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Screening of selected maize varieties cultivated in the Lake Chad Province for tolerance to fall armyworm infestation.

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Abstract

The recent invasion of the fall armyworm continues to cause substantial yield losses in maize in Chad, particularly in the Lake Province. As a result, the use of tolerant genotypes has become a key strategy in integrated pest management. The objective of this study is to conduct a field evaluation of the tolerance of five maize varieties (2009TZEEW-STR, 97TZEE-W-C2, CMS8507C1, MATAFO I, and MATAFO II) to damage caused by *Spodoptera frugiperda*, using analysis of variance. The experimental design is a randomized complete block with five treatments and three replications. The results indicate that the average infestation rate is significantly higher (P < 0.0001) with MATAFO II variety, whereas the varieties 2009TZEEW-STR, 97TZEE-W-C2, CMS8507C1, and MATAFO I exhibited significantly lower and statistically similar infestation rates. The variety 2009TZEEW-STR recorded the lowest leaf damage index and ear damage (P < 0.0001), followed by varieties 97TZEE-W-C2, CMS8507C1, and MATAFO I, which showed similarly high levels of both leaf and ear damage. The highest grain yield is obtained with the variety 2009TZEEW-STR, followed by MATAFO I, 97TZEE-W-C2, and CMS8507C1, all of which have similarly high average yields. The results demonstrate that, under our experimental conditions, the variety 2009TZEEW-STR is the least susceptible to pest attacks, followed by MATAFO I and 97TZEE-W-C2.

Keywords: *Zea mays*, *Spodoptera frugiperda*, Varietal tolerance, integrated pest management

Résumé

La récente invasion de la chenille légionnaire d'automne continue de causer des pertes de rendement énorme sur le maïs au Tchad et particulièrement dans la Province du Lac. Ainsi, l'utilisation de génotypes résistants est devenue une stratégie importante dans la lutte intégrée contre les ravageurs. L'objectif de cette étude était une évaluation au champ de la résistance de 5 variétés de maïs (2009TZEEW-STR, 97TZEE-W-C2, CMS8507C1, MATAFO I et MATAFO II ainsi que des dommages causés par *Spodoptera frugiperda*, au moyen d'une analyse variance. Le dispositif expérimental a été un bloc aléatoire complet avec 5 traitements et 3 répétitions. Il ressort que le taux moyen d'infestation a été significativement élevé (P < 0,0001) sur la variété MATAFO II tandis que les variétés 2009TZEEW-STR, 97TZEE-W-C2, CMS8507C1 et MATAFO I ont obtenu les taux moyens d'infestation les plus faibles et statistiquement similaire. La variété 2009TZEEW-STR a enregistré le plus faible indice de dégâts foliaires et les dégâts sur les épis (P < 0,0001) suivi des variétés 97TZEE-W-C2, CMS8507C1 et MATAFO I qui ont obtenu des indices de dégâts foliaires et des dégâts sur les épis élevés et statistiquement similaire. Quant au rendement en grain de maïs il a été plus élevé sur la variété 2009TZEE W-STR suivi des variétés MATAFO I, 97TZEE-W-C2 et CMS8507C1 qui ont enregistré des rendements moyens élevé et statistiquement similaire. Les résultats ont montré que dans nos conditions expérimentales, c'est la variété 2009TZEE W-STR, qui a été le moins sujette à l'attaque du ravageur suivi des variétés MATAFO I et 97 TZEE-W-C2.

