EVALUATION OF NEWLY DEVELOPED FALL ARMYWORM [*SPODOPTERA FRUGIPERDA* (J. E. SMITH)] TOLERANT MAIZE FOR THE SOUTHERN ECOLOGY OF NIGERIA

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ABSTRACT

Two newly developed fall armyworm (FAW) tolerant maize (white and yellow) were evaluated with the parents and two newly released FAW tolerant maize, under artificially-infested conditions to test their yield performance. The evaluation was conducted at the Institute of Agricultural Research and Training, Ibadan, Nigeria, in the early and late seasons of 2024. The experiment was laid out in a randomized complete block design in three replications. Data were collected on FAW severity on a rating scale of 1-9, and agronomic and yield parameters. Descriptive statistics and analysis of variance (ANOVA) were conducted using SAS. Average FAW severity and plant aspect rating were good (between 3 and 4) under artificially-infested conditions. Mean grain yield was better under non-infested conditions (3.88 t/ha) than under infested conditions (2.76 t/ha). Mean squares of environment were significant for most of the traits, while mean squares of variety were significant for ears per plant, cob length, and grain yield under infested conditions. The newly developed FAW-tolerant maize compared favourably with the released FAW-tolerant checks in terms of yield. Despite the reduction in plant height of the newly-developed FAW-tolerant white maize between week 3 and 6, and the increased FAW severity rating at 6 WAP, the genotype still performed comparably with the white check and yielded higher than the yellow check. The newly developed FAW-tolerant yellow maize (FAW-Y MS4) also yielded higher (3.01 t/ha) than the yellow check (1.15 t/ha) under infested conditions. The two newly developed FAW-tolerant maize are therefore good candidates for further testing in multi-location trials.

Keywords: ***Artificial infestation, Crop improvement, Fall armyworm, Grain yield, Maize (Zea mays L.)***

INTRODUCTION

Maize (*Zea mays* L.) is a staple cereal crop grown across diverse agro-ecological zones in Nigeria ranging from the humid rainforest in the south to the savanna ecologies in the north. it serves as a primary source of food, feed, and income for millions of smallholder farmers (Hazell, 2020; Chiaka, 2022; Onumah *et al.,* 2023). About 80% of maize production in Nigeria is consumed by man and animals, while 20% is utilized in a variety of industrial processes such as production of starch, oil, high fructose, corn sweetener and ethanol (Oluwaranti *et al.,* 2022). Maize is therefore of major economic importance in Nigeria.

Average maize yield in Nigeria has consistently fallen far below its yield potential, with national averages around 1.8–2.5 t/ha compared to an attainable yield of over 6 t/ha under optimal management and with the use of improved varieties (FAO, 2021; Prasanna *et al.,* 2022). This yield gap is attributed to a combination of biotic and abiotic constraints, among which insect pests represent a major limiting factor. One of the most serious insect pests of maize in Nigeria is the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith).

Since its invasion in 2016, FAW has been consistently reported as a major constraint to maize productivity in Nigeria and across sub-Saharan Africa, causing characteristic damage symptoms such as window-pane feeding, leaf whorl destruction, leaf defoliation and ear damage, which often result in severe yield losses (Day *et al.*, 2017; Ojumoola *et al*., 2022).

Fall armyworm infestations are visible shortly after crop establishment, sometimes as early as two weeks after sowing (FAO/CABI, 2018), and many farmers resort to various management practices such as the use of synthetic insecticides, cultural control and the use of plant botanicals (Ojumoola *et al.,* 2022; Otim *et al.*, 2024; Niassy *et al.,* 2024). Nigerian smallholder farmers largely rely on the use of chemical control, which more often than not is used inappropriately, either by the method of application, dose of application, or sometimes, the use of banned chemical products, which are harmful to humans and the environment. Therefore, effective management of FAW remains a challenge, with many farmers constrained by limited access to technical information and sustainable and appropriate control strategies (Fadairo, 2021). These challenges underscore the need for pest management approaches that strategically integrate multiple control methods within an integrated pest management (IPM) framework, in which host plant resistance is recognized as a pivotal component (Dara, 2019; Prasanna *et al.,* 2022).

