Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252026v3914022rc

Scientific Article

Dynamics of *Spodoptera frugiperda* in Bt and non-Bt maize hybrids semi-arid ecotone of northeastern Brazil

Dinâmica de *Spodoptera frugiperda* em híbridos de milho Bt e não Bt em ecótono semiárido do nordeste do Brasil

Carlos M. P. dos Santos[1], Ana C. M. de Moura[1], Sara dos S. Nunes[1], Daniel M. Pacheco[1], José B. Malaquias[2], Eliseu J. G. Pereira[3], Bruno E. Pavan[4], Luciana B. Silva[1]*

[1]Graduate Program in Agricultural Sciences, Universidade Federal do Piauí, Bom Jesus, PI, Brazil. [2]Department of Agricultural Sciences, Universidade Federal da Paraíba, Areia, PB, Brazil. [3]Department of Entomology, Universidade Federal de Viçosa, Viçosa, MG, Brazil. [4]Department of Crop Science, Universidade Estadual Paulista Júlio de Mesquita Filho, Ilha Solteira, SP, Brazil.

ABSTRACT - The fall armyworm (*Spodoptera frugiperda*; Lepidoptera: Noctuidae) is a major maize pest that causes substantial yield losses worldwide. A widely adopted management strategy involves genetically modified maize hybrids that express *Bacillus thuringiensis* (Bt) genes and produce insecticidal proteins such as Cry and Vip3Aa. However, the long-term sustainability of Bt technology depends on continuous field monitoring, particularly in regions characterized by high temperatures and seasonal drought. This study evaluated the field incidence, infestation levels, and foliar damage caused by *S. frugiperda* in Bt and non-Bt maize hybrids. Two Bt hybrids (NK 555 VIP3 and DKB 390PRO4) were compared with two non-Bt hybrids (DKB 3800RR and P3889 R) in a randomized block design conducted over two consecutive cropping seasons (2022 and 2023) under semi-arid conditions in Northeastern Brazil. Across both cropping seasons, no larvae or significant leaf damage were recorded in the Bt hybrids, whereas the non-Bt hybrids exhibited larval infestations beginning at 29 days after sowing (DAS), which led to moderate leaf damage levels. Infestation peaks occurred between 30 and 70 DAS and demonstrated consistent seasonal patterns in non-Bt hybrids. These findings demonstrate the stability of field performance of pyramided Bt hybrids against *S. frugiperda* under semi-arid ecotone conditions and reinforce the importance of regional surveillance programs to support insect resistance management strategies and sustain Bt technology in maize production systems.

Keywords: Fall armyworm. Field monitoring. Bt maize. Cry and Vip proteins. Semi-arid agriculture.

RESUMO - A lagarta-do-cartucho (*Spodoptera frugiperda*; Lepidoptera: Noctuidae) é uma das principais pragas do milho, causando perdas expressivas de produtividade em todo o mundo. Uma estratégia amplamente adotada para seu manejo envolve o uso de híbridos de milho geneticamente modificados que expressam genes de *Bacillus thuringiensis* (Bt) e produzem proteínas inseticidas, como Cry e Vip3Aa. Entretanto, a sustentabilidade de longo prazo dessa tecnologia depende do monitoramento contínuo em campo, especialmente em regiões caracterizadas por altas temperaturas e estiagem sazonal. Este estudo avaliou a incidência em campo, os níveis de infestação e os danos foliares causados por *S. frugiperda* em híbridos de milho Bt e não-Bt. Dois híbridos Bt (NK 555 VIP3 e DKB 390PRO4) foram comparados com dois híbridos não-Bt (DKB 3800RR e P3889 R) em delineamento em blocos casualizados, durante duas safras consecutivas (2022 e 2023), em condições semiáridas no Nordeste do Brasil. Em ambas as safras, não foram registradas larvas ou danos foliares significativos nos híbridos Bt, enquanto os híbridos não-Bt apresentaram infestação larval a partir de 29 dias após a semeadura (DAS), com níveis moderados de dano foliar. Os picos de infestação ocorreram entre 30 e 70 DAS, evidenciando padrões sazonais consistentes nos híbridos não-Bt. Esses resultados demonstram a estabilidade do desempenho em campo de híbridos Bt piramidados no controle de *S. frugiperda* sob condições de ecótono semiárido e reforçam a importância de programas regionais de monitoramento para subsidiar estratégias de manejo da resistência de insetos e garantir a sustentabilidade da tecnologia Bt nos sistemas de produção de milho.

Palavras-chave: Lagarta-do-cartucho. Monitoramento em campo. Milho Bt. Proteínas Cry e Vip. Agricultura semiárida.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: February 14, 2025.
Accepted in: March 18, 2026.