Mots clés :, *Zea mays*, *Spodoptera frugiperda*, Tolérance variétale, Gestion intégrée des ravageurs

INTRODUCTION

The Lake Province is a region with high agricultural potential, where crop pest-related issues remain a major concern in the current context of agricultural production. It is therefore urgent to propose effective management strategies for maize pests. The recent invasion of the fall armyworm (*Spodoptera frugiperda*, JE) in Chad has caused significant damage to maize crops across various provinces, particularly in the Lake Province. Results from a survey conducted in May 2023 by ITRAD as part of a pest inventory in the Lake region revealed that 53.3% of the farmers interviewed reported having observed fall armyworm in their fields five years ago; 17.8% observed it four years ago, while 15.6% reported its presence seven years ago. Yield losses due to FAW infestation, are estimated at 80% by 31.8% of farmers, while 22.7% reported yield reductions of 50% (Mbaidiro and Adam, 2023). As one of the country's key maize-producing zones, this invasive pest has not spared the Lake Chad Province. Maize production in the province dropped from 106,097 tons in 2016 to 72,585 tons in 2022, representing a 31.58% reduction (DSA, 2022). To combat this pest, most farmers in the Lake region resort to synthetic pesticides, which pose risks to both human health and the environment. Findings from the May 2023 survey showed that 48.9% of farmers relied exclusively on chemical products to treat their crops, 11.1% used natural alternatives, while 40% applied no treatment at all (Mbaidiro and Adam, 2023). It is therefore imperative to develop alternative methods to chemical control in order to enhance maize productivity and contribute to household food security. Among these alternatives, varietal resistance represents an effective and sustainable strategy for managing FAW. Studies aimed at identifying maize genotypes that are potentially tolerant to fall armyworm damage were first conducted in Mexico, the United States and Brazil, where the selected materials demonstrated partial tolerance to fall armyworm infestation and other pests (Prasanna et al., 2018). In Chad, a study by Mbaidiro et al. (2021) conducted in the Sudanian zone evaluated the susceptibility of three maize varieties, among which the variety 2009TZEEW-STR. This study demontrated partial tolerance to fall armyworm infestation. The adoption of tolerant cultivars is an effective method of pest control, which may exert detrimental effects on insect biology (antibiosis) or lead insects to prefer one plant over another for feeding (non-preference), due to its biochemical and physical characteristics (Lara, 1993). In integrated pest management, the use of tolerant plants is considered as one of the key pillars of an effective strategy against fall armyworm (Prasanna et al., 2018). The lack of knowledge regarding the performance of maize varieties cultivated by farmers in the Lake Chad province has contributed to severe infestations of this pest on maize crops. In this context, a screening trial of the maize varieties grown in the Lake region was conducted to assess their susceptibility and level of tolerance to fall armyworm.

Materials and Methods

Materials

Study Site

The study was conducted at the Matafo support station of the Chadian Institute of Agricultural Research for Development (ITRAD), located in the Lake Province (Figure 1). The Matafo station is situated 7 kilometers from the town of Bol, on the shores of Lake Chad, approximately 153 km north of the capital, N'Djamena, in the Sahelian zone of Chad, at coordinates Latitude: 13°31'28"N and Longitude: 14°40'57"E. The province lies within the Sahelian region, which receives annual rainfall ranging from 200 to 600 mm. The area experiences an arid climate, with an average annual temperature of 28°C and mean annual precipitation of approximately 234 mm. This thermal regime and rainfall distribution result in three distinct seasons: a cool dry season (from November to February), a hot dry season (from March to mid-June), and a rainy season (from mid-June to early November) (Djako et al., 2024).