Breeding efforts aimed at improving host plant resistance have led to the identification of some maize genotypes with reduced FAW damage under controlled and field conditions (Oloyede-Kamiyo and Odeyemi, 2021). In addition, efforts of national and international research institutions have led to the release of FAW-tolerant maize varieties with promising agronomic performance across multiple agro-ecologies. Nevertheless, it is important to strengthen and expand the genetic pool for fall armyworm resistance by developing more FAW resistance/tolerant maize with wider adaptation and higher yields. Continuous varietal evaluation is essential to identify, validate, and conserve diverse sources of FAW resistance under field conditions. This process would build a robust pool of genetically characterized materials expressing stable resistance for a long-term improvement programme.

The objective of this study was to evaluate two newly developed FAW-tolerant maize varieties for yield performance.

MATERIALS AND METHODS

The six top-performing maize varieties (at 25% selection intensity) from the previous FAW screening trial (Oloyede-Kamiyo and Odeyemi, 2021) were used to develop FAW-tolerant maize. The six varieties consisted of three white-kernel and three yellow-kernel maize varieties. The white and the yellow maize varieties were crossed separately in a diallel version to generate two base populations – the white population (TZBR ELD 4-W C2 x BR9943DMRSR x AMATZBR-W C4) and the yellow population (BRLNTP-Y x SUWAN 1-SR x TZBR ELD 4-Y C2). The two base populations were subjected to four cycles of mass selection under artificial and natural FAW infestations. In each cycle, individual plants with FAW severity rating above 4 on a scale of 1-9 (1 for excellent, 9 for poor) were eliminated before flowering. The remaining plants were crossed using bulk pollination. After each harvest, the best cobs were selected, shelled, and bulked before moving to the next round. At the end of the 4th cycle, the best cobs were selected in the white and the yellow populations separately, and a known quantity of seeds was shelled from each cob and mixed thoroughly to represent the newly developed population.

The newly developed FAW-tolerant white and yellow maize populations were evaluated along with the six parents and two newly released FAW-tolerant maize varieties (as checks). The parent, TZBR ELD 4-Y C2, was, however, lost during evaluation due to poor germination and was replaced with BR9928DMRSR. The 10 maize varieties were evaluated in the early and late seasons of 2024 in the maize breeding nursery of the Institute of Agricultural Research and Training, Ibadan, Nigeria, under FAW-infested and non-infested conditions. The list of the varieties with their attributes is presented in Table 1. The trial was laid out in a randomized complete block design in three replications. Each plot size was a 4-row plot of 3 m long. Plant spacing was 75 cm between rows and 25 cm within rows. Two seeds were planted per hole and later thinned to one, three weeks after planting (WAP), to have a plant population of 53,333 plants/ha.

Each plant in the infested plots was artificially infested with five 3rd instar larvae of FAW at two weeks after planting, while non-infested plots were protected by spraying with Emamectin Benzoate 5% (caterpillarforce) insecticide at a rate of 15 g per 16 litres knapsack sprayer. Weeds were controlled using Glufosinate ammonium 200g/L SL (Dragon super) at the rate of 150ml per 16 litres knapsack sprayer. Fertilizer application was carried out using NPK and urea at 14 days after planting and before tasseling, respectively.

Data collection

Fall armyworm severity was rated per plot at 3, 4, 5 and 6 WAP on a scale of 1-9 according to the leaf damage rating (LDR) modification of Soujanya *et al.* (2022), where 1 stands for plants with no defoliation or leaf damage by FAW, and 9 for highly susceptible with severe defoliation and leaf damage. Days to 50% pollen shed and silking are the number of days from sowing to when half of the plants in a plot shed pollen and develop silks, respectively. Plant height at 3, 4, 5, and 6 WAP was measured in centimeters from the soil surface to the highest point of the main stem, using a long ruler. Plant height at maturity was measured from the soil surface to the base of the tassel. Plant aspect was rated after flowering according to Oloyede-Kamiyo *et al*. (2012) on a scale of 1-9, 1 for very appealing plants without diseases and carrying cobs at the middle of the plants, and 9 for very poor appealing plants. Ears per plant were calculated by dividing the number of cobs harvested by the number of plants at harvest, per plot. Ear aspect was rated on a scale of 1-5, where 1 stands for very clean cobs without damage by FAW, and 5 for highly damaged cobs. Grain yield was calculated from field weight per plot adjusted to 14% moisture content and 80% shelling percentage and expressed in tons/ha. Cob length and diameter were measured on an average of 5 cobs per plot using a ruler.

