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Evaluation of stem borer resistant maize genotypes for resistance to fall armyworm (*Spodoptera frugiperda* J.E. SMITH) infestation

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Fall armyworm (FAW) is currently the most destructive insect pest of maize in sub-Saharan Africa (SSA). Varieties that combine high grain yield (GY) with tolerance to FAW would enhance and stabilize maize productivity in SSA. Genotypes resistant to lepidopteran pests like stem borer (SB) could serve as potential sources of alleles for development of FAW resistant varieties. This study was conducted to assess some SB-resistant maize genotypes for FAW tolerance, and to identify genotypes that combined high GY with tolerance to FAW. Twenty-nine white maize genotypes with varying levels of SB resistance were evaluated under artificial FAW-infested and FAW-protected conditions using randomized complete block design with three replicates. Genotypic differences were significant for all the traits under both FAW-infested and FAW-protected conditions. Under FAW-infested condition, GY ranged from 3.44 (FAWTH-8) to 5.81 t ha^{-1} (FAWTH-1) (mean = 4.61 t ha^{-1}), and from 3.42 (FAWTH-25) to 6.85 t ha^{-1} (FAWTH-18) (mean = 4 .86 t ha^{-1}) under FAW-protected condition. Across genotypes, FAW infestation reduced GY by 5.1% suggesting that SB resistance could confer tolerance to FAW. Association of GY under FAW-infested condition with FAW Leaf Damage (FAWLD; r=-0.45) and FAW Ear Damage (FAWED; r=-0.65) were significant. Base index (BI) was significantly correlated with GY (r=0.93), ear aspect (r=-0.84), FAWLD (r=-0.66) and FAWED (r=-0.78). Six moderately resistant genotypes (FAWTH-1, FAWTH-13, FAWTH-4, FAWTH-10, FAWTH-23 and FAWTH-6) with GY ≥ 5.13 t ha^{-1} and positive BI ≥ 4.0 were identified. The genotypes varied for FAW tolerance. Base index and low FAW damage scores could serve as selection criteria for combined tolerance to FAW and high GY. The identified genotypes are recommended for further development as FAW tolerant varieties.

Key words: Base index, fall armyworm ear damage, fall armyworm leaf damage, maize grain yield, stem borer resistance.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important staple food and industrial crop in sub-Saharan Africa (SSA) where it contributes to the livelihoods and food security of smallholder farmers (Erenstein et al., 2022). In SSA human consumption accounts for about 63% of maize produced (Santpoort, 2020) which supplies about 30% of the food calorie requirement of more than 300 million people (Shiferaw et al., 2011; Smale et al., 2013; Beyene et al., 2016). Although maize has a high yield potential in SSA (IITA, 2017), average maize grain yield is very low

(1.5 t ha^{-1}) compared to global average of 4.9 t ha^{-1} (OECD, 2018; FAOSTAT, 2021; Grote et al., 2021).

The low maize productivity and production in SSA is a function of several biotic (e.g. *Striga* spp., foliar diseases, insect pests including stem borers and fall armyworms) and abiotic (e.g. drought, flood. heat and low soil fertility) stress factors, as well as socio-economic restrictions which included fragmented pieces of land, unaffordable input costs (OECD, 2018), wars and terrorism among others.

Of all the biotic constraints to maize productivity, insect pests alone cause an estimated 60% of yield losses in SSA (Mugo et al., 2018). No insect pests of economic importance to maize production include *Busseola fusca* (African stem borer), *Eldana saccharina* (African sugarcane borer), *Sesamia calamistis* (African pink stem borer), *Chilo partellus* (Spotted stem borer), *Cicadulina mbila* (Maize leafhopper), some termite species (Macrotermes and Microtermes species), and more recently *Spodoptera frugiperda* (fall armyworm) (Assefa and Ayalew, 2019). However, stem borers and fall armyworm (FAW) are the two most important insect pests of maize in SSA (Ajala et al., 2008; Nagoshi et al., 2017; Job et al., 2022). The FAW is a highly polyphagous, invasive pest of global economic importance (Kasoma et al., 2021a; Matova et al., 2020; Overton et al., 2021) with a wide host range cutting across over 80 species and more than 353 plants (Prasanna, 2018; Wan et al*.,* 2021). Although native to tropical and subtropical regions of America, FAW was first reported in West Africa in 2016 and has spread rapidly to other regions of the continent (Goergen et al*.,* 2016; Cock et al., 2017; Tepa-Yotto et al*.,* 2021). Currently, FAW has assumed the status of the most destructive, yield-limiting insect pest of maize in SSA where it causes severe grain yield losses, thereby becoming a grave threat to food and livelihood security (Day et al., 2017; Abrahams et al., 2017; Prasanna et al., 2018; Kumela et al., 2019; Matova et al., 2022). Depending on the plant's genetic make-up, extent of infestation and in the absence of appropriate control measures, maize grain yield losses due to FAW can be up to 100% (Prasanna et al., 2018). It is therefore necessary to design an effective management strategy to control FAW infestation in farmers' fields to avert high grain yield losses on farmers' fields in SSA.

Common control strategies to FAW attack includes the use of insecticides, biological control agents, cultural practices and host plant resistance (Prasanna et al., 2018, 2021). However, several factors including costs and legislative barriers hinder availability and use of these FAW control measures by most smallholder African farmers. Furthermore, independent deployment of each of the control strategies in SSA is not neither sustainable nor effective. Therefore, a multifaceted approach which includes the use tolerant/resistant varieties is required to provide a durable and sustainable FAW management in SSA (Prasanna et al., 2022).

