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Assessment of maize hybrids for agronomic and fall armyworm tolerant traits

Innocent ISEGHOHI[1] (✉), Emmanuel OGUNDARE[1], Segun FAYEMIRO[1], Oluwafemi OBISESAN[1], Antony JOB[2]

[1] Department of Crop Science and Horticulture, Federal University Oye-Ekiti, Ekiti State, Nigeria
[2] Flour Mills of Nigeria PLC, Apapa, Lagos State, Nigeria

✉ Corresponding author: innocent.iseghohi@fuoye.edu.ng

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ABSTRACT

Fall armyworm (FAW) *Spodoptera frugiperda*, an invasive pest, feeds on maize leaves and kernels. Several studies speculate that FAW leaf damage reduces grain yield (GY), but there is limited data to show the most critical period of FAW damage for maize yield. The assessment of maize hybrids for agronomic and FAW-resistant traits would provide useful information. The objectives of the study were to (i) assess the agronomic performance of maize hybrids for GY and FAW-resistant traits and (ii) determine the effects of FAW-leaf damage on GY of the maize hybrids. Fifteen candidate maize hybrids and two commercial checks were evaluated at the FAW hotspot for two years. Data were analyzed using descriptive statistics and ANOVA at $\alpha_{0.05}$. Trait association was determined using correlation and sequential path analysis. Leaf damage (LDM) scores were regressed on GY. The mean Days to anthesis (DA), plant height (PHT), LDM score 2, 4, 6 and 8 weeks after planting (WAP), chlorophyll content (CHLC) and GY was 61.83±1.1, 209.58±5.9 cm, 2.49±0.2, 2.72±0.2, 2.45±0.2, 1.88±0.2, 57.80±0.4 µg/cm^2 and 7.07±0.8 t/ha^2, respectively. DA and PHT had a significant positive correlation with GY, while LDM4WAP and LDM6WAP had a significant negative correlation with GY. LDM2WAP and LDM4WAP also had a significant negative correlation with CHLC. The regression model predicted a 0.63 and 1.70 t/ha^2 decrease in GY based on a unit rise of LDM scores at 6 and 8 WAP, respectively. Leaf damage peaked at 4-WAP but with direct GY reduction at 6-WAP. Six hybrids had outstanding GY and were identified.

Keywords: chlorophyll content, grain yield, leaf damage, *Spodoptera frugiperda*, *Zea mays*

INTRODUCTION

Maize is an important staple in the global agro-food system. It serves as food, feed and feedstock for fuel production and is processed into corn flour, breakfast cereals, gruels, bakery items, pharmaceuticals and corn syrups (Serna-Saldivar and Perez Carrillo, 2019). In 2022, global maize production was estimated to be over 1.16 billion tonnes on approximately 204 million hectares of land, making it the leading cereal in the world, ahead of wheat and rice (FAOSTAT, 2022). In Nigeria and sub-Saharan Africa (SSA), it is a major source of calories, protein, fibre and micronutrients (Prasanna et al., 2020). Maize is widely grown across diverse African agroecologies and soil types.

However, its production is hampered by various constraints, including poor-quality seeds, small farm holdings, applications of crude farming techniques, low soil nitrogen, drought stress, heat stress, pests and diseases (Job et al., 2022; Abang et al., 2024). One of the economic pests affecting maize production is the Fall Armyworm (FAW) *Spodoptera frugiperda* (Overton et al., 2021). It is an exotic Lepidoptera native to the tropical and subtropical regions of the Americas but has rapidly spread to Africa, Asia and beyond (Day et al., 2017). The FAW is a nocturnal insect and can migrate hundreds of kilometres in one night (Westbrook et al., 2016). The adults lay eggs in the whorls and leaves of maize and complete their lifecycles within 21 – 27 days (FAO and CABI, 2019). It was first reported in Africa in 2016 and has since become a serious invasive pest in the region (Goergen et al., 2016). It is a polyphagous pest feeding on arrays of cultivated and wild species of cereals, legumes and vegetables (Montezano et al. 2018). However, it is considered mainly a pest of maize and sorghum with a preference for maize for oviposition (Kenis et al., 2023). The larva feeds on all aerial parts of the maize plant, damaging the leaves and stalks at vegetative stages, silks, tassels, husks and ears at the reproductive stage. The leaf damage disrupts photosynthesis and reduces the plant aspect, while ear damage diminishes kernel quality, and paves the way for secondary infections and potential yield losses (Kushwaha, 2022).

Yield loss due to FAW could be 100% if resistant varieties and adequate control measures are not adopted (Overton et al., 2021; Kenis et al., 2023). Losses from FAW infestation could result in 8.3 – 20.6 tonnes per year in major maize-growing countries of Africa (Day et al., 2017), while Eschen et al. (2021) estimated the loss to amount to US$9.4 billion in Africa alone. Several control strategies have been used by farmers against FAW. These include picking and crushing FAW eggs and larvae, removing weeds and plant residues that serve as alternate hosts, early planting, applications of local substances, such as soil, ash, lime, salt, detergents, oil, extracts of local pepper, marigold flowers and neem to the whorl of the maize plant (FAO and CABI, 2019). Although varying levels of success have been reported with some of these approaches, they have been regarded to be labour-intensive and crude (Matova et al., 2020). Therefore, most farmers spray synthetic pesticides, such as cypermethrin, emamectin benzoate, etc. These are toxic to humans and animals, harmful to biodiversity and the environment and affect the socio-economic of rural farmers (FAO and CABI, 2019). The development of host-resistant varieties and the use of Integrated Pest Management (IPM) have been reported to be the safest and most effective control strategies for mitigating yield loss due to FAW (Womack et al., 2020; Matova et al., 2020; Job et al., 2022).