Table 1. List of the varieties evaluated with their attributes

Name	Kernel colour	Attributes
AMATZBR-W C4	White	Stem borer resistant, Old variety.

Name	Kernel colour	Attributes
TZBR ELD 4-W C2	White	Stem borer resistant, Old variety.
BR9943DMRSR	White	Stem borer, downy mildew, and streak resistant, Old variety.
FAW-Y MS4	Yellow	Fall armyworm-tolerant. Newly-developed
FAW-W MS4	White	Fall armyworm-tolerant. Newly-developed
BRLNTP- Y C6	Yellow	Stem borer resistant and low soil nitrogen tolerant
ARTMAZ 01 (Check 1)	White	Fall armyworm resistant. Newly released
ARTMAZ 02 (check 2)	Yellow	Fall armyworm resistant. Newly released
SUWAN 1-SR	Yellow	Streak resistant. Old variety
BR9928DMRSR	Yellow	Stem borer, downy mildew, and streak resistant

RESULTS

Mean, Range, and Coefficient of variation for the traits measured

Mean, range, and coefficient of variation (CV) were presented in Table 2. The mean days to 50% pollen shed and silking were 55 and 58 days, respectively. The varieties are of moderate height (134.6 cm). FAW severity and plant aspect rating were good, with a rating of 3-4 (on a rating scale of 1-9). Ear aspect rating was moderate with a mean rating of 2.8 (on a scale of 1-5). Mean grain yield was better under protected conditions (3.88 t/ha) than under infested conditions (2.76 t/ha). Mean cob length and diameter were 12.51 cm and 2.98 cm, respectively. Range was high, and the coefficient of variation was moderate for almost all the traits.

Table 2. Mean ± S.E., range, and CV for the 10 maize varieties evaluated under FAW-infested conditions in Ibadan in the early and late seasons of 2024

Trait	Mean ± S.E.	CV(%)	Range
Days to 50% pollen shed	55.04±0.41	3.81	50.00- 64.00
Days to 50% silking	57.93±0.42	3.40	53.00- 67.00
Plant height (cm)	134.60±2.34	10.54	98.00- 177.00
Plant aspect (1-9)	3.36±0.12	19.42	2.00- 7.00
FAW severity @3 WAP (1-9)	3.75±0.11	23.76	2.00- 6.00
FAW severity @6WAP (1- 9)	4.00±0.13	24.06	3.00-6.00
Ears per plant	0.74±0.04	31.01	0.17- 2.00
Ear aspect (1-5)	2.78±0.08	20.31	2.00- 4.00
Cob length (cm)	12.51±0.23	12.21	7.30- 16.30
Cob diameter (cm)	2.98±0.08	11.25	1.50- 4.20
Grain yield t/ha (infested)	2.76±0.20	43.33	0.55- 7.30
Grain yield t/ha (non-infested)	3.88±0.24	24.21	0.83- 7.10

S.E: Standard error; CV: Coefficient of variation; cm: centimeter; 1- 5: 1 for excellent, 5 for poor; 1- 9: 1 for excellent, 9 for poor; t/ha: tonnes/hectare; WAP: weeks after planting

Mean squares from analysis of variance for the traits measured

Mean squares from analysis of variance for the traits measured are presented in Table 3**.** Mean squares of season were highly significant for most of the traits except for plant height, FAW severity at 3WAP, cob length, and number of ears per plant. The varietal effect was significant for FAW severity at 6WAP, number of ears per plant, cob length, and grain yield, while the season-by-variety interaction effect was significant for days to 50% pollen shed, silking, and plant aspect. Coefficient of determination

(R^2) was moderate to high for all the traits except for FAW severity ratings.