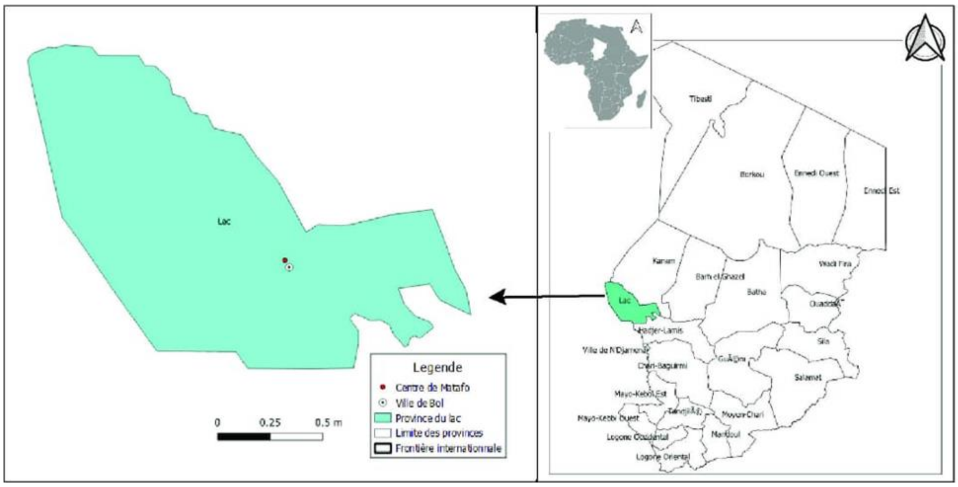


Figure 1. Location of the study site

Insect Material

Spodoptera frugiperda was the only one insect pest targeted in the field study.

Plant Material

The plant material consisted of five varieties of maize (*Zea mays* L.) representing different production cycles: extra-early, early, and intermediate. The seeds of each maize variety were obtained from the Chadian Institute for Agronomic Research for Development (ITRAD) and the SODELAC.

Methods

Experimental Design

A randomized complete block design (RCBD) was implemented, consisting of five treatments and three replications:

- T1: early-maturing variety Matafo I
- T2: extra-early variety Matafo II
- T3: intermediate-maturing variety CMS8501C1
- T4: extra-early variety 97TZEE-W2-C1
- T5: extra-early variety 2009TZEEW-STR

Replications are separated by a distance of 1 meter. Each elementary plot is 5 meters long and 4 meters wide. Each block has five 20 m² plots, separated by 0.6 meters. Each plot consisted of seven planting rows.

Trial Establishment

The experimental plots were manually tilled. Sowing was carried out on July 21, 2023, following a 20 mm irrigation of the plots. Three seeds were sown per hill at a depth of approximately 5 cm, with spacing of 60 cm between rows and 40 cm between hills. A first weeding was performed 14 days after emergence, followed by a second weeding 21 days later. No fertilizers were applied, and no phytosanitary treatments were administered during the trial.

Data Collection

Assessment of *S. frugiperda* Population Density and Infestation Rate on the Tested Varieties

The population density of the Fall Armyworm (*Spodoptera frugiperda*) is assessed through direct larval counts on 30 maize plants randomly selected from the three central rows of each elementary plot, amounting to a total of 90 plants per variety. Observations were conducted weekly, starting on the 14th day after sowing (DAS) and continuing until 49 DAS. On each sampling date and for each elementary plot, the infestation rate was calculated as the ratio of infested plants (i.e., those hosting the pest) to the total number of sampled plants (i.e., 25), multiplied by 100.

Estimation of leaf and ear damage

The extent of foliar damage is assessed on 30 randomly selected plants from the three central rows of each plot, totaling 90 plants per variety. Damage evaluation is conducted using a 0-to-4 scale (Figueiredo et al., 2006; Dal Pogetto et al., 2012; Grijalba et al., 2018; Fotso Kuate et al., 2019; dos Santos et al., 2020; Toepfer et al., 2021), which is a modified version of the 0-to-9 scale developed by Davis et al. (1992) (Figure 1). Sampling is performed on the three central rows, with 30 plants randomly selected within each elementary plot. Each leaf is individually inspected for damage. Damage scores assigned to individual leaves are summed and then divided by the total number of leaves assessed to obtain a mean foliar damage index per plant. This scale is commonly used in research settings, including efficacy trials of plant protection treatments (Toepfer et al., 2021).