A characteristic of FAW leaf feeding is leaf damage. It is more severe at the young growing stage, usually the period of active photosynthesis (V3 – V5 stage) when tassel and cob initiation commences (Bell, 2017). At this stage, a new leaf emerges every three days, and the number of kernels/rows and yield potential are pre-determined (Ransom and Endres, 2020). Furthermore, chlorophyll degradation has been reported to be a major consequence of insect herbivory on host leaves (Ni et al., 2001). Nevertheless, there is a lack of information on the effects of FAW leaf damage on the agronomic performance and grain yield of maize genotypes. In addition, no study has reported the most critical vegetative stage in maize, which LDM predicts yield loss, as this informs timeliness in pest management. However, studies have shown that several maize varieties possess natural adaptive mechanisms to insect herbivory without compensating for yield. These include thickening of leaf cuticle, secretions of allelochemicals, production of defense proteins, toxic chemicals and silk maysin (Anjorin et al., 2022). Therefore, the assessment of maize hybrids for agronomic performance and tolerance to FAW leaf damage will provide useful information and a pointer to the most critical vegetative stage for pest control. The objectives of this study were to (I) assess the agronomic performance of maize hybrids improved for FAW tolerance, (II) identify the most critical vegetative stage with the highest yield reduction due to LDM and (III) determine the effects of FAW leaf damage on grain yield.

MATERIALS AND METHODS

Description of study location

Ikole-Ekiti is an agrarian town in the Ikole Local Government Area of Ekiti State, South West Nigeria. It is popular for its high production of maize, yam, cassava, rice and vegetables. The annual temperature ranged between 21 – 32 °C with an average of 27.42 °C, about 2.04% lower than Nigeria's average temperature (Weather and Climate, 2024). Ikole-Ekiti receives rainfall for about 9 months (March – November) annually. The average annual rainfall is 1393 mm, with September being the highest. The dry season usually lasts between December and February. The average annual relative humidity is 72.53%. The study site, the Teaching and Research Field of the Department of Crop Science and Horticulture, Federal University Oye-Ekiti, is situated at N 7°48' E 5°21', 556 m asl, and is endemic to Fall armyworm (Job et al., 2022).

Genetic materials

Fifteen maize hybrids improved for FAW tolerance and two proven commercial checks (Oba Super 9 and SC719) were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria. The SC719 is a popular commercial variety of the SeedCo Seed Company.

Experimental design and management

The study was conducted in the 2022 and 2023 rainy seasons (June – October). The experiments were laid out in Randomized Complete Block Design (RCBD) in three replicates. Each plot was a two-row of 4 m length. The intra- and inter-row spacing was 50 cm and 75 cm, respectively. Two seeds were planted per hole, and the supply of missing stands was done 1 week after planting (WAP). Fertilizer in the form of NPK 15:15:15 was applied two weeks after planting (2 WAP) at the rate of 400 kg/ha to supply 60 kg N/ha, 60 kg P_2O_5/ha, and 60 kg K_2O/ha. This was top-dressed with 60 kg N/ ha using urea (46:0:0) at 6 WAP. Weeds were managed with the application of 500 g/L of atrazine and 200 g/L of glufosinate ammonium as pre- and post-emergence herbicides, respectively which was complemented with hand weeding to keep plots free of weeds. Pesticides were not applied throughout the season to encourage a high population of FAW. The experiments were established in isolations in FAW hotspot environments over the two years.

Data collection

Data were recorded on a plot basis. Days to anthesis (DA) and days to silking (DS) were recorded as the number of days from planting to when 50% of the plants in a plot have shed pollens and emerged silks, respectively. Plant height was measured as the distance (cm) from the base of the plant to the leaf collar of the tassel branch. Leaf damage (LDM) at 2, 4, 6 and 8 WAP, and ear damage (EDM) were visually scored on a 5-point hedonic scale (Figure 1, Table 1, Figure 2 and Table 2, respectively). The chlorophyll content (μg/cm^2) of the leaves was determined using the At Leaf chlorophyll meter. At physiological maturity, maize ears were harvested, threshed and weighed (Kg) per plot. The grain moisture content (%) was measured using a portable moisture meter and grain yield was computed based on the formula:

Grain yield (t/ha) = [FWT x ((100-MOIST%)/85)] x (10000/(Plot size)) x (80/100)

where:

- *FWT* = Fresh weight of ears measured in kilograms per plot at harvest;
- *MOIST* = grain moisture content measured by using a digital grain moisture analyzer;
- 85 = adjustment factor of grain moisture to 15%;
- 10, 000 m² = 1 hectare, 80% = shelling percentage.