Editor in Chief: Aurélio Paes Barros Júnior
Section Editor: Carlos Henrique Brito

Data Availability: The data that support the findings of this study can be made available, upon reasonable request, from the corresponding author.

***Corresponding author:**
<lubarbosabio@ufpi.edu.br>

INTRODUCTION

Maize (*Zea mays* L.) is a major crop in Brazilian agriculture, contributing substantially to national grain production and regional economies (ISAAA, 2023). However, crop productivity is significantly threatened by the fall armyworm, *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae), one of the most destructive pests of maize worldwide (GE; WANG; ZHANG, 2021; HE; DENG; LI, 2021). Larval feeding on leaves and reproductive structures can compromise plant development and reduce grain yield, particularly in tropical and subtropical production systems.

Genetically modified maize expressing *Bacillus thuringiensis* (Bt) proteins has become a widely adopted strategy for managing *S. frugiperda* populations (CHANDRASENA; SRIJAYA; KARMAN, 2018; PAREDES-SÁNCHEZ et al., 2021). Bt maize produces insecticidal proteins such as Cry and Vip3Aa that target specific receptors in the insect midgut, thereby reducing larval survival and leaf damage. The adoption of Bt hybrids has reduced insecticide applications and improved pest management efficiency (GOUSE; TSHIMBU; JONGA, 2016; HUANG, 2021).

Nevertheless, field-evolved resistance to some Cry proteins has been documented in Brazilian populations of *S. frugiperda*, including resistance to

Cry1F and Cry1Ab in major maize-producing regions (MONNERAT; FIGUEIREDO; PACHECO, 2015; FARIAS; GONÇALVES; PEREIRA, 2016; OMOTO et al., 2016). Although Vip3Aa proteins remain effective in most field scenarios, their long-term durability depends on appropriate insect resistance management (IRM) strategies (WAN et al., 2021; AMARAL; SANTOS; GOMES, 2020).

Pyramiding of multiple Bt proteins within the same hybrid has been proposed as a strategy to delay resistance evolution by targeting different physiological mechanisms in the pest (CARRIÈRE; CRICKMORE; TABASNIK, 2015). In addition, the implementation of refuge areas with conventional or non-Bt maize remains a fundamental component of IRM programs. Continuous regional monitoring of pest incidence, infestation levels, and leaf damage is therefore essential to assess the field performance of Bt technologies and to support decision-making in different agroecological contexts (TOEPFER et al., 2021; SILVA et al., 2024).

Despite the extensive adoption of Bt maize in Brazil, information on the seasonal field dynamics of *S. frugiperda* under semi-arid ecotone conditions in Northeastern Brazil remains limited. Climatic characteristics such as high temperatures, irregular rainfall, and prolonged dry periods can influence pest population dynamics and crop–pest interactions and may affect the field performance of Bt hybrids.

In this context, this study evaluated the field incidence, infestation levels, and foliar damage caused by *S. frugiperda* in Bt and non-Bt maize hybrids over two consecutive cropping seasons under semi-arid conditions in Northeastern Brazil. Documentation of pest dynamics across cropping seasons provides regional evidence to support monitoring programs and contributes to the sustainable use of Bt maize technology.

MATERIALS AND METHODS

Experimental Site

The study was conducted during two consecutive cropping seasons (2022 and 2023) at the Experimental Farm of the Technical College of Floriano (06°46′01″S; 43°01′21″ W; 112 m altitude), operated by the Universidade Federal do Piauí (UFPI, Federal University of Piauí), in Floriano, southwestern Piauí, Brazil.

The region is characterized as a semi-arid ecotone with transitional vegetation between the Caatinga and Cerrado biomes. The climate is classified as Aw, tropical savanna, according to the Köppen classification, characterized by high temperatures throughout the year, with a mean annual temperature of 27 °C and frequent peaks reaching 40 °C. Average annual rainfall is approximately 1,100 mm, concentrated between November and April, followed by a pronounced dry season from May to September (LIMA; CAVALCANTI, 2020). These environmental conditions provide a representative scenario for maize production under semi-arid conditions in Northeastern Brazil.

Crop Establishment and Management

Maize was cultivated under conventional tillage with two soil preparation operations prior to sowing. Soil fertility was assessed through chemical analysis, and fertilization was performed according to agronomic recommendations. Basal fertilization consisted of 300 kg ha^{-1} of N–P–K (05–30–15). Seeds were sown on 11 January, 2022, and 25 January, 2023 at a rate of four seeds per linear meter at a depth of 2–3 cm, with 0.7 m between rows and 0.25 m between plants, resulting in a uniform plant density.

