <sup>c</sup>	0.0 <sup>d</sup>	10.2 <sup>cd</sup>
Paloma	0.53 <sup>ab</sup>	38.0 <sup>cd</sup>	16.8 <sup>c</sup>	0.0 <sup>d</sup>	13.9 <sup>b</sup>
Fortuna	0.42 <sup>ab</sup>	45.0 <sup>cd</sup>	17.5 <sup>c</sup>	1.2 <sup>d</sup>	9.9 <sup>cd</sup>
195-2	0.73 <sup>ab</sup>	61.6 <sup>a-c</sup>	20.8 <sup>c</sup>	0.6 <sup>d</sup>	13.7 <sup>b</sup>
197-1	0.44 <sup>ab</sup>	46.6 <sup>b-d</sup>	17.3 <sup>c</sup>	0.0 <sup>d</sup>	6.6 <sup>ef</sup>
197-1-1	0.37 <sup>ab</sup>	46.6 <sup>b-d</sup>	19.7 <sup>c</sup>	0.6 <sup>d</sup>	8.2 <sup>de</sup>

In lodging plants, significant differences were found between treatments ( $p < 0.050$ ), with estimated values ranging from 0% to 95% (Table 1). 'Proconsul' genotype showed the highest lodging rate (95.2%), followed by 'Verde Pacas' genotype with a rate of only 24%. The genotypes '197-1-1', '197-1', '195-2', 'Fortuna', 'Paloma', 'Williams', 'Arcos', and pearl millet exhibited statistically similar lodging, with values of less than or equal to

1.2%. ‘Gobernador’ genotype stood out among the genotypes with the highest number of larvae, infestation, and infestation intensity; however, it showed only 12.1% of lodging plants. With respect to total soluble solids (°Brix), significant differences were found between genotypes ( $p = 0.001$ ). The highest concentration of sugars was found in ‘Caramelo’, at 17.9% (Table 1). ‘Verde Pacas’, ‘Proconsul’, and ‘197-1’ genotypes had the lowest values: 4.0%, 5.7%, and 6.6%, respectively.

During the second cut, the number of larvae per plant did not show significant differences ( $p < 0.050$ ). ‘Paloma’, ‘195-2’, ‘Arcos’, and ‘Fortuna’ genotypes had the highest values, with 0.45, 0.40, 0.18, and 0.15 larvae per plant, respectively (Table 2). Significant differences ( $p < 0.050$ ) were found for infestation, with values ranging from 23% to 82%. ‘Paloma’, ‘195-2’, ‘Gladiador’, ‘Gobernador’, and ‘Caramelo’ genotypes had the highest infestation rates, at 82%, 77%, 68%, 65%, and 59%, respectively. Differences in infestation intensity were only found between the genotypes ‘197-1’, ‘Arcos’, and pearl millet, with values of 16%, 16%, and 27%, respectively. For the lodging plants variable, ‘Gladiador’ showed the greatest damage, with 57.3% of lodging plants; the rest of the genotypes presented values from 0% to 12.8% for this same variable (Table 2).

The damage caused by *E. loftini* consisted of horizontal and vertical tunnels in the stems. In this regard, Showler (2019) reports that the tunnels do not have a fixed orientation and can fill them with excrement, which protects the larvae from contact with insecticides and natural enemies. It is worth noting that lesions were identified within the stems with an absence of larvae, because the internal larval period of *E. loftini* is between 18 and 24 d (Beuzelin et al., 2016), and in this study, during sampling, the previous initial population had already completed its internal larval and pupal stages.

**Table 2.** Infestation and damage caused by *Eoreuma loftini* in sorghum and pearl millet in first ratoon crops. Different letters indicate differences between treatments (Tukey;  $\alpha = 0.05$ ). <sup>1</sup>The number of larvae per plant presented in the tables are averages of stems that had larvae; stems that did not have larvae were excluded.