Data analysis

All data were subjected to analysis of variance (ANOVA) after being scored. A log transformation (cap Y equals l o g open paren cap Y to the i. plus cap K, close paren close paren) was applied to ensure normality of variance. The ANOVA was done using PROC General Linear Model (GLM) in SAS (SAS Institute, 9.4). Means were separated using the Least Significant Difference (LSD) at *P*≤0.05. Pearson’s correlation coefficients among traits were calculated in SAS using PROC CORR. A sequential path analysis procedure was used to determine the inter-trait relationship (Talabi et al., 2017). Standardized stepwise regression coefficients, or path coefficients, were obtained by regressing all the measured LDM stages on grain yield. The significant direct contributors to grain were regarded as the first-order traits. The other traits were subsequently regressed on each of the first-order traits on the remaining traits to determine how they affect grain yield through the first-order traits. The procedure was repeated till there were no significant (α = 0.05) relationships. Leaf damage scores were regressed on GY using R V4.1.3 (R Core Team, 2022). All biplots were drawn in R using the ggplot function.

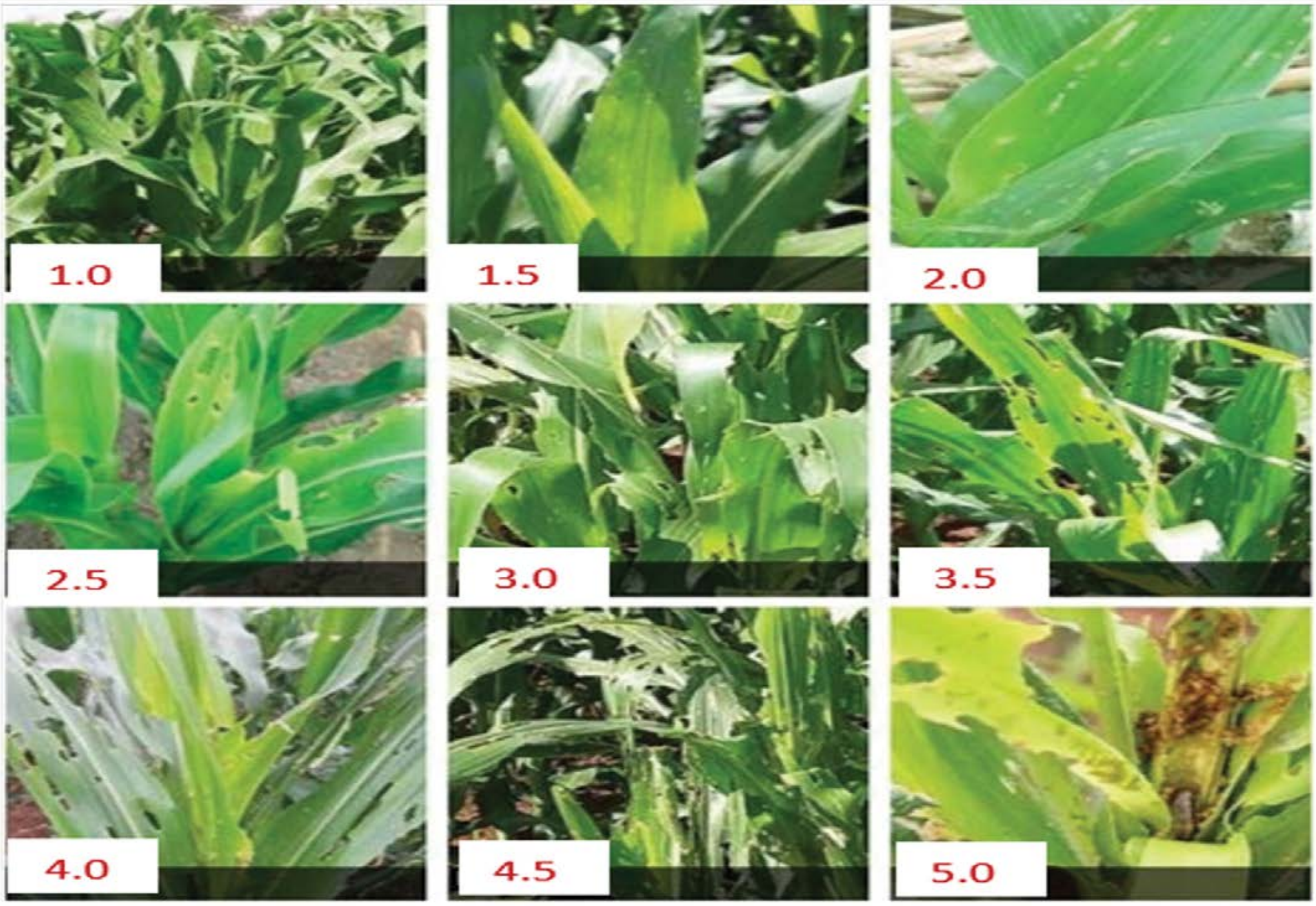

Figure 1. Scale for the assessment of FAW leaf damage of maize hybrids evaluated in 2022 and 2023 in Nigeria (Source: Adapted from Prasanna et al., 2018)

Table 1. Interpretation of scale for the assessment of fall armyworm leaf damage of maize hybrids