Weed management included pre-emergence application of glyphosate (Roundup®) and complementary manual weeding when necessary. No insecticides were applied during the experimental period, which allowed natural infestation by *S. frugiperda*.

Plant Material and Experimental Design

Two Bt maize hybrids (NK 555 VIP3 and DKB 390PRO4) and two non-Bt hybrids (DKB 3800RR and P3889 R) were evaluated. The hybrid NK 555 VIP3 expresses Cry1Ab and Vip3Aa20 proteins (Agrisure Viptera® technology). The hybrid DKB 390PRO4 expresses Cry1A.105, Cry2Ab2, Vip3Aa, and Cry3Bb1 proteins (VTPRO4® technology). The non-Bt hybrids DKB 3800RR and P3889 R express glyphosate tolerance only and do not contain insecticidal Bt proteins.

The experiment followed a randomized complete block design with four replicates per treatment, for a total of 16 plots. Each plot measured 10 × 10 m (100 m²), with a row spacing of 0.7 m and a plant spacing of 0.25 m (Figure 1).

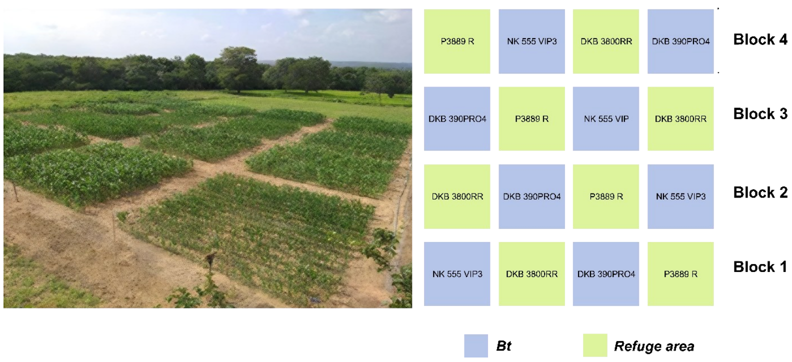


Figure 1. Experimental layout and field arrangement of maize hybrids in a randomized complete block design. The photograph (left) illustrates the experimental area under field conditions. The schematic diagram (right) shows the spatial distribution of four maize hybrids (two Bt and two non-Bt) across four blocks (Blocks 1–4), for a total of 16 plots. Blue plots represent Bt hybrids (NK 555 VIP3 and DKB 390PRO4), and green plots represent non-Bt hybrids (DKB 3800RR and P3889 R).

Spodoptera frugiperda Larval incidence

Evaluations were conducted weekly from the early vegetative stages until physiological maturity (R6), following the phenological scale described by Ritchie, Hanway, and Benson (1993). In each assessment, 10 plants were randomly selected per plot. All leaves and the whorl of each plant were carefully inspected for the incidence of *S. frugiperda* larvae, which were then classified into two size categories: small larvae (≤ 0.5 cm) and large larvae (> 0.5 cm).

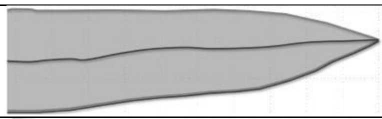
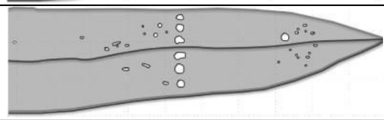
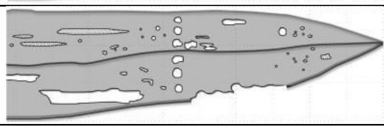
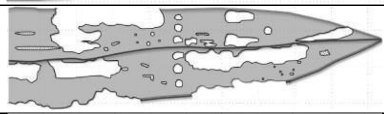
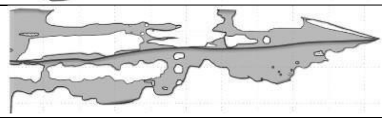
Larvae were removed after counting to avoid repeated observations of the same individuals in subsequent assessments. This procedure allowed consistent weekly evaluation of new infestations; however, it may have reduced subsequent larval density.

Assessments were conducted at 18, 23, 29, 37, 42, 48, 55, 62, 69, and 83 days after sowing (DAS) in 2022 and at 13, 20, 27, 34, 41, 48, 55, 62, 69, and 76 DAS in 2023. Larval counts were expressed as mean number of larvae per plot and as the percentage of infested plants.

Foliar Damage Assessment

Leaf damage was assessed using a 0–4 visual scale adapted from Toepfer et al. (2021) (Table 1). Each leaf of the selected plants was individually evaluated, and the damage index was calculated for each plant as the mean score across evaluated leaves. Senescent leaves were excluded from the analysis. This standardized scale enabled consistent comparison of damage severity between Bt and non-Bt hybrids.