Table 3. Mean squares from analysis of variance for the traits measured under infested conditions in the early and late seasons of 2024

Source of variance	df	Days to 50% pollen shed	Days to 50% silking	Plant height (cm)	Plant aspect (1-9)	FAW severity score (1- 9)		Ears per plant	Ear aspect (1-5)	Cob length (cm)	Cob diameter (cm)	Grain yield t/ha	
						3 WAP	6 WAP					Infested	Non-infested
Rep (Season)	4	13.83*	14.01**	886.00**	2.83**	1.40	0.82	0.15	0.40	2.89	2.48**	2.56	8.15**
Season, S	1	90.52**	165.5**	4.25	4.14**	2.24	8.21**	0.02	2.42**	3.23	4.23**	12.82**	88.16**
Variety, V	9	10.21	9.85	485.90	0.56	0.19	0.56*	0.16*	0.35	7.99**	0.15	3.37*	1.34*
S x V	9	12.98**	10.72*	226.30	0.78**	0.49	0.59	0.05	0.35	1.56	0.06	1.47	1.00
Error	36	4.40	3.87	201.20	0.43	0.80	0.93	0.05	0.32	2.33	0.11	1.43	0.88
R^2		0.71	0.76	0.61	0.67	0.33	0.43	0.60	0.47	0.54	0.83	0.60	0.83

d.f- degree of freedom; Rep.: Replications; R^2: Coefficient of determination; **: Significant at 1% level of probability; *: Significant at 5% level of probability; cm: centimeter; 1- 5: 1 for excellent, 5 for poor; 1- 9: 1 for excellent, 9 for poor; t/ha: tonnes/hectare; WAP: weeks after planting

Mean performance of the varieties evaluated under FAW-infested conditions

The performance of each of the maize varieties is presented in Table 4. The FAW severity ratings of the newly developed maize were not significantly different from those of the checks at 3WAP but were significant at 6WAP, with FAW-W MS4 having the highest score (4.7). The cob length of FAW-W MS4 (12.93 cm) was significantly longer than that of TZBR ELD 4-W C2 (10.3 cm), which is one of its parents. The cob length of FAW-Y MS4 (13.43 cm) and FAW-W MS4 (12.93 cm) was significantly longer than that of the yellow check (10.5 cm). The cob diameter ranged from 2.5 cm to 3.22 cm, which did not vary significantly among the varieties.

Grain yield was higher under non-infested conditions than in the infested condition for all the maize genotypes except ARTMAZ 01-W. Grain yield was highest for TZBR ELD 4-W C2 (5.08 t/ha), one of the parents of the newly developed white maize, followed by FAW-Y MS4 (4.52 t/ha) under non-infested conditions. Under infested conditions, ARTMAZ 01-W (white check) had the highest yield of 4.21t/ha followed by FAW-W MS4 (newly-developed white maize) with 3.58 t/ha and FAW-Y MS4 (newly-developed yellow maize) with 3.01 t/ha, although their yields were not statistically different. The yields of the two newly developed varieties were significantly higher than those of the yellow check (1.15 t/ha) and TZBR ELD 4-W C2 (1.9 t/ha), which is one of the parents of FAW-W MS4. FAW-Y MS4 also had a higher yield than those of its parents (BRLNTP-Y C6 with 2.58 t/ha and SUWAN 1-SR with 2.41 t/ha) (Table 4).

Trends in plant growth under FAW infestation are presented in Fig. 1. The rate of growth in plant height from week 3 to week 4 reduced under infestation (Fig. 1) when compared to the non-infested condition for AMATZBR-W C4, ARTMAZ 01-W, BR9943DMRSR, FAW-W MS4, and TZBR ELD 4-W C2 (Fig. 2). Between week 5 and week 6, there was reduction in plant height under infested condition (Fig. 1) for ARTMAZ 01-W, ARTMAZ 02-Y, BR9943DMRSR, BRLNTP-Y C6 and TZBR ELD 4-W C2 compared to non-infested condition.