Damage	Score	Description	Pant status
Low	1.0	No leaf damage	Highly resistant
	1.5	Up to three minor injuries on older leaves	Resistant
	2.0	Several shot-hole injuries on a few leaves (<5 leaves) and small circular hole damage to leaves.	Resistant
Average	2.5	Several shot-hole injuries on several leaves (6 – 8 leaves) or small circular lesions, and a few elongated lesions of 1.3 cm in length present in whorl and furl leaves.	Partially resistant
High	3.0	Elongated lesions (> 2.5 cm long) on 8-10 leaves, plus a few small-to-mid-sized irregular-shaped holes eaten from the whorl and/or furl leaves.	Partially susceptible
	3.5	Many elongated lesions of different sizes on several leaves, and several large uniform to irregular-shaped holes eaten from the whorl and furl leaves	Susceptible
Very High	4.0	Many large, elongated lesions of all sizes on leaves and expanded leaves, plus large holes eaten from whorls and furl leaves.	Susceptible
	4.5	Many elongated lesions of all sizes on all leaves and large holes eaten from the whorl and furl leaves.	Highly susceptible
	5.0	Leaves are almost completely defoliated with injuries on stalks, and FAW shit on the majority of the plants	Highly susceptible

Source: Adapted from Prasanna et al. (2018)

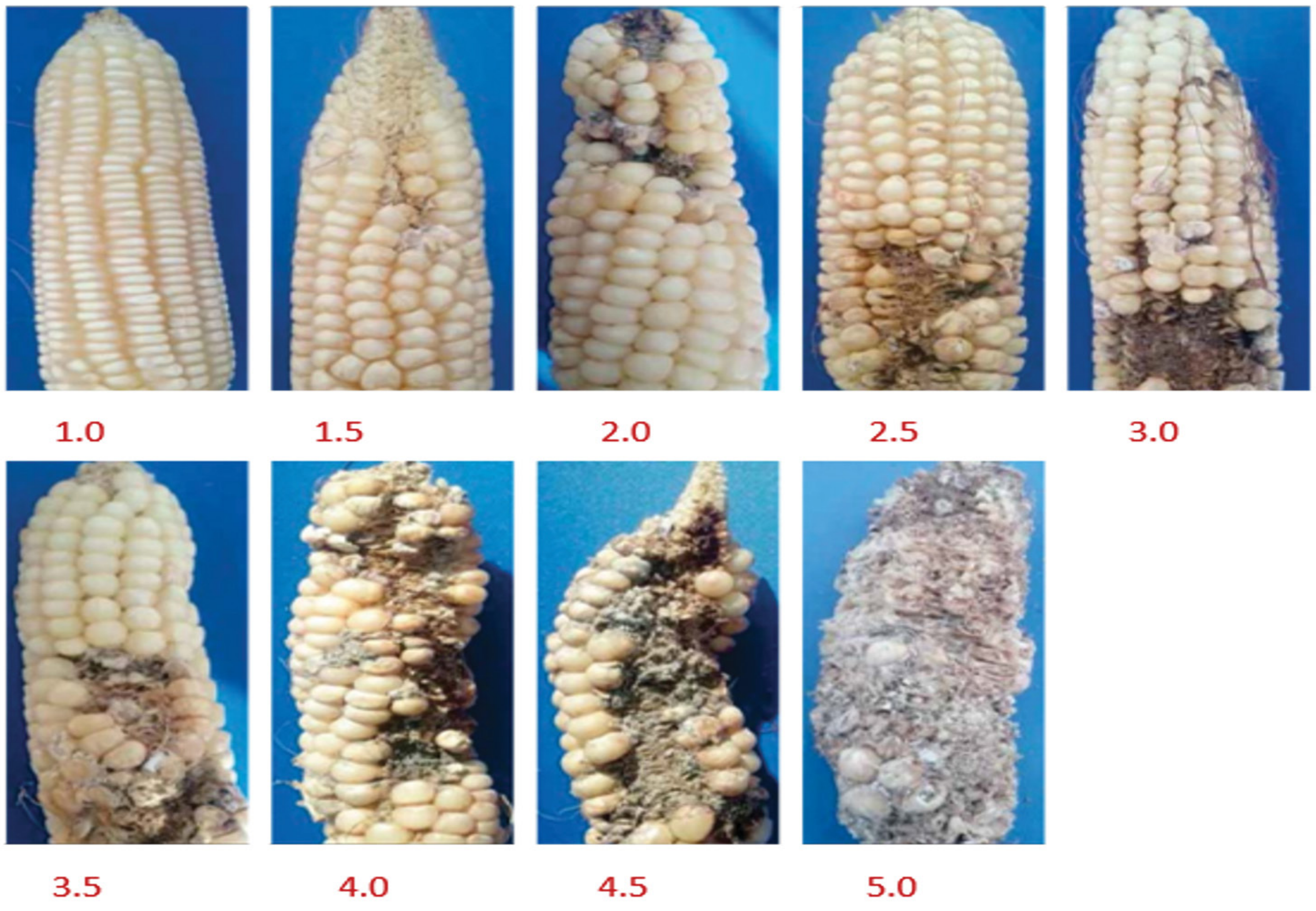

Figure 2. Visual scale for the assessment of FAW ear damage of maize hybrids evaluated in 2022 and 2023 in Nigeria (Source: Adapted from Prasanna et al., 2018)

Table 2. Interpretation of scale for the assessment of fall armyworm ear damage of maize hybrids