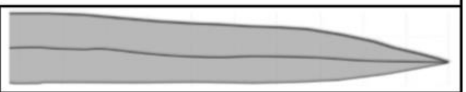
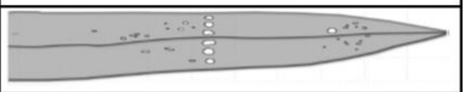
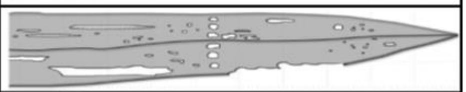
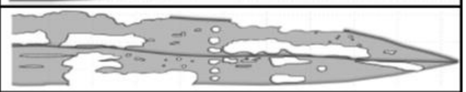
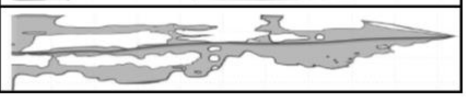
Score	Damage symptoms	
0	No damage	
1	Little damage (pinholes, and/or small holes, small leaf edge parts eaten, shot holes)	
2	Medium damage (some larger holes and/or larger leaf edge areas eaten)	
3	Heavy damage (many larger holes and/or larger leaf edge areas eaten)	
4	Total damage (destroyed, non-functional leaves)	

Figure 1. Index ranging from 0 to 4 for leaf damage caused by the fall armyworm. Source: Toepfer et al., 2021.

The damage to the ears of corn was assessed through a participatory approach involving local farmers. A sample of 30 ears was randomly selected from the three central rows of each elementary plot, totaling 90 ears per variety (Photos 1 & 2). The severity of pest-induced damage on each ear was evaluated using a 1 to 9 rating scale (Figure 2) proposed by CIMMYT (2020; unpublished protocol), where:

1 = No visible damage on the ear;
2 = Minor damage affecting a few kernels (<5) or less than 5% of the ear;
3 = Damage to 6 to 15 kernels or less than 10% of the ear;
4 = Damage to 16 to 30 kernels or less than 15% of the ear;
5 = Damage to 31 to 50 kernels or less than 25% of the ear;
6 = Damage to 51 to 75 kernels or more than 35% but less than 50% of the ear;
7 = Damage to 76 to 100 kernels or more than 50% but less than 60% of the ear;
8 = Damage to more than 100 kernels or more than 60% but less than 100% of the ear;
9 = Nearly complete damage (approximately 100%) of the ear.

Photos 1 & 2. Participatory assessment of *Spodoptera frugiperda* damage on maize ears.

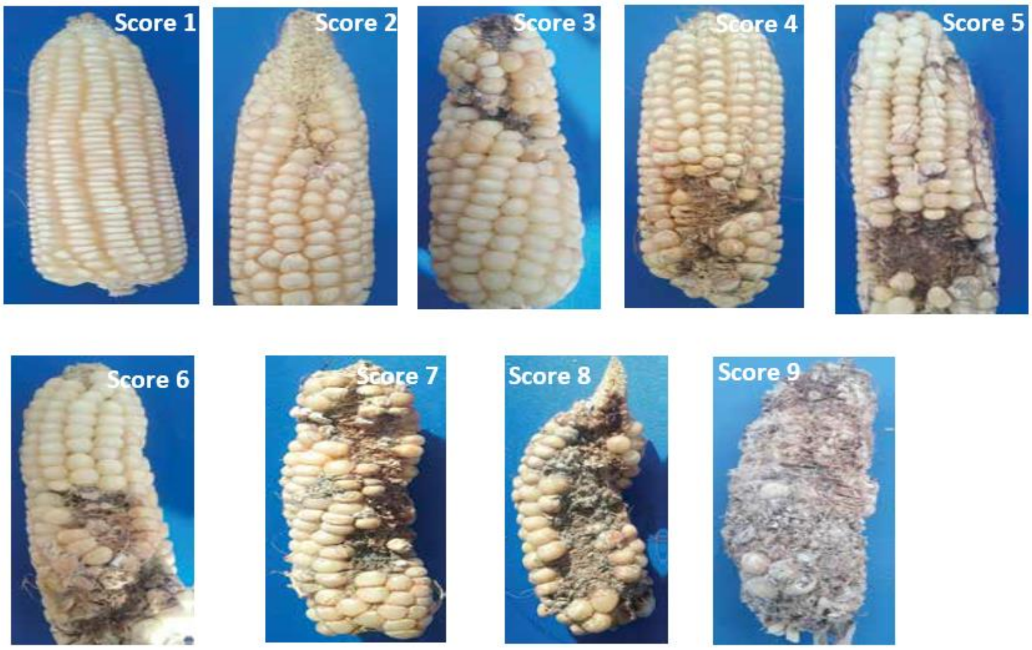


Figure 2. Scale of ear damage in maize caused by *S. frugiperda*
Source: Adapted from CIMMYT, 2020.