Fall armyworm severity was highest at week 5, but reduced drastically at week 6 for most of the varieties except for FAW-W MS4 (Fig. 3). The reduction was highest in ARTMAZ 01-W, ARTMAZ 02-Y, BR9928DMSR, BR9943DMSR, and SUWAN 1-SR. Severity was highest in ARTMAZ 01-W at weeks 3 and 5.

Table 4. Mean values of the 10 maize varieties for FAW severity scores, grain yield, and yield-related traits under FAW infestation

Variety	FAW severity score @ (1- 9)		Ears per plant	Cob length (cm)	Cob diameter (cm)	Grain yield t/ha	
	3 WAP	6 WAP				infested	non-infested
AMATZBR-W C4	3.50a	4.00ab	0.64bc	12.35ab	2.87a	2.94abc	3.85ab
TZBR ELD 4-W C2	3.67a	4.00ab	0.56bc	10.30c	3.04a	1.90bc	5.08a
BR9943DMRSR	3.83a	4.00ab	0.82ab	12.48a	2.83a	3.14ab	3.71ab
FAW-Y MS4	3.83a	3.67ab	0.76abc	13.43a	3.15a	3.01ab	4.52ab
FAW-W MS4	3.67a	4.70a	0.85ab	12.93a	2.98a	3.58ab	4.31ab
BRLNTP-Y C6	3.50a	4.30ab	0.82ab	13.65a	2.97a	2.58abc	4.42ab
ARTMAZ 01-W	4.00a	4.00ab	1.05a	13.23a	3.22a	4.21a	3.37ab
ARTMAZ 02-Y	3.83a	3.80ab	0.42c	10.50bc	2.50a	1.15c	3.89ab
SUWAN 1-SR	4.00a	4.00ab	0.65bc	12.72a	3.03a	2.41abc	3.94ab
BR9928 DMRSR	3.67a	3.00b	0.77abc	13.00a	3.20a	2.29bc	2.48b

1- 9: 1 for excellent, 9 for poor; t/ha: tonnes/hectare; WAP: weeks after planting; Values with similar alphabets are not significantly different from one another