Damage	Score	Description	Pant status
Low	1.0	No ear damage	Highly resistant
	1.5	Damage to a few kernels (<5) or less than 5% damage to an ear	Resistant
	2.0	Damage to 6 – 15 kernels or less than 10% damage to an ear	Resistant
Average	2.5	Damage to 16 – 30 kernels or less than 15% damage to an ear	Partially resistant
High	3.0	Damage to 31 – 50 kernels or less than 25% damage to an ear	Partially susceptible
	3.5	Damage to 51 – 75 kernels or more than 35% but less than 50% damage to an ear	Susceptible
Very High	4.0	Damage to 76 – 100 kernels or more than 50% but less than 60% damage to an ear	Susceptible
	4.5	Damage to >100 kernels or more than 60% but less than 100% damage to an ear	Highly susceptible
	5.0	Almost 100% damage to an ear	Highly susceptible

Source: Adapted from Prasanna et al. (2018)

RESULTS

Variation for agronomic and fall armyworm resistant traits of maize hybrids

From the analysis of variance, the two years of evaluation differed significantly for all the traits evaluated. The hybrids differed for grain yield, flowering traits, and leaf damage (LDM) scores 4 WAP and 6 WAP, but they were not significantly different for LDM2WAP, LDM8WAP, EDM score, EASP scores, and chlorophyll content (Table 3). The hybrid × year effect was significant for LDM6WAP and EASP scores. The coefficient of variation ranged from 3.0% for DS to 20.3% for LDM8WAP, which is ideal for selection.

Hybrid performance for agronomic and fall armyworm-resistant traits

Across the years of evaluation, hybrid AS2001-19 had the highest grain yield (8.60 t/ha) but was comparable to the yields of the top five hybrids and the check variety SC716 (8.16 t/ha). Meanwhile, the second check variety, Oba Super-9, had the lowest grain yield (5.49 t/ha) and was comparable to the grain yield of the other nine maize hybrids (Table 4). The average days to anthesis and silking of the maize hybrids were 61.83 and 62.97, respectively. Five of the hybrids had a relatively lower number of days to attain flowering and silking when compared to the two checks and the other hybrids (Table 4). The hybrids AS2001-24 took the longest time to attain flowering (64.99 days) and emerged silks (66.91 days). The commercial check, SC719, was distinctly the tallest among the hybrids, while six other hybrids (AS2001-22, AS2001-3, AS2106-22, AS2106-42, AS2106-43 and AS2106-66) had comparable plant heights (Table 4). The shortest of the hybrids was AS2001-24 with 195.54 cm.

Hybrids responded differently to FAW foliar feeding. The mean leaf damage score declined with the plants' growing stages. The leaf damage score was highest at 4 WAP (2.72) and lowest at 8 WAP (1.88) (Figure 3). Most of the hybrids had leaf damage scores in the range of partial resistance and partial susceptibility, 2 WAP and 4 WAP, but increased to resistance status 8 WAP (Table 4 and Figure 3).

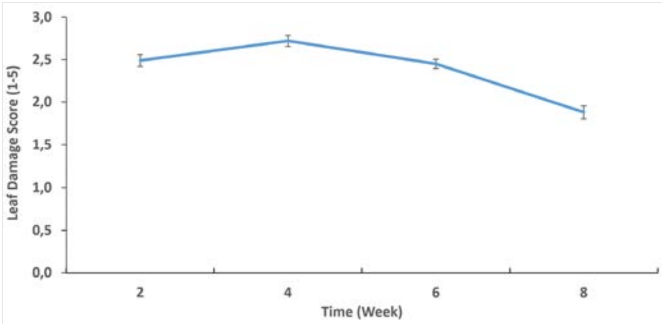

Figure 3. Response of maize hybrids to fall armyworm leaf damage over time

Table 3. Mean squares from the analysis of variance of maize hybrids for agronomic and FAW-resistant traits

Source	DF	GY	DA	DS	PHT	LDM2WAP	LDM4WAP	LDM6WAP	LDM8WAP	EASP	EDM	CHLC
Year (YR)	1	182.8	450.8***	477.7***	720.7*	5.0***	2.9***	3.9***	1.3***	0.6*	0.5**	420.5***
REP(YR)	4	2.9	4.3	2.3	346.6*	0.3*	0.9***	1.1***	0.8**	0.1	0.1	144.15**
BLK(YR*REP)	36	4.8**	5.4	7.0*	247.1*	0.2	0.2*	0.4***	0.2	0.2	0.1	27.41
HYBRID	16	2.3*	15.6**	17.2**	368.7*	0.1	0.1*	0.2*	0.2	0.1	0.1	32.10
YR*HYBRID	16	3.3	3.9	5.2	131.7	0.1	0.0	0.3***	0.1	0.2*	0.1	3.0
ERROR	28	1.0	3.8	3.7	104.3	0.1	0.1	0.1	0.1	0.1	0.1	23.72
CV		19.2	3.2	3.0	4.9	13.8	11.5	10.8	20.3	16.2	17.7	8.4

*, **, ***: $P \leq 0.05$, 0.01, 0.001, GY: Grain yield, DA: Days to anthesis, DS: Days to silking, PHT: Plant height, LDM: Leaf damage, EASP: Ear aspect, EDM: Ear damage, CHLC: Chlorophyll content.