Grain yield evaluation of the tested maize varieties

At maturity, all maize plants from each elementary plot were harvested. The ears were detached, dehusked, air-dried, and manually shelled. The grains were then further dried to a residual moisture content of 12% and subsequently weighed using a Steinberg electronic scale (capacity: 300 kg; precision: 50 g) to determine the grain yield per elementary plot (20 m²). This yield was then extrapolated to a per-hectare basis for clarity.

Data analysis

All data were first subjected to the Shapiro–Wilk normality test (Shapiro and Wilk, 1965) before analysis of variance (ANOVA) was performed. In cases where the data did not follow a normal distribution, appropriate transformations were applied: log(X+1) for larval densities and infestation rates, and arcsine√(X/100) for percentage and damage score data. When ANOVA indicated significant differences among treatments, means were separated using the Student–Newman–Keuls (SNK) multiple comparison test at the 5% significance level. All statistical analyses were conducted using XLSTAT software, Version 2016.02.27444.

Results

Assessment of *S. frugiperda* population density and infestation rate on the tested varieties

The mean larval density of *Spodoptera frugiperda* ranges from 1.11 ± 0.43 to 2.22 ± 0.89 larvae per 90 plants across the different maize varieties (Table 2). Analysis of variance revealed no significant effect of variety on the number of *S. frugiperda* larvae (df = 4; F = 0.627; P < 0.645). The mean infestation rate ranges from 4.67 ± 1.30% to 10.89 ± 1.36%. Analysis of variance indicated a significant effect of variety on the infestation rate (df = 4; F = 3.30; P < 0.0001). The highest mean infestation rate was recorded for the variety MATAFO II (10.89 ± 1.36%), whereas the varieties 2009TZEEW-STR, 97TZEE-W-C2, CMS8507C1, and MATAFO I showed the lowest and statistically similar infestation rates.

Table 2. Mean density of *Spodoptera frugiperda* larvae and infestation rate of maize plants.

Treatment	Mean number of larvae /90 plants	Infestation rate/90 plants
MATAFO II	2.22 ± 0.36 a	27.44 ± 2.94 a
MATAFO I	1.83 ± 0.28 a	17.11 ± 1.88 b
97TZEE-W-C2	2.22 ± 0.31 a	8.22 ± 0.78 c
CMS8507C1	1.50 ± 0.45 a	6.89 ± 0.99 c
2009TZEEW-STR	1.11 ± 0.29 a	4.67 ± 1.30 c
df	4	4
F-value	0.63	32.43
Pr > F	0.645	0.0001

In a column, means followed by the same letter are not significantly different according to the Student-Newman-Keuls Test at 5% threshold.

Assessment of foliar and ear Damage

The mean damage scores caused by *Spodoptera frugiperda* on maize leaves and ears range from 0.33 ± 0.09 to 2.22 ± 0.35, and from 0.77 ± 0.16 to 2.53 ± 0.20, respectively (Table 4). Analysis of variance revealed a significant effect of variety on foliar damage (df = 4; F = 13.38; P < 0.0001). The variety 2009TZEEW-STR recorded the lowest foliar damage index, followed by the varieties 97TZEE-W-C2, CMS8507C1, and MATAFO I, which also exhibited low and statistically similar levels of foliar damage. The highest foliar damage index was recorded on the variety MATAFO II. Similarly, analysis of variance indicated a significant effect of variety on ear damage (df = 4; F = 10.05; P < 0.0001). The variety 2009TZEEW-STR exhibited the lowest ear damage score, followed by MATAFO I and 97TZEE-W-C2. In contrast, the highest ear damage index was observed on CMS8507C1 and MATAFO II varieties.