Table 1. Visual leaf damage scale (0–4) used to assess foliar damage caused by *Spodoptera frugiperda* in maize plants, adapted from Toepfer et al. (2021).

Score	Damage index	Graphical representation
0	No visible damage	
1	Little damage (small holes or slight feeding on leaf margins)	
2	Medium damage (some larger holes or partial feeding on leaf margins)	
3	Severe damage (many larger holes or extensive feeding on leaf margins)	
4	Total damage (complete leaf destruction)	

Statistical Analysis

Larval count data were analyzed using generalized linear models (GLM) with a Poisson distribution and log-link function. When overdispersion was detected, models were adjusted using a negative binomial distribution. Infestation percentage data were analyzed using Gaussian GLM after confirmation of homoscedasticity and normality of residuals. Leaf damage scores were analyzed using GLM with a negative binomial distribution, which is appropriate for count-based and overdispersed ordinal data. Cumulative larval counts per cropping season were analyzed using non-parametric comparisons among hybrids with the Friedman test, followed by Bonferroni-adjusted pairwise comparisons. All analyses were conducted in R (R CORE TEAM, 2023) at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Incidence of *Spodoptera frugiperda*

The incidence of *Spodoptera frugiperda* larvae differed significantly among maize hybrids throughout the crop cycle in both cropping seasons (Table 2). Significant effects of hybrid and days after sowing (DAS) were detected for small larvae (≤ 0.5 cm), large larvae (> 0.5 cm), and total larval counts in 2022 and 2023 ($p < 0.01$). In contrast to non-Bt hybrids, near-zero larval incidence was detected in the Bt hybrids NK 555 VIP3 and DKB 390PRO4 during both cropping seasons, demonstrating consistent field performance of pyramided Bt technology under semi-arid conditions (Table 2).

Larval counts in each plot confirmed the GLM results (Table 3). During 2022, the non-Bt hybrids (DKB 3800RR and P3889 R) showed significantly higher median larval counts than the Bt hybrids ($p \leq 0.01$). In 2023, larval incidence remained significantly lower in the Bt hybrids, although overall population levels were lower than in 2022 (Table 3).

Table 2. Deviance analysis from generalized linear models (GLM) with Poisson distribution for *Spodoptera frugiperda* larval incidence in maize hybrids during the 2022 and 2023 cropping seasons.

SV	DF	DF_R	Larvae ≤ 0.5 cm			Larvae > 0.5 cm			Total		
			DEV	RES	*p*	DEV	RES	*p*	DEV	RES	*p*
2022											
Block	3	1596	10.36	829.07	0.02	0.57	839.71	0.90	7.35	1318.56	0.06
Hybrid (H)	3	1593	216.29	612.78	<0.01	255.86	583.85	<0.01	467.43	851.13	<0.01
DAS	9	1584	68.88	543.90	<0.01	112.21	471.64	<0.01	145.28	705.85	<0.01
H × DAS	27	1557	18.27	525.63	0.90	10.28	461.36	0.99	25.22	680.63	0.56
2023											
Block	3	1596	10.55	530.43	0.01	2.81	329.26	0.42	11.05	747.86	0.01
Hybrid (H)	3	1593	95.67	434.76	<0.01	55.72	273.54	<0.01	149.54	598.32	<0.01
DAS	9	1584	161.70	273.06	<0.01	70.28	203.26	<0.01	217.96	380.36	<0.01
H × DAS	27	1557	20.79	252.28	0.80	13.31	189.95	0.99	25.04	355.32	0.57

SV = source of variation; DAS = days after sowing; DF = degrees of freedom; DF_R = residual degrees of freedom; DEV = deviance; RES = residual deviance; *p* = *p*-value.

Table 3. Median (± interquartile range) number of *Spodoptera frugiperda* larvae per plot in Bt and non-Bt maize hybrids during the 2022 and 2023 cropping seasons.

Variable	Bt maize hybrid		Non-Bt maize hybrids		χ^2	*P*
	NK555VIP3	DKB 390PRO4	DKB 3800RR	P3889 R		
2022						
Total larvae	0.00 ± 0.00 b	0.00 ± 0.00 b	4.25 ± 1.12 a	4.25 ± 0.62 a	11.7273	0.00
Large larvae	0.00 ± 0.00 b	0.00 ± 0.00 b	2.50 ± 1.25 a	2.00 ± 0.00 a	11.0571	0.01
Small larvae	0.00 ± 0.00 b	0.00 ± 0.00 b	1.50 ± 0.50 a	2.50 ± 1.25 a	11.6471	0.00
2023						
Total larvae	0.00 ± 0.03 c	0.05 ± 0.10 bc	1.55 ± 0.50 ab	1.60 ± 1.12 a	10.8333	0.01
Large larvae	0.00 ± 0.00 c	0.00 ± 0.03 bc	0.65 ± 0.15 a	0.40 ± 0.12 ab	10.8333	0.01
Small larvae	0.00 ± 0.03 b	0.00 ± 0.03 b	0.90 ± 0.35 a	1.10 ± 0.90 a	11.0571	0.01

Means followed by different letters within rows indicate significant differences among hybrids by the Friedman test ($p \leq 0.05$).