Table 4. Mean performance of maize hybrids for agronomic and fall armyworm-resistant traits in Nigeria

GEN	GY (t/ha)	DA (Days)	DS (Days)	PHT (cm)	LDM2WAP (1 – 5)	LDM4WAP (1 – 5)	LDM6WAP (1 – 5)	LDM8WAP (1 – 5)	EASP (1 – 5)	EDM (1 – 5)	CHLC (µg/cm^2)
AS2001-12	6.16	59.89	60.64	201.64	2.32	3.08	3.00	1.96	1.98	1.66	58.5
AS2001-19	8.60	64.35	66.01	207.31	2.34	2.67	2.20	1.75	1.76	1.39	51.9
AS2001-20	7.36	63.39	63.78	203.32	2.33	2.61	2.39	1.86	1.93	1.60	55.6
AS2001-22	6.62	64.08	64.94	211.63	2.27	2.52	2.43	1.89	2.11	1.51	57.3
AS2001-24	6.66	64.99	66.91	195.54	2.24	2.37	2.53	1.91	2.29	1.27	65.1
AS2001-25	6.90	64.42	65.55	201.61	2.47	2.68	2.25	1.92	1.93	1.59	57.4
AS2001-3	7.77	59.41	59.99	217.12	2.88	2.70	2.58	2.14	1.92	1.54	53.6
AS2001-4	6.69	59.91	60.92	209.19	2.78	2.89	2.71	2.04	1.85	1.49	59.5
AS2106-22	7.29	61.00	61.27	222.46	2.49	2.94	2.83	1.79	1.74	1.52	59.9
AS2106-42	7.02	62.67	63.96	212.05	2.58	2.69	2.20	1.49	2.01	1.30	49.4
AS2106-43	7.98	62.80	62.98	211.18	2.66	2.71	2.11	1.62	1.83	1.36	58.7
AS2106-63	6.00	59.22	61.28	203.94	2.61	2.41	2.30	2.07	1.75	1.19	54.5
AS2106-66	6.90	62.47	63.30	212.22	2.56	2.46	2.36	1.99	2.10	1.35	60.0
M1628-10	7.46	60.54	62.74	199.71	2.22	2.83	2.42	1.48	2.33	1.60	58.6
M1628-8	6.84	58.35	59.61	202.25	2.38	2.65	2.11	1.66	1.70	1.40	55.5
Oba Super-9	5.49	62.71	63.54	206.72	2.23	2.53	2.34	2.19	1.82	1.17	58.8
SC719	8.16	64.71	65.53	238.39	2.67	2.96	2.53	1.93	1.82	1.65	54.0
Mean	7.07	61.83	62.97	209.58	2.49	2.72	2.45	1.88	1.91	1.44	57.8
LSD (0.05)	1.61	2.31	2.27	12.08	0.41	0.37	0.31	0.45	0.13	0.10	8.10

GY: Grain yield, DA: Days to anthesis, DS: Days to silking, PHT: Plant height, LDM: Leaf damage, WAP: Weeks after planting, EASP: Ear aspect, EDM: Ear damage, CHLC: Chlorophyll content.

The EASP and EDM scores were generally low and ideal for all the hybrids and checks, while the mean values for chlorophyll content were not significantly different at α≤0.05 (Table 4).

Association among agronomic and fall armyworm-resistant traits of maize hybrids

Based on Pearson's correlation coefficient, GY had a significant positive correlation with DA, PHT, and LDM2WAP but a significant negative correlation with LDM4WAP, LDM6WAP, and EASP (Table 5). Days to anthesis and days to silking had significant negative associations with LDM4WAP but significant positive associations with LDM8WAP and EDM, respectively. Plant height also had a negative association with leaf damage score that was significant at 6 WAP but not at 8 WAP. Chlorophyll content had a negative correlation with leaf damage scores, but this correlation was only significant at 2WAP and 4WAP. In contrast, EDM had a significant positive correlation with the EASP score.

Table 5. Pearson's correlation coefficient for agronomic and FAW-resistant traits of maize hybrids

	GY	DA	DS	PHT	LDM2WAP	LDM4WAP	LDM6WAP	LDM8WAP	PASP	EASP	EDM
DA	0.23^{*}										
DS	0.17	0.96^{***}									
PHT	0.68^{***}	-0.04	-0.12								
LDM2WAP	0.51^{***}	0.17	0.13	0.34^{**}							
LDM4WAP	-0.21^{*}	-0.34^{**}	-0.34^{**}	-0.11	-0.12						
LDM6WAP	-0.49^{***}	-0.14	-0.13	-0.32^{**}	-0.22^{*}	0.58^{***}					
LDM8WAP	0.04	0.27^{**}	0.26^{**}	0.03	0.32^{**}	-0.03	0.28^{**}				
PASP	-0.29^{**}	0.12	0.13	-0.22^{*}	0.12	0.23*	0.42^{***}	0.54^{***}			
EASP	-0.36^{**}	0.04	0.06	-0.32^{**}	-0.29^{**}	0.14	0.26^{*}	0.11	0.22^{*}		
EDM	0.07	0.23^{*}	0.21^{*}	-0.03	0.08	0.07	0.09	0.04	0.23^{*}	0.22^{*}	
CHLC	0.21	0.02	0.01	0.14	-0.40^{**}	-0.23*	-0.20	-0.19	-0.17	0.10	-0.08

*, **, ***: $P \le 0.05$, 0.01, 0.001, respectively. GY: Grain yield, DA: Days to anthesis, DS: Days to silking, PHT: Plant height, LDM: Leaf damage, EASP: Ear aspect, EDM: Ear damage, CHLC: Chlorophyll content.