Table 3. Indices of leaf and ear damage caused by *Spodoptera frugiperda*.

Treatment	Leaf damage index	Ear damage index
CMS8507C1	1.22 ± 0.15 b	2.53 ± 0.29 a
MATAFO II	2.22 ± 0.19 a	2.03 ± 0.26 a
97TZEE-W-C2	1.11 ± 0.90 b	1.43 ± 0.14 b
MATAFO I	1.28 ± 0.23 b	1.23 ± 0.09 bc
2009TZEEW-STR	0.33 ± 0.11 c	0.77 ± 0.79 c
df	4	4
F-value	13.38	10.05
Pr > F	0.0001	0.0001

In a column, means followed by the same letter are not significantly different according to the Student-Newman-Keuls Test at 5% threshold.

Evaluation of yield performance of the tested maize varieties

The average ear weight per plot ranges from 4.33 ± 0.57 to 6.97 ± 1.39 kg (Table 4). Analysis of variance revealed no significant effect of maize variety on ear weight (df = 4; F = 1.41; P < 0.299). The estimated mean grain yield per hectare, based on ear weight per plot, ranges from 1,583.33 ± 261.94 to 3,550 ± 132.29 kg/ha. The analysis of variance showed a significant effect of maize variety on grain yield (P < 0,009). The variety 2009TZEE W-STR recorded the highest grain yield, followed by MATAFO I, 97TZEE-W-C2, and CMS8507C1, which also produced high and statistically similar yields. The lowest grain yield was recorded for the variety MATAFO II.

Table 4. Ear weight and grain yield of maize

Varieties	Ear weight per plot (kg)	Grain yield (kg/ha)
2009TZEE W-STR	6.87 ± 0.72 a	3550 ± 132.29 a
MATAFO I	6.97 ± 1.39 a	3116.67 ± 268.23 ab
97 TZEE-W--C2	5.63 ± 1.12 a	2233.33 ± 541.86 abc
CMS 85 07C1	4.87 ± 0.94 a	1816.67 ± 358.62 bc
MATAFO II	4.33 ± 0.57 a	158.33 ± 261.94 c
Ddl	4	4
F	1.41	6.15
Pr > F	0.299	0.009

In a column, means followed by the same letter are not significantly different according to the Student-Newman-Keuls Test at 5% threshold.