Genotype	Larvae per plant <sup>1</sup>	Infestation	Intensity of infestation	Lodging plants
	Nr plant <sup>-1</sup>	%	%	%
Proconsul	0.9 <sup>a</sup>	47 <sup>cd</sup>	20 <sup>ab</sup>	0.6 <sup>bc</sup>
Verde Pacas	1.0 <sup>a</sup>	50 <sup>c</sup>	22 <sup>ab</sup>	0.0 <sup>c</sup>
Gladiador	1.0 <sup>a</sup>	68 <sup>abc</sup>	25 <sup>ab</sup>	57.3 <sup>a</sup>
Gobernador	1.0 <sup>a</sup>	65 <sup>abc</sup>	23 <sup>ab</sup>	2.6 <sup>bc</sup>
Caramelo	1.1 <sup>a</sup>	59 <sup>abc</sup>	21 <sup>ab</sup>	3.4 <sup>bc</sup>
Pearl Millet	0.8 <sup>a</sup>	23 <sup>e</sup>	27 <sup>a</sup>	1.7 <sup>bc</sup>
Arcos	1.1 <sup>a</sup>	51 <sup>c</sup>	16 <sup>b</sup>	0.0 <sup>c</sup>
Williams	1.0 <sup>a</sup>	52 <sup>c</sup>	19 <sup>ab</sup>	5.5 <sup>bc</sup>
Paloma	1.2 <sup>a</sup>	82 <sup>a</sup>	20 <sup>ab</sup>	12.8 <sup>b</sup>
Fortuna	1.3 <sup>a</sup>	53 <sup>bc</sup>	21 <sup>ab</sup>	0.0 <sup>c</sup>
195-2	1.2 <sup>a</sup>	77 <sup>ab</sup>	22 <sup>ab</sup>	7.7 <sup>bc</sup>
197-1	0.7 <sup>a</sup>	25 <sup>de</sup>	16 <sup>b</sup>	0.0 <sup>c</sup>
197-1-1	0.7 <sup>a</sup>	45 <sup>cde</sup>	21 <sup>ab</sup>	0.0 <sup>c</sup>

*Eoreuma loftini* has been documented to prefer dry leaves as oviposition sites, so drought-stressed genotypes tend to be more susceptible (Wilson et al., 2015). In this research, the most damaged genotypes were those with the early-cycle, which had a greater number of senescent leaves at the time of sampling. Furthermore, other research indicates that the establishment of neonate larvae may be influenced by the physical characteristics of the plant, such as leaf pubescence and the hardness of the midrib of the leaves and stems. On the other hand, Salgado et al. (2022) mention that the damage caused by *E. loftini* is closely related to the feeding ability of neonate larvae and not to the females’ preference for laying eggs on specific genotypes. Regarding damages, Vanweelden et al. (2015) reported 16% damage to internodes of the forage sorghum ‘ES-5200’, with a 0.74% reduction in yield for each unit increase in the percentage of damaged internodes. These results are similar to those obtained in this research in the genotypes ‘Paloma’, ‘Fortuna’, and ‘197-1’; however, we also observed damage of up to 57.2% in more susceptible genotypes.

Lodging plant can be caused by several factors, including plant height, fiber content, lignin, cellulose, hemicellulose, stem diameter, and leaf sheath apprehension, which provides rigidity and strength to the stem (Li et al., 2022; Wang et al., 2022; Huang et al., 2025). However, the results presented in Tables 1 and 2 were caused exclusively by *E. loftini*. Therefore, all the evaluated stems were examined, and it was verified that the damage caused by borers was the cause of the lodging. If the lodging was due to another factor, it was excluded from the count. Another factor that could increase plant lodging in genotypes such as ‘Proconsul’, ‘Verde Pacas’, and ‘Gladiador’ was wind (Kang et al., 2022; Huang et al., 2025), since plants with structural damage may be more susceptible to this type of damage. Regarding the total soluble solids (°Brix) variable, differences were found between genotypes; however, no correlation was observed with other variables such as infestation or damage. In this regard, Vanweelden et al. (2015) and Reyes-Hernández et al. (2024) found a negative relationship between the proportion of perforated internodes and sucrose concentration in forage sorghum; they emphasize that for each unit increase in damaged internodes, the sucrose concentration decreased by 0.01% to 0.20%.

### Evaluation of height and forage yield

The days to harvest varied between treatments because the genotypes reached the soft dough stage at different dates. Therefore, they were grouped into three categories: Early-cycle (‘Gobernador’, pearl millet, and ‘Proconsul’), intermediate-cycle (‘195-2’, ‘Arcos’, ‘Caramelo’, ‘Fortuna’, ‘Gladiador’, ‘Paloma’, ‘Verde Pacas’, and ‘Williams’), and late-cycle (‘197-1’ and ‘197-1-1’), with a duration of 77, 90, and 105 d to harvest, respectively. Plant height was not influenced by the crop cycle, as tall genotypes ( $\geq 170$  cm) were recorded in each cycle. Genotypes ‘197-1-1’ and ‘Verde Pacas’ had the greatest plant heights, at 281 and 233 cm, respectively (Table 3), while pearl millet and ‘Proconsul’ had the lowest heights, at 107 and 140 cm, respectively. In terms of panicle height, genotype ‘197-1-1’ had the greatest height, at 273 cm, while pearl millet had the lowest value, at 88 cm (Table 3). Regarding flag leaf height, genotype ‘197-1-1’ remained the tallest, at 251 cm. Conversely, pearl millet and ‘Proconsul’ remained the shortest genotypes, at 89 and 101 cm, respectively (Table 3).