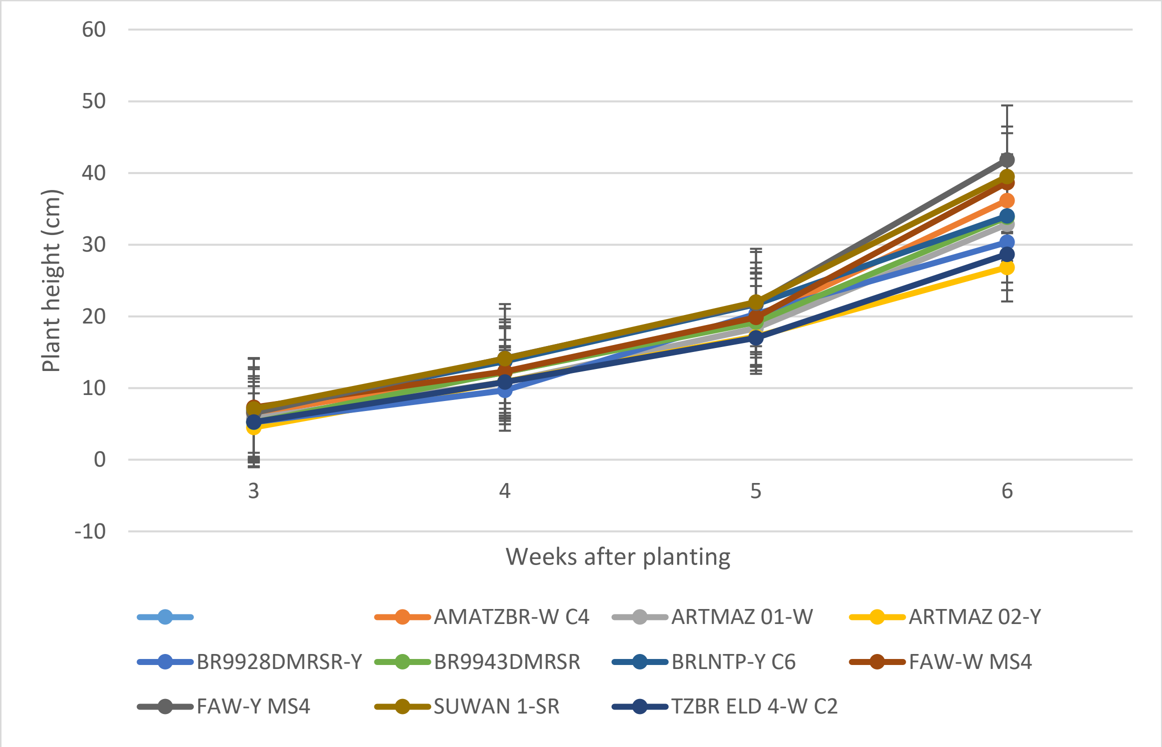

Fig.1. Trends in plant height under infested conditions

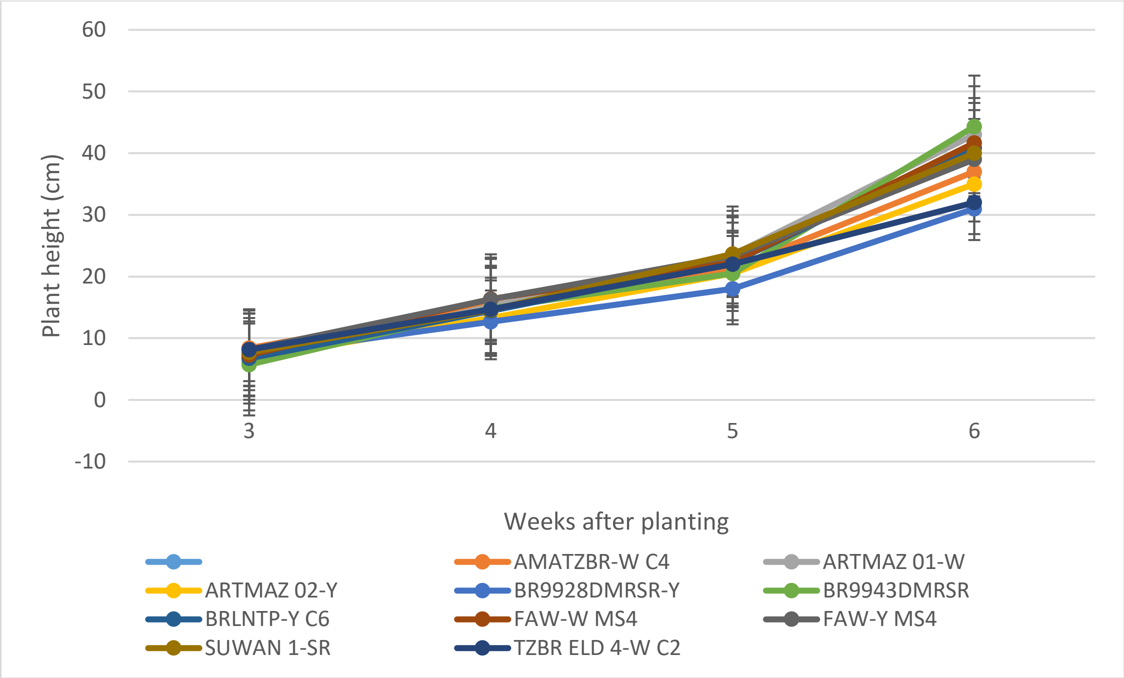

Fig. 2: Trends in plant height under non-infested conditions

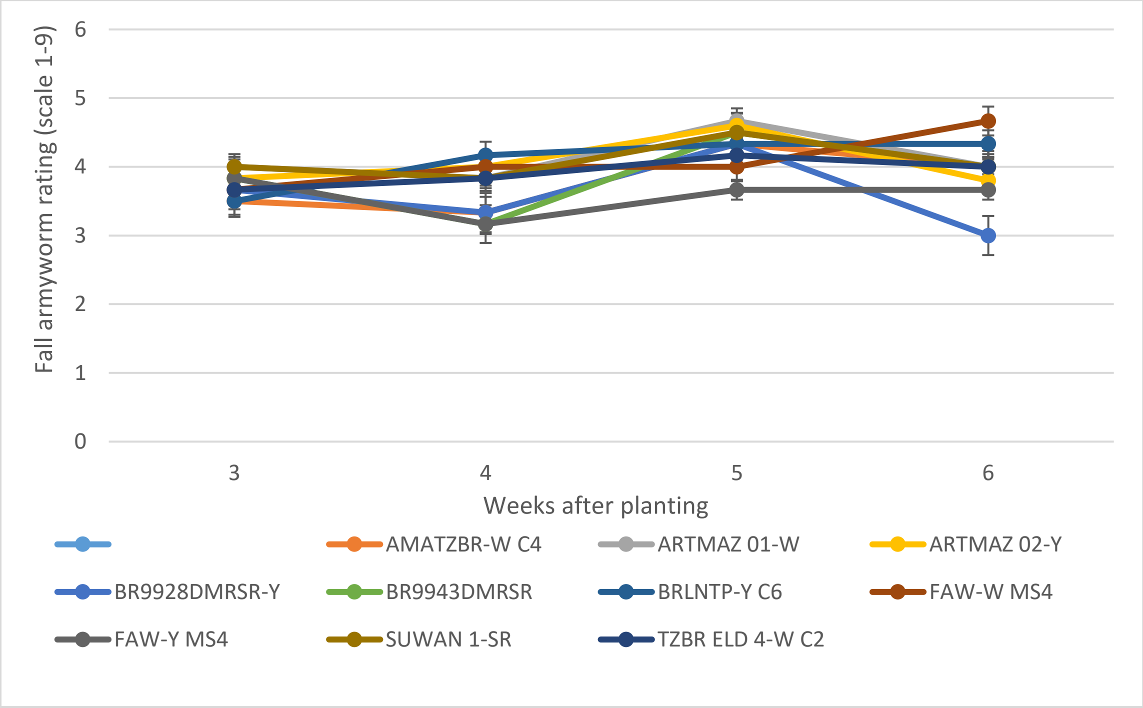

Fig. 3. Fall armyworm severity over time among the maize genotypes

DISCUSSION

This study provided field-based evidence on the performance of the newly developed FAW-tolerant maize under the southern ecology of Nigeria, where FAW pressure is typically high. The maize genotypes shed pollen and produced silks at an average of 55 and 58 days, respectively, with moderate plant height. This is an indication that the genotypes were intermediate-maturing varieties. Yield reduction of 31.17% between infested and non-infested conditions is within the range reported in previous studies (Tambo *et al.*, 2020; Job *et al.*, 2022). The wide range for the traits studied showed the varietal divergence, while the moderate coefficients of variation (CV) observed confirmed acceptable experimental precision for the measured traits.

The significant season effect for most of the traits reflected the environmental variability between the early and late planting seasons. Nevertheless, the absence of a season × variety interaction effect for key traits such as grain yield and FAW severity indicated that the varieties were generally stable across seasons. This is, however, in contrast to the findings of Ni *et al*. (2024) and Amegbor *et al.* (2025). The absence of varietal effects for early FAW incidence and severity (at 3WAP) was also reported by Kasoma *et al.* (2022), and they attributed this to the uniform feeding damage caused by 1st-3rd instar larvae used for the artificial infestation of the plants. This is, however, contrary to the findings of Amegbor *et al.* (2025). The significant varietal effect observed for grain yield under infested conditions was also reported by Amegbor *et al.,* 2025. This revealed distinctiveness and variation in the performance of the varieties. The moderate to high coefficient of determination (R^2) recorded for the traits indicated that the experimental model adequately explained a large proportion of the observed variation.