Seasonal dynamics

The temporal distribution of larvae throughout the crop cycle is illustrated in Figure 2. In the non-Bt hybrids, larval incidence began at 29 DAS in 2022 and at 34 DAS in 2023, persisting until late vegetative and early reproductive stages. Peak larval densities occurred between 30 and 70 DAS in both cropping seasons. In contrast, the Bt hybrids showed near-zero larval incidence throughout the evaluation period (Figure 2).

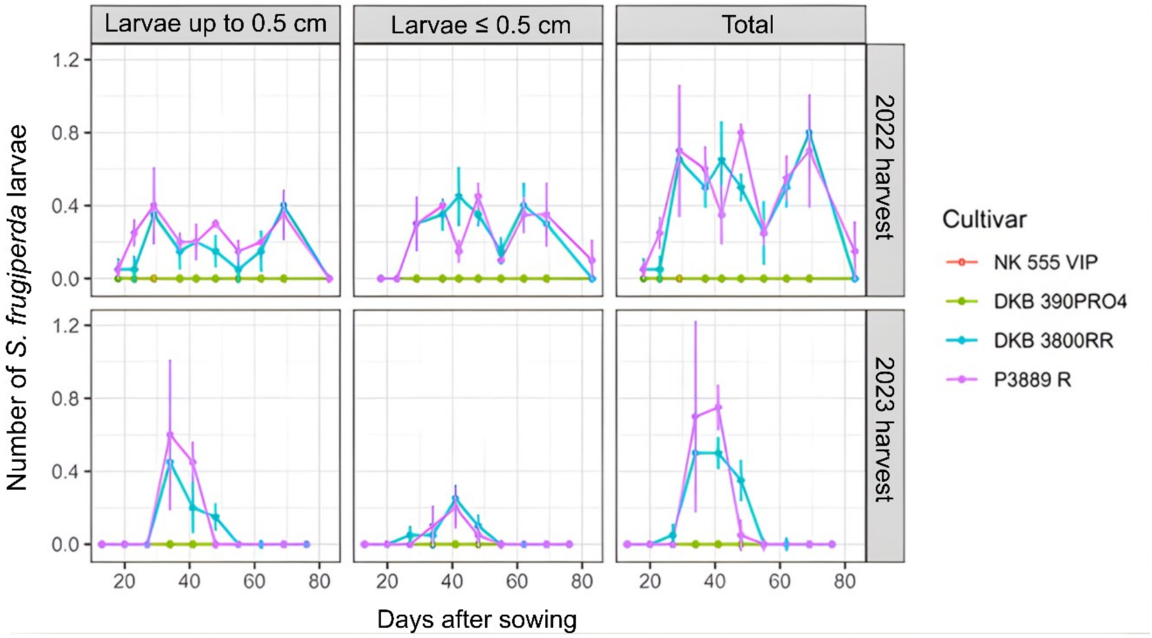


Figure 2. Temporal dynamics of *Spodoptera frugiperda* larval incidence (small larvae ≤ 0.5 cm, large larvae > 0.5 cm, and total larvae) in Bt (NK 555 VIP3, DKB 390PRO4) and non-Bt (DKB 3800RR, P3889 R) maize hybrids during the 2022 and 2023 cropping seasons. Values represent median ± interquartile range (n = 4 replicates).

Infestation levels

Infestation levels differed significantly among hybrids and with DAS in both cropping seasons (Table 4). Non-Bt hybrids exhibited higher percentages of infested plants, with peaks reaching 57% at 69 DAS in 2022 and 47% at 41 DAS in 2023 (Figure 3). The Bt hybrids remained with infestation levels close to zero across all evaluations.

Overall infestation intensity was numerically lower in 2023 than in 2022; however, no formal statistical comparison between years was conducted because the cropping seasons were analyzed independently.

Table 4. Deviance analysis from Gaussian generalized linear models (GLM) for infestation levels (%) of *Spodoptera frugiperda* in maize hybrids during the 2022 and 2023 cropping season.