DISCUSSION

The imperative of sustainably protecting maize cultivation from the damage caused by the fall armyworm and mitigating the resulting yield losses remains a priority. This entails the use of integrated, multi-method strategies, among which the deployment of maize varieties with native tolerance continues to be a key research priority in Africa (FAO, 2019). The objective of the present study was to evaluate the susceptibility of selected maize varieties cultivated in the Lake Province and to identify genetic material tolerant to the fall armyworm (FAW) for use in future resistance breeding programs. None of the tested varieties proved to be completely tolerant to FAW larval infestation; however, certain differences in feeding preference were observed during the experiment. In our experimental context, preference occurs when an insect, given a choice, consistently feeds more heavily on one of the alternative plant varieties. The process by which an insect selects and accepts a host plant involves several behavioral stages and results from the integration of parameters related to the insect's internal physiological state (Knolhoff and Heckel, 2014; Schoonhoven et al., 2005). Our results indicate that the variety 2009TZEE-W STR sustained the least damage from the pest, followed by MATAFO I and 97 TZEE-W-C2**.** Despite being attacked by the fall armyworm, these varieties exhibited a degree of tolerance, as evidenced by lower larval infestation rates, reduced leaf and ear damage indices, and comparatively higher yields than the other two varieties. The low larval infestation rates and foliar damage indices observed on the variety 2009TZEE-W STR**,** followed by MATAFO I**,** CMS8507C1, and 97 TZEE-W-C2 varieties**,** suggest a reduced feeding preference of the fall armyworm for these cultivars. This may be attributed to the physical characteristics of plant organs or tissues, as well as the presence of toxic secondary metabolites in these varieties, which can influence host plant selection behavior. As described by several authors, such traits are part of the plant's direct defense mechanisms and may induce avoidance behavior in insects (Gatehouse, 2002; Schoonhoven et al., 2006). Indeed, in maize, several traits confer resistance to damage caused by the fall armyworm. Physical characteristics such as the structure of cuticular compounds, leaf roughness, and/or leaf thickness may have contributed to the reduced feeding preference observed on the variety 2009TZEE-W STR, followed by MATAFO I**,** CMS8507C1, and 97 TZEE-W-C2**.** The tolerance of 2009TZEE-W STR to *Spodoptera frugiperda* attack has been demonstrated in the Sudanian zone of Chad (Mbaidiro et al., 2021). Similar findings regarding maize resistance to fall armyworm infestation have been reported and described by Lara et al. (1993) and Marcos et al. (2023). The higher foliar damage index and larval infestation rate observed in the variety MATAFO II, compared to the four other cultivars, suggest that differences in leaf composition may be involved. This could be a lower content of hemicellulose and cellulose in the whorls of maize plants from this variety, which is more susceptible to the fall armyworm, than in the plants of the other varieties, as reported by Hedin et al. (1996). This study supports the findings of Bergvinson et al. (1995), who demonstrated the role of leaf composition in maize resistance to the European corn borer, *Ostrinia nubilalis* Hübner (Crambidae). Furthermore, several factors beyond feeding preference such as protein content, may influence insect feeding behavior on a given plant (Knolhoff and Heckel, 2014). The variety 2009TZEE-W STR recorded the lowest ear damage index, followed by MATAFO I and 97 TZEE-W-C2. In contrast, ear damage was more pronounced in MATAFO II and CMS8507C1, suggesting more intense feeding by *Spodoptera frugiperda* on the ears of these varieties. These findings are consistent with those of Bangale (2019), who reported that, in addition to the direct damage caused by fall armyworm larvae to maize, the pest can severely compromise the ears and induce indirect damage that affects grain quality. In a pattern similar to that observed for infestation rates and foliar damage indices, grain yield was higher in 2009TZEE-W STR**,** MATAFO I, and 97 TZEE-W-C2. However, infestation level alone is a poor predictor of yield loss. The high yields recorded in these three cultivars may be attributed to natural mortality of *S. frugiperda* larvae, likely induced by natural enemies and other environmental factors such as rainfall (Varella et al., 2015). The lower yields observed in the varieties MATAFO II and CMS8507C1 suggest significant feeding by fall armyworm larvae on maize ears, potentially resulting in grain damage due to aflatoxin contamination. This yield reduction may also be attributed to extensive foliar damage, which leads to a direct loss of photosynthetic capacity and disrupts the normal functioning of the remaining leaf tissue (Nabity et al., 2009). Foliar feeding by *Spodoptera frugiperda* reduces the leaf surface area, thereby adversely affecting photosynthesis and assimilate partitioning both of which are critical for proper grain filling. Furthermore, the tunneling of maize stems by fall armyworm larvae disrupts the uptake of water and nutrients, which may negatively impact grain yield (Kamweru et al., 2022).

Conclusion

Taken as a whole, these results suggest that the maize cultivars evaluated do not exhibit complete tolerance to feeding by fall armyworm larvae. However, there are notable differences in acceptance and preference among certain maize cultivars. The variety 2009TZEE-W STR proved to be the least susceptible to *S. frugiperda* attack, followed by the varieties MATAFO I and 97 TZEE-W-C2**.** This study contributes to the identification of cultivars exhibiting tolerance to fall armyworm infestation, which could be employed alongside other management options in Chad. Consequently, further research is warranted to explore how additional control strategies, such as biological control and habitat management, might be integrated with maize cultivars demonstrating tolerance to the fall armyworm.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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