Yield was consistently lower under infested conditions than in the protected plots across all genotypes, confirming the substantial negative impact of FAW on maize productivity, even in moderately resistant germplasm. Similar observations have been reported in previous studies (Tambo *et al.*, 2020; Job *et al.,* 2022; Amegbor *et al.,* 2025). However, the magnitude of yield reduction varied among genotypes, highlighting their differential levels of tolerance. Under infested conditions, the two newly developed varieties outperformed the yellow check (ARTMAZ 02-Y). Their yield reduction (16.9% for FAW-W MS4 and 33.4% for FAW-Y MS4) was also significantly lower than that of the yellow check (70.4%). This indicated that the newly developed white (FAW-W MS4) variety is a better variety to be deployed to locations with high FAW pressure. The newly developed maize significantly outperformed many of the parents under infested conditions, demonstrating better-parent heterosis and also indicating effective accumulation of favorable alleles conferring resistance over the rounds of mass selection without jeopardizing performance under non-infested conditions. Importantly, under non-infested conditions, the newly developed genotypes also performed favorably, indicating that resistant traits did not incur a yield penalty in the absence of pest pressure. This is a critical consideration for farmer adoption and breeder utilization.

The newly developed FAW-white and yellow maize compared well with the released FAW-tolerant checks in flowering. Early flowering has been associated with partial escape from the peak of FAW infestation and reduced cumulative feeding damage, particularly under environments with prolonged pest pressure (Oluwaranti *et al.,* 2022; Durocher-Granger, 2024; Tabu *et al.,* 2024). Associations between early phenology and reduced FAW damage have been reported in maize germplasm evaluated across eastern and southern Africa (Prasanna *et al.,* 2022). This phenological advantage may have contributed to the moderate FAW severity ratings observed across the assessment periods.

There were reductions in plant height under infested conditions between week 3 and week 4, and between week 5 and week 6 for some varieties, compared to the protected plots. These reductions are also reflected in FAW-W MS4 and the two checks. FAW severity rating remained consistently moderate (≤4 on a 1–9 scale) at both 3 and 6 weeks after planting for most varieties, and a general decline in severity was observed for most varieties between week 5 and week 6, except in FAW-W MS4. The observed reduction in severity over time, particularly under artificial infestation, indicated that the newly developed maize possessed the capacity to withstand and recover from FAW feeding rather than completely suppressing larval establishment, a trait commonly associated with tolerance rather than complete antibiosis (Hruska, 2019; Prasanna *et al.,* 2022). Similar observations have been reported in previous studies (Odeyemi *et al.,* 2020; Lima *et al.*, 2022; Matova *et al.*, 2022; Oluwaranti *et al*., 2022; Kamweru *et al.,* 2023; and Abang *et al.,* 2024). Oluwaranti *et al.* (2022) reported higher severity at 28 DAP than at 56 DAP and attributed it to the toughness of the leaves at that stage, which made it difficult for the larvae to chew. FAO (2017) also reported that FAW damage is growth stage-specific and is dependent on the nutrition and water balance status of the plant.

The high yield of FAW-W MS4 despite the reduction in plant height and the high severity rating even at 6 WAP proved its high tolerance to FAW and presented it as a good candidate for use in FAW- prone areas.

CONCLUSION

The significant varietal effect for yield under artificial infestation and the mean yield performance of the newly developed varieties confirmed the accumulation of tolerant genes over time, with competitive yield performance. The absence of a season-by-variety interaction effect on yield under infested conditions indicated that the varieties are stable irrespective of the environment. These genotypes represent valuable genetic resources for maize improvement programmes and provide a practical pathway toward sustainable FAW management in southern Nigeria and similar agro-ecological zones. Particularly, the newly developed white maize (FAW-W MS4) performed very well under infested and protected conditions despite its high level of FAW severity, making it a valuable material for farmers' use in the zone. It holds strong potential for integration into FAW management strategies.

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