SV	DF	DF_R	Larvae ≤ 0.5 cm			Larvae > 0.5 cm			Total		
			DEV	RES	*p*	DEV	RES	*p*	DEV	RES	*p*
2022											
Block	3	156	0.07	3.03	0.02	0.02	4.80	0.64	0.05	8.97	0.35
Hybrid	3	153	1.28	1.74	<0.00	1.81	2.99	<0.00	4.49	4.48	<0.00
DAS	9	144	0.42	1.32	<0.00	0.76	2.22	<0.00	1.24	3.24	<0.00
C × DAS	27	117	0.46	0.86	0.00	1.03	1.19	<0.00	1.44	1.80	<0.00
2023											
Block	3	156	0.02	1.98	0.22	0.01	0.97	0.51	0.02	3.06	0.43
Hybrid	3	153	0.22	1.76	<0.00	0.11	0.86	<0.00	0.43	2.62	<0.00
DAS	9	144	0.55	1.21	<0.00	0.21	0.65	<0.00	0.84	1.78	<0.00
C × DAS	27	117	0.61	0.60	<0.00	0.24	0.41	<0.00	0.93	0.85	<0.00

SV = source of variation; DAS = days after sowing; DF = degrees of freedom; DF_R = residual degrees of freedom; DEV = deviance; RES = residual deviance; *p* = *p*-value.

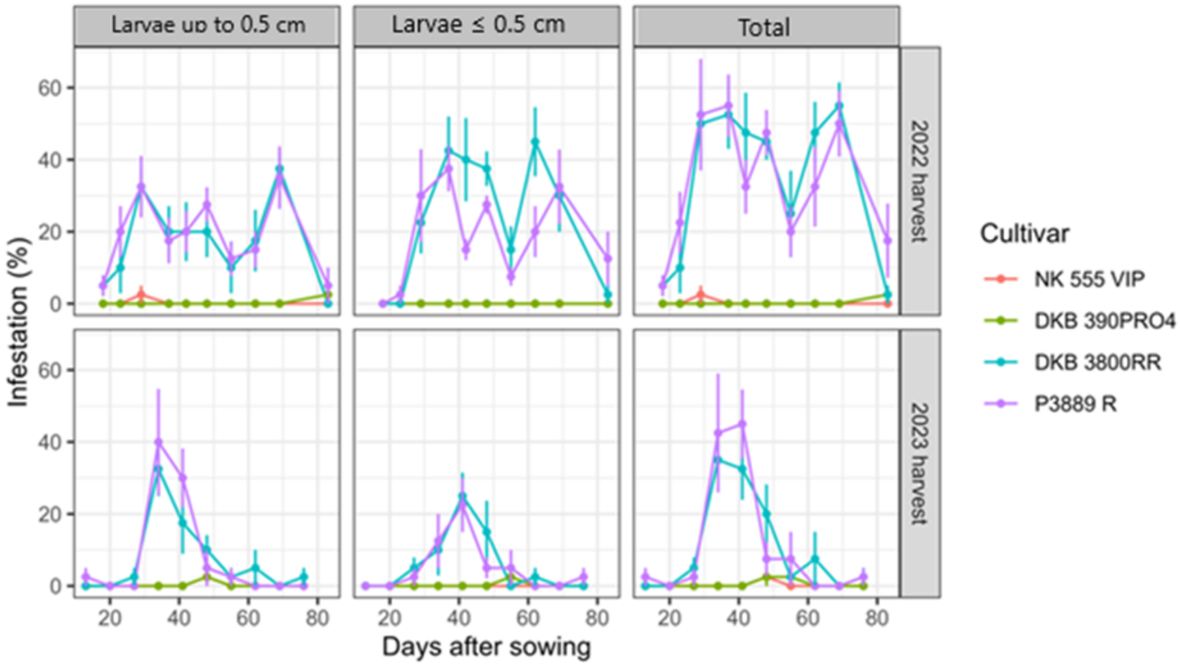


Figure 3. Infestation percentage of maize plants by *Spodoptera frugiperda* larvae in Bt and non-Bt hybrids during the 2022 and 2023 cropping seasons. Values represent mean ± standard error (n = 4 replicates).

Foliar damage

Leaf damage scores varied significantly among hybrids ($p < 0.01$) in both cropping seasons (Table 5). No leaf damage was recorded in the Bt hybrids. Conversely, the non-Bt hybrids exhibited moderate damage according to the scale of Toepfer et al. (2021), particularly between 30 and 60 DAS (Figure 4).

Fall armyworm (*Spodoptera frugiperda*) infestation levels, larval density, and associated leaf damage were consistently lower in Bt maize hybrids than in non-Bt hybrids across both cropping seasons. In the pyramided Bt hybrids evaluated (NK 555 VIP3 and DKB 390PRO4), no larvae or leaf damage were recorded throughout the assessment period, whereas the non-Bt hybrids exhibited measurable larval incidence and moderate leaf damage (Tables 2 and 5; Figures 2 and 4). These findings indicate stable field performance of Bt technology under semi-arid ecotone conditions in Northeastern Brazil.