The regression model shows that FAW leaf damage 2, 4, 6 and 8 WAP did not significantly decrease GY (Figure 4). However, the model predicted a decline in GY by 0.63 t/ha and 1.7 t/ha if there is a unit increase in FAW leaf damage score at 6 and 8 WAP, respectively (Figure 4).

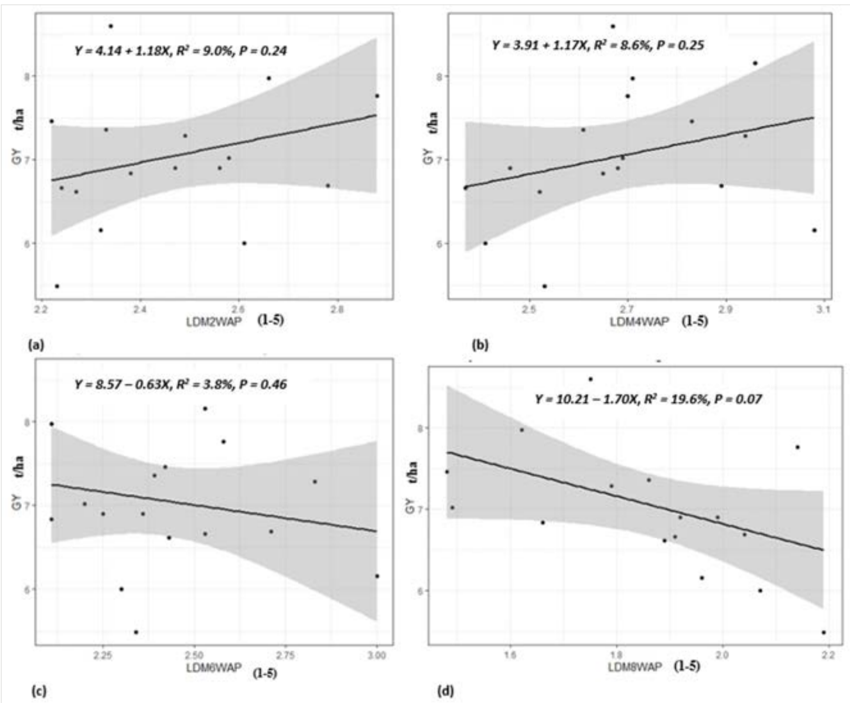

Figure 4. Relationship between fall armyworm leaf damage (LDM) 2 – 8 weeks after planting (WAP) and grain yield (GY) of maize hybrids evaluated in Nigeria

The sequential path analysis further points to the effects of LDM on grain yield. The modal accounted for over 40% of the total variation in grain yield. The LDM2WAP and LDM6WAP were the first-order traits, with path coefficients of 0.42 and -0.40, respectively. The LDM4WAP and LDM8WAP were the second-order traits. LDM4WAP contributed to grain yield through LDM6WAP, while LDM8WAP contributed to grain yield through both LDM2WAP and LDM6WAP (Figure 5).

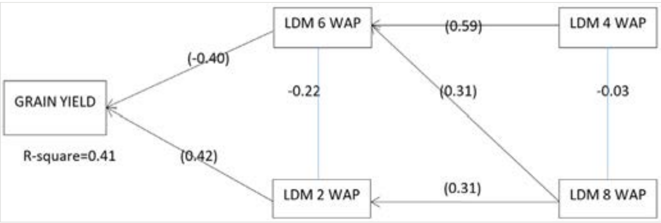

Figure 5. Inter-trait relationships among leaf damage scores collected at 2, 4, 6 and 8 weeks after planting on 15 FAW-tolerant hybrids and two commercial checks at the Federal University Oye Ekiti Teaching and Research Farm

DISCUSSION

The current study assessed candidate maize hybrids and commercial varieties for agronomic and fall armyworm (FAW)-resistant traits. The significant year effect for all traits evaluated indicated that the two growing seasons differed significantly. Climatic variations from season to season usually influence the agronomic performance of maize and insect herbivory (Anjorin et al., 2022). The FAW requires suitable climatic conditions for reproduction, growth and development (Anjorin et al., 2022). Therefore, the severity of FAW leaf and ear damage will vary depending on the prevailing environmental conditions. High temperatures and drought stress have been reported to aggravate FAW leaf damage (Rwomushana et al., 2018; Abang et al., 2024).

The significant difference among the maize hybrids for GY, flowering traits, PHT, and leaf damage scores 4 and 6 WAP indicated that genetic variation existed among the hybrids for these characteristics. Therefore, selection can be made based on the respective traits. However, the nonsignificant differences among hybrids for LDM2WAP and LDM8WAP suggested that the hybrids were not different in FAW leaf damage scores at these stages. There is often no visible FAW leaf damage in maize at 2 WAP because it usually takes 14 – 22 days for the FAW eggs to mature into voracious larvae in tropical climatic conditions (Prasanna et al., 2018). However, the average FAW leaf damage score was highest at 4 WAP, suggesting that the leaf feeding effect was at its peak at this stage, consistent with the report of FAO and CABI (2019). The mean leaf damage score of most of the candidate maize hybrids and the commercial checks was in the partial susceptibility mark, indicating that the hybrid leaves were highly vulnerable to FAW damage at this stage. Nevertheless, the similarity in leaf damage score among the maize hybrids 8 WAP might be due to the foliage recovery capacity of maize, especially in favourable conditions. In addition, the gradual decline in the average leaf damage score from 2.72 (4 WAP) to 2.45 (6 WAP) and 1.88 (8 WAP) underscored the recovery process occasioned by the emergence of new foliage and the thickening of cuticles of the older leaves. These resistant mechanisms have been previously reported in maize germplasm (William and Davis, 1982).