**Table 3.** Heights and total green matter (TGM) yield at forage harvest in sorghum genotypes and pearl millet during the first forage cutting. <sup>1</sup>Days after sowing. Different letters indicate differences between treatments (Tukey;  $\alpha = 0.05$ ).

Harvest days <sup>1</sup>	Genotype	Plant height cm	Panicle height cm	Height to flag leaf cm	TGM t ha <sup>-1</sup>
77	Gobernador	172 <sup>c-f</sup>	154 <sup>e</sup>	132 <sup>ef</sup>	23.2 <sup>h-g</sup>
	Pearl Millet	107 <sup>g</sup>	88 <sup>h</sup>	89 <sup>h</sup>	14.8 <sup>j</sup>
	Proconsul	140 <sup>fg</sup>	119 <sup>g</sup>	101 <sup>gh</sup>	20.8 <sup>hi</sup>
90	195-2	154 <sup>ef</sup>	129 <sup>fg</sup>	117 <sup>fg</sup>	22.9 <sup>gh</sup>
	Arcos	205 <sup>bc</sup>	183 <sup>c</sup>	165 <sup>bc</sup>	32.1 <sup>cd</sup>
	Caramelo	201 <sup>b-d</sup>	182 <sup>cd</sup>	163 <sup>b-d</sup>	27.1 <sup>e</sup>
	Fortuna	181 <sup>c-f</sup>	158 <sup>e</sup>	147 <sup>c-e</sup>	32.8 <sup>c</sup>
	Gladiador	188 <sup>b-e</sup>	162 <sup>de</sup>	139 <sup>d-f</sup>	19.8 <sup>i</sup>
	Paloma	156 <sup>d-f</sup>	142 <sup>ef</sup>	118 <sup>fg</sup>	24.6 <sup>fg</sup>
	Verde Pacas	233 <sup>ab</sup>	211 <sup>b</sup>	187 <sup>b</sup>	25.2 <sup>ef</sup>
	Williams	170 <sup>c-f</sup>	148 <sup>ef</sup>	133 <sup>ef</sup>	29.9 <sup>d</sup>
105	197-1	209 <sup>bc</sup>	201 <sup>bc</sup>	179 <sup>b</sup>	63.2 <sup>b</sup>
	197-1-1	281 <sup>a</sup>	273 <sup>a</sup>	251 <sup>a</sup>	73.6 <sup>a</sup>

The total green matter yield between genotypes and the number of days to harvest showed significant differences (Table 3). Among the early-cycle genotypes, 'Gobernador' had the highest green matter yield, with 23.2 t ha<sup>-1</sup>, while pearl millet had the lowest, with 14.8 t ha<sup>-1</sup>. Among the intermediate-cycle genotypes, 'Fortuna' and 'Arcos' had the highest yield, with 32.8 and 32.1 t ha<sup>-1</sup>, and 'Gladiador' the lowest, with 19.8 t ha<sup>-1</sup>. Among the late-cycle genotypes, '197-1-1' and '197-1' showed significant differences, with yields of 73.6 and 63.2 t ha<sup>-1</sup>, respectively.

The number of days elapsed from the first cut to the harvest of the second cut (first ratoon crops) was 104, 111, and 126 d for the early, intermediate, and late-cycle genotypes, respectively (Table 4). The height was greatest in genotypes '197-1-1', '197-1', and 'Caramelo', with 264, 238, and 214 cm, respectively. On the other hand, pearl millet, 'Gladiador', 'Williams', '195-2', and 'Paloma' were characterized as genotypes of lower size, with values between 103 and 139 cm. Regarding total green matter (TGM) variable, the genotypes '197-1' and '197-1-1' stood out for having higher yields with values between 28.6 and 30.2 t ha<sup>-1</sup>, while the genotypes 'Paloma', 'Proconsul', pearl millet, and 'Gladiador' presented lower yields with values between 4.2 and 7.5 t ha<sup>-1</sup> (Table 4).