Table 5. Deviance analysis from negative binomial generalized linear models (GLM) for leaf damage scores caused by *Spodoptera frugiperda* in maize hybrids during the 2022 and 2023 cropping seasons.

SV	DF	DF_R	DEV	RES	*p*
			2022		
Block	3	156	0.1535	119.6179	0.98
Hybrid (H)	3	153	54.6606	64.9573	0.00
DAS	9	144	32.1870	32.7703	0.00
H × DAS	27	117	3.4479	29.3224	1.00
			2023		
Block	3	156	0.8846	74.4525	0.82
Hybrid (H)	3	153	23.3097	51.1429	0.00
DAS	9	144	13.4285	37.7144	0.14
H × DAS	27	117	0.8348	36.8796	1.00

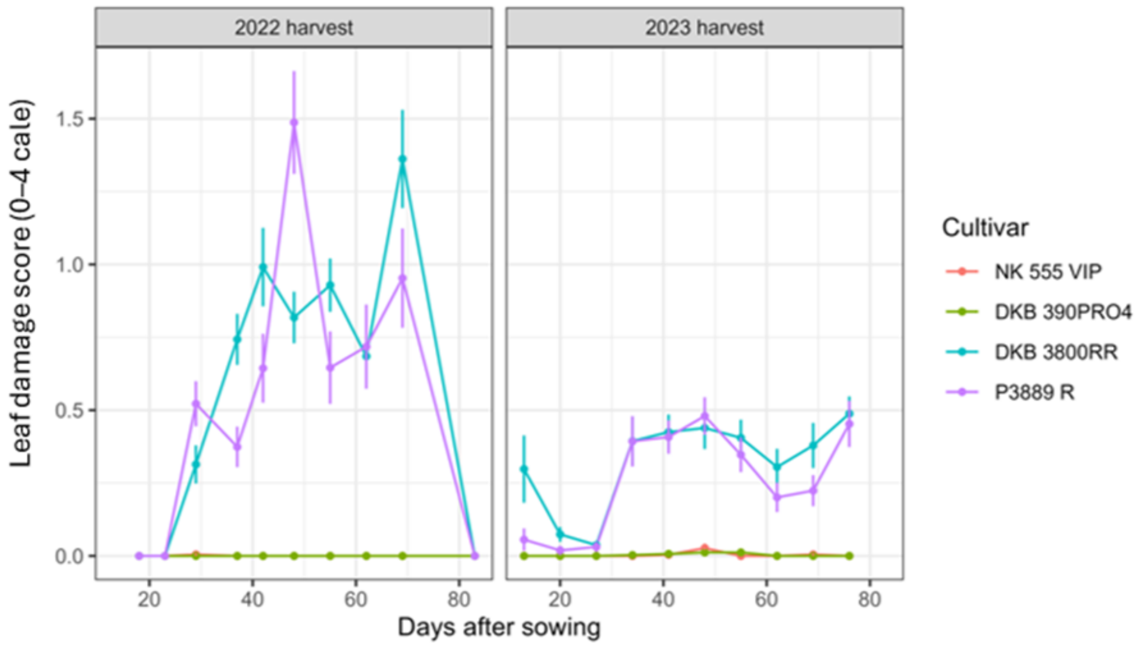


Figure 4. Mean leaf damage scores (0–4 scale; Toepfer et al., 2021) caused by *Spodoptera frugiperda* in Bt and non-Bt maize hybrids during the 2022 and 2023 cropping seasons.

Field-evolved resistance to some Cry1 proteins has been documented in Brazilian populations of *S. frugiperda* (OMOTO et al., 2016). However, Vip3Aa proteins remain largely effective under field conditions, with confirmed resistance reported primarily under laboratory selection (AMARAL; SANTOS; GOMES. 2020). The sustained suppression observed in the present study is consistent with previous reports indicating that pyramided Bt hybrids expressing Cry and Vip proteins provide enhanced protection against *S. frugiperda* (VAN DEN BERG et al., 2021). The distinct modes of action and binding sites of Cry and Vip proteins in the insect midgut are considered important for reducing the likelihood of cross-resistance (CARRIÈRE; CRICKMORE; TABASHNIK, 2015).

This study did not assess physiological susceptibility or resistance allele frequency. Therefore, the results should be interpreted as evidence of field-level efficacy during the evaluated cropping seasons rather than as direct confirmation of resistance status. Continued regional monitoring remains essential to detect potential shifts in pest response over time.