According to Singh et al. (2021), host plant resistance generally operates on three mechanisms: antibiosis (host plant's adverse effects on the insect pest), antixenosis (non-preference/avoidance of host plants), and tolerance (host plant's natural ability to yield well despite pest infestation). The decrease in the leaf damage score indicated that the maize hybrids built immune responses against FAW herbivory. The defence responses may have been antibiosis in nature, such as the production of allelochemicals, defence proteins, and toxic chemical compounds, such as jasmonic acids, flavone glycoside (silk maysin), and isoorientin, (Shivaji et al., 2010; Singh et al., 2021; Anjorin et al., 2022). It could have been FAW antixenosis response, such as thicker cuticles and epidermal cell walls, higher fibre leaves, dense surface wax and vascular bundles (Yang et al., 1993). Furthermore, the average 1.88 leaf damage score at 8 WAP and the 1.44 ear damage score indicated that the candidate maize hybrids and the commercial checks were resistant to FAW infestation under natural conditions. This can be linked to the resistant genetic background of the parents, which have been selected for FAW resistance under artificial infestation at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (Prasanna et al., 2018).

The significant positive correlation between GY and PHT indicated a positive association between GY and PHT. This is consistent with the result of Job et al. (2022), who reported a significant positive correlation between GY and PHT across environments under variable FAW pressures. Tall and vigorous plants bear more leaves, thus higher photosynthetic efficiency and photoassimilate conversion. In contrast, the significant negative correlation between GY and LDM4WAP, LDM6WAP, PASP and EASP scores indicated that these traits had a significant negative association with GY. The result is consistent with the result of Bakry and Abdel-Baky (2023), who reported a highly significant negative correlation between GY and FAW leaf damage of single-cross maize hybrids evaluated in Egypt. The 4 – 6 WAP coincides with the rapid vegetative growth stage of maize that requires high photosynthetic efficiency of leaves (Bell 2017; Anjorin et al., 2022). Therefore, the significant correlation between GY and leaf damage scores at these stages indicated the potential of FAW leaf feeding to reduce GY, which may arise from possible disruption of photosynthesis. The significant negative correlation between chlorophyll content and leaf damage scores 2 and 4 WAP underscores the association between FAW leaf feeding and photosynthesis. An earlier study by Darby and Lauer (2000) pointed out that FAW leaf feeding limits the availability of photosynthates due to the loss of photosynthetic Leaf area, especially during grain filling, leading to grain death and lower yield potential. Nevertheless, the effect of FAW leaf feeding on GY is dependent on the crop stage and level of leaf damage.

Based on the regression models, the predicted 0.63 t/ha and 1.7 t/ha yield reduction because of LDM6WAP and LDM8WAP was indicative of the potential effect of FAW leaf feeding on the grain yield of maize. Although the yield reduction was not statistically significant, probably due to the resistant genetic background of the maize hybrids, it underscores the possible yield loss that FAW leaf damage could cause if resistant varieties are not used. Therefore, it is important to emphasize the use of host-resistant varieties as it has proven to be the most efficient approach to mitigate the effects of FAW and minimize pesticide usage (Prasanna et al., 2018; Job et al., 2022).

The significant negative direct effect of leaf damage score at 6 WAP indicated that damage by FAW at this vegetative stage has a crippling effect on the grain yield of maize. The evaluated maize belongs to the intermediate maturing group, as it flowers around 62 days after planting. For maize varieties in this maturity, booting begins at 6 WAP, which is critical for the flowering stage, hence the grain yield. Leaf damage at this stage of development could reduce assimilates needed for the formation of the sink, which could lead to a reduction in grain yield. The observed non-negative direct effect of leaf damage at 2WAP on the grain might be due to the inherent ability of the evaluated hybrids to tolerate damage at early vegetative stages without serious repercussions on grain yield. This aligns with the finding of Tambo et al. (2019) that damage to maize during the vegetative stage reduces economic yields through damage to the leaf and dead heart, while damage at the reproductive stage reduces fertilization and grain formation, resulting in reduced grain yield. Since the result showed that LDM4WAP is a predictor of LDM6WAP and influences yield through LDM6WAP, pest management intervention, if applied between 4 and 6 WAP, would be most efficient for this set of hybrids.

The high level of resistance to FAW among the evaluated hybrids accounted for the outstanding GY and low LDM8WAP among the hybrids evaluated for this trial. Six of the candidate maize hybrids (AS2001-19, AS2106-43, AS2001-3, M1628-10, AS2001-20 and AS2106-22) with significantly more grain yields than the commercial check (Oba Super-9) and comparable yields with SeedCo's hybrid (SC719) were identified for further testing.

CONCLUSIONS

Fall armyworm leaf damage has a potentially severe impact on corn grain yield, especially when host-resistant varieties are not grown. The present study showed that fall armyworm leaf damage between 4 and 6 weeks after planting could significantly reduce the grain yield of maize. Therefore, this vegetative stage could be targeted for an effective integrated pest management strategy.

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