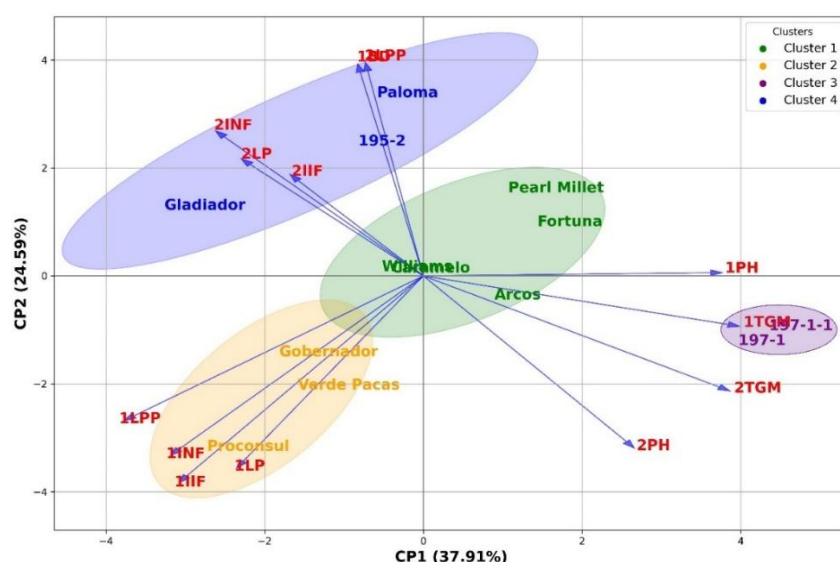
**Table 4.** Height plant and total green matter (TGM) yield during the second cutting (first ratoon crops) of forage in sorghum genotypes and pearl Millet. <sup>1</sup>Days after the first cut. Different letters indicate differences between treatments (Tukey;  $\alpha = 0.05$ ).

Harvest days <sup>1</sup>	Genotype	Plant height cm	TGM t ha <sup>-1</sup>
104	Gobernador	197 <sup>b-d</sup>	11.6 <sup>b-d</sup>
	Pearl Millet	103 <sup>fg</sup>	4.7 <sup>f</sup>
	Proconsul	154 <sup>c-e</sup>	7.0 <sup>ef</sup>
111	195-2	139 <sup>e-g</sup>	9.1 <sup>c-e</sup>
	Arcos	209 <sup>bc</sup>	12.7 <sup>bc</sup>
	Caramelo	214 <sup>ab</sup>	12.0 <sup>bc</sup>
	Fortuna	182 <sup>c-e</sup>	14.1 <sup>b</sup>
	Gladiador	127 <sup>fg</sup>	4.2 <sup>f</sup>
	Paloma	139 <sup>e-g</sup>	7.5 <sup>d-f</sup>
	Verde Pacas	212 <sup>b</sup>	12.7 <sup>bc</sup>
	Williams	131 <sup>e-g</sup>	11.4 <sup>b-d</sup>
126	197-1	238 <sup>ab</sup>	30.2 <sup>a</sup>
	197-1-1	264 <sup>a</sup>	28.6 <sup>a</sup>

Niu et al. (2021) and Wu et al. (2022) mention that crops with tall plant characteristics are undesirable because they often present lodging plant problems; however, in this study, genotypes with these characteristics did not show this problem. In this regard, Caramello et al. (2024) mention that there is a positive correlation between height and DM production in forage sorghum, which indicates that at larger plant size, forage yield increases proportionally; however, in this study, tall genotypes showed variable yields that can range from 27.1 to 73.6 t ha<sup>-1</sup> green matter (Table 3). Not all tall genotypes necessarily produced higher yields, as was the case with 'Verde Pacas', 'Caramelo', and 'Arcos', which exceeded 2 m in height and whose yields ranged between 25 and 32 t ha<sup>-1</sup> green matter compared to the genotype '197-1' with a similar height with yields of 63.2 t ha<sup>-1</sup>. For their part, Williams-Alanis et al. (2021) mention that experimental sorghum varieties have obtained an average yield of 21.7 t ha<sup>-1</sup> green matter, results similar to those obtained in this study, in short materials from 140 to 188 cm. Likewise, Aranda-Lara et al. (2024) report yields of 27.8 and 28.5 t ha<sup>-1</sup> green matter for 'Arcos' and 'Fortuna' grown in five environments, considering them an alternative for producers in the region.

### Principal component analysis (PCA)

Multivariate analysis identified four groups among the sorghum and millet genotypes evaluated in response to *E. loftini* infestation and infestation intensity in yield-related variables. In Group 1: 'Arcos', 'Caramelo', 'Fortuna', 'Williams', and pearl millet displayed favorable morphological characteristics associated with plant height (PH) and TGM variables in the first and second cuttings at the plant stage and during the first ratoon crop (Figure 1). However, an intermediate proximity was observed with Group 4 ('195-2', 'Gladiator', and 'Paloma') with respect to the vectors in the infestation, infestation intensity, and lodging plants variables evaluated in the second cutting, indicating low susceptibility to *E. loftini* and less damage to plants at the first ratoon crop. This may suggest a partial tolerance to borers, which directly depends on the crop cycle. This could explain why damage is lower during the first ratoon crop, due to the intrinsic climatic conditions of the agroecosystem and natural enemies, such as predators and parasitoids, as well as effective pest control management during the planting stage (Figure 1).