Larval incidence in the non-Bt hybrids began between 29 and 34 DAS and persisted until late vegetative stages, in some cases extending to 83 DAS. These results indicate that infestation can occur across multiple phenological stages under semi-arid conditions. Previous studies have reported peak infestation between 15 and 30 DAS (NAVIK et al., 2021), often declining during reproductive stages. In contrast, the prolonged infestation period observed in this study may reflect regional climatic factors, including high temperatures and irregular rainfall patterns, which can influence pest development and crop–pest synchrony (BAUDRON; BROWN; CHARLES, 2019; NBOYINE et al., 2020). Similar patterns of higher larval density and greater leaf damage in non-Bt relative to Bt maize hybrids have been reported by He, Deng and Li (2021) and Silva et al. (2024).

Although infestation and damage levels were numerically lower in 2023 than in 2022, the experimental design did not include interannual statistical comparison, and thus these differences should be interpreted cautiously. Seasonal variation in pest pressure may be influenced by multiple interacting factors, including climatic variability, landscape-level host availability, and natural enemy activity (GARCÍA-GUTIÉRREZ; GONZÁLEZ-MALDONADO; CORTEZ-MONDACA, 2012; HRUSKA, 2019). Additionally, larvae were removed during sampling to prevent recounting, which may have reduced subsequent larval density estimates. However, this procedure was applied uniformly across treatments, thereby minimizing treatment-specific bias.

Leaf damage in the non-Bt hybrids reached moderate levels according to the scale of Toepfer et al. (2021), particularly between 30 and 60 DAS, coinciding with peak larval density. Although grain yield was not evaluated, previous studies have demonstrated a positive relationship between early vegetative leaf damage and yield reduction in maize (YAMÉOGO et al., 2024). Nevertheless, yield impact depends on the timing and severity of leaf damage, with plants often capable of compensatory growth outside key developmental stages (CHISONGA et al., 2023). Subsequent studies integrating productivity and economic analysis would strengthen applied recommendations for the semi-arid production systems evaluated.

The primary objective of this study was to characterize pest field dynamics and hybrid performance under natural infestation pressure rather than to quantify agronomic productivity; however, the absence of larval establishment and foliar damage in the Bt hybrids throughout both cropping seasons strongly suggests a protective effect during critical vegetative stages. Nevertheless, integrating yield and economic injury level assessments in future regional studies would provide a more comprehensive evaluation of the agronomic and economic benefits of Bt technology under semi-arid conditions.

The results contribute region-specific field data from a semi-arid ecotone, a context in which high temperatures and seasonal drought may influence pest population dynamics and crop performance. Such information is valuable for guiding local monitoring programs and supporting the sustainable use of Bt technology within integrated pest management frameworks.

Semi-arid ecotone regions of Northeastern Brazil present distinct climatic constraints, including elevated temperature regimes and irregular rainfall distribution, which may alter pest population dynamics, crop development, and the expression stability of Bt proteins. Field validation under these environmental conditions is essential, as most resistance monitoring studies have been conducted in high-production tropical regions of central and southern Brazil. Therefore, documentation of two consecutive cropping seasons of consistent Bt hybrid performance under semi-arid conditions provides relevant regional evidence to support local insect resistance management strategies.

CONCLUSION

Pyramided Bt maize hybrids expressing Cry and Vip proteins (NK 555 VIP3 and DKB 390PRO4) maintained effective suppression of *Spodoptera frugiperda* across two consecutive cropping seasons under semi-arid field conditions in Northeastern Brazil. In contrast, the non-Bt hybrids (DKB 3800RR and P3889 R) exhibited measurable larval infestation and moderate leaf damage.

Although this study did not directly assess resistance status or grain yield, the absence of larval establishment and leaf damage in the Bt hybrids during the evaluation period indicates stable field performance under the tested conditions. Continuous regional monitoring remains essential to sustain the long-term efficacy of Bt technology and to support integrated pest management strategies adapted to semi-arid maize production systems.

The generation of region-specific, multi-season field data is particularly relevant for semi-arid ecotone environments, where climatic variability may influence pest pressure and resistance evolution dynamics.

ACKNOWLEDGEMENTS

The authors thank the technicians, local growers, and affiliates of biotechnology and seed companies for enabling the insect collections and for providing seeds of the maize hybrids used in this research. Special thanks to the team members of the Plant Protection Laboratory (CPCE), Federal University of Piauí (UFPI), who assisted with insect rearing, plant cultivation, and laboratory maintenance. Financial support was provided by the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES), the Brazilian National Council for Scientific and Technological Development (CNPq), the Foundation for Research Support of the State of Piauí (FAPEPI), and the Foundation for Research Support of the State of Minas Gerais (FAPEMIG) through the grant of scholarships for graduate and undergraduate students involved in this research.

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