**Figure 1.** Principal component analysis (PCA) biplot of sorghum genotypes and pearl millet, grouped using K-means according to infestation variables, *Eoreuma loftini* infestation intensity, and yield-related variables at the plant stage (1, first cut) and first ratoon crop (2, second cut). LPP: Larvae per plant; INF: infestation; IIF: infestation intensity; LP: lodging plants; GD: total soluble solids ( $^{\circ}$ Brix); PH: plant height; TGM: total green matter.

Group 3 ('197-1' and '197-1-1') was characterized by lower infestation, less *E. loftini* damage, and higher TGM, located in the region opposite the infestation and lodging plant vectors. Its positive association with the TGM variable suggests excellent agronomic performance and high tolerance or resistance to *E. loftini* (Figure 1). The genotypes in Group 2 ('Gobernador', 'Proconsul', and 'Verde Pacas') showed higher incidence and damage by borer insects in the first cut (planting stage) and lower stability compared to other genotypes for the variables associated with borer attack. Furthermore, these genotypes, being in vectors opposite TGM, are associated with lower forage yield (Figure 1).

The various groups obtained from principal components analysis and K-means showed significant variability among the evaluated genotypes, as well as specific correlations with infestation intensity variables and agronomic characteristics. These types of studies stand out as tools in the characterization of germplasms for genetic improvement (Sarkar et al., 2024). For example, Ali et al. (2022) agree that certain studies highlight the importance of selecting genotypes with pest resistance and high yields; however, other researchers report that certain genotypes may present partial defenses that may not be sufficient under high pest pressure (Cuevas and Prom, 2020).

The genotypes in Group 2 ('Gobernador', 'Proconsul', and 'Verde Pacas') showed less damage during the second cut (first ratoon crops) (Figure 1). This partial resistance is dependent on the crop cycle and climatic conditions and may also be more closely related to pest management at the plant stage. This underscores the need to consider evaluating stubble cycles in crop genetic improvement programs for crops that have the potential to be used as forage crops, as has been discussed in various studies on genetic variability and its impact on crop productivity (Cuevas and Prom, 2020). On the other hand, genotypes '197-1' and '197-1-1' could be considered elite lines for improvement programs due to their tolerance to borers, as well as their high yields compared to other widely used sorghum genotypes. This is deduced from previous studies on the identification of superior genotypes through multivariate analysis (Ali et al., 2022; Sarkar et al., 2024) and from the results obtained in this research.

## CONCLUSIONS

Overall, during the first cut, sorghum and pearl millet genotypes showed lower infestation and damage by *Eoreuma loftini* compared to first ratoon crops. Sorghum genotypes 'Paloma', 'Fortuna', '197-1-1', and '197-1', as well as pearl millet, showed the lowest infestation rates and intensities by *E. loftini*, indicating that these genotypes may be potentially tolerant to *E. loftini* infestation. This finding could inform the development of an integrated management plan for this pest, including host tolerance. Regarding plant lodging, genotypes '197-1-1', '197-1', 'Paloma', 'Williams', and pearl millet did not show lodging due to the effect of the stem borer, suggesting that the stem has a higher fiber content and larger size, making it resistant to lodging. The genotypes evaluated were classified into three categories until forage harvest at the plant stage (early, intermediate, and late cycle). The late genotypes ('197-1-1' and '197-1') had the highest yields of forage, followed by the mid-season genotypes, while the early genotypes had the lowest yields.

### Author contribution

Conceptualization: M.F-V., J.R.G-M., S.J-C. Methodology: G.G-O., M.F-V., J.J.Q-M. Software: G.G-O., B.E-D. Validation: M.F-V., J.R.G-M., G.G-O. Formal analysis: G.G-O., B.E-D. Investigation: M.F-V., J.R.G-M., G.G-O. Data curation: B.E-D., G.G-O., J.J.Q-M. Writing-original draft: G.G-O. Writing-review and editing: M.F-V., J.R.G-M., S.J-C., B.E-D., J.J.Q-M. Visualization: M.F-V., G.G-O. Supervision: M.F-V., J.R.G-M., S.J-C. Project administration: M.F-V., S.J-C. All co-authors reviewed the final version and approved the manuscript before submission.

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