Host-plant resistance is economic, sustainable, environmentally friendly and compatible with other pest management strategies (Abrahams et al., 2017; Kumela et al., 2019; Job et al., 2022; Prasanna et al., 2022). However, only few commercial maize cultivars with resistance to FAW are available in Africa. Since the mode of action of FAW and that of stem borers are very similar, and significant correlations have been reported between the resistance indices of both pests (Williams et al., 1998; Abel et al., 2000; Prasanna et al., 2018), it could be considered that stem borer resistance would confer resistance to FAW. Furthermore, resistance to insect pests in maize has been shown to be genetically broad-based suggesting that resistance of some maize genotypes to a given insect pest could influence their resistance to another insect pest (Brooks et al., 2005). Hence, evaluating maize genotypes developed for stem borer resistance or tolerance under FAW infestation will provide a basis for selecting best performing ones. Therefore, the present study was carried out to: evaluate some stem borer resistant tropical white maize genotypes for their grain yield performance under fall armyworm infested and protected conditions and to identify and select maize genotypes that combined high grain yield with tolerance to fall armyworm infestation.

MATERIALS AND METHODS

Description of experimental site

The experiment was carried out at the experimental field of the Department of Crop and Horticultural Sciences, along Parry Road, University of Ibadan (N07.45164°, E003.8906; 208 masl), Oyo State, Nigeria in two cropping seasons. The location of the experimental site is characterized by high incidence of fall armyworm (FAW) infestations both on and off season. The soil at the experimental site was sandy-loam with a pH (H_2O) of 5.5. It was low in total nitrogen (1.30 g kg^{-1}), available P (0.75 mg kg^{-1}) and K (0.28 cmol kg^{-1}), while the organic carbon (12.90 g kg^{-1}) was moderate.

Genetic materials used in the experiment

Twenty-nine white maize genotypes which comprised 19 top cross hybrids, three single cross hybrids, one population cross hybrid and six open pollinated varieties of similar maturity and varying levels of resistance to stem borers were used for the study (Table 1). The genetic materials were sourced from Value Seeds Ltd, Kaduna, Nigeria.

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Table 1. Genetic materials used in the experiment.

S/N	Code	Pedigree	Type
1	FAWTH-1	AWRSYN-W2 × 1393	Top cross
2	FAWTH-2	AWRSYN-W2 × CML 331	Top cross
3	FAWTH-3	AWRSYN-W2 × CKSBL 10060	Top cross
4	FAWTH-4	AMATZBR-WC3 × 1393	Top cross
5	FAWTH-5	AMATZBR-WC3 × CML 331	Top cross
6	FAWTH-6	AMATZBR-WC3 × CKSBL 10060	Top cross
7	FAWTH-7	TZBR-ELd4WC2 × 1393	Top cross
8	FAWTH-8	TZBR-EL4WC2 × CML 331	Top cross
9	FAWTH-9	TZBR-EL4WC2 × CKSBL 10060	Top cross
10	FAWTH-10	TZBSR X 1393	Top cross
11	FAWTH-11	TZBSR × CML 331	Top cross
12	FAWTH-12	TZBSR × CKSBL 10060	Top cross
13	FAWTH-13	TZBR Comp 1- WC2 × 1393	Top cross
14	FAWTH-14	TZBR Comp 1-WC2 × CML 331	Top cross
15	FAWTH-15	TZBR Comp 1-WC2 × CKSBL 10060	Top cross
16	FAWTH-16	TZBR Comp 2-WC2 × 1393	Top cross
17	FAWTH-17	TZBR Comp 2-WC2 × CML 331	Top cross
18	FAWTH-18	TZBR Comp 2-WC2 × CKSBL 10060	Top cross
19	FAWTH-19	1393 × AbSL50	Single cross
20	FAWTH-20	1393 × CML 331	Single cross
21	FAWTH-21	1393 × CKSBL 10060	Single cross
22	FAWTH-22	AWRSYN-W2	OPV
23	FAWTH-23	TZBR Comp 1-WC2	OPV
24	FAWTH-24	TZBR Comp 2-WC2	OPV
25	FAWTH-25	TZBR ELd4-WC2	OPV
26	FAWTH-26	AMATZBR-WC3	OPV
27	FAWTH-27	Sammaz 15	OPV
28	FAWTH-28	SC 651	Top cross
29	FAWTH-29	TZBR Comp-1 WC2 × TZBR Comp-2 WC2	Population cross

OPV = Open pollinated variety.

Experimental design, crop establishment and management

The experiment was laid out in a randomized complete block design with three replicates. The experimental field was divided into two blocks, namely: FAW-infested and FAW-protected. The FAW-infested block was artificially infested with FAW larvae, while the FAW-protected block served as control. The two blocks were separated by a 10.0 m alley to which seeds of a maize population of similar maturity with the test genotypes were densely sown to trap insecticide spray drifts from the protected block. Plots consisted of single rows, each 3.0 m long and spaced 0.75 m. Seeds were sown 0.25 m apart within rows. Two seeds were sown per hole and the seedlings later thinned to one plant at two weeks after sowing (WAS) to achieve a plant population of 53,333 plants per hectare. The plants were grown under rain-fed conditions, with supplemental drip irrigation when necessary to prevent drought stress. Weeds were controlled using a combination of atrazine (250 g L^{-1}) and S-metolachlor (250 g L^{-1} SC) at the rate of 4.0 L ha^{-1} as pre-emergence herbicide, and this was complemented with one round of hand weeding. At 2WAS, NPK 15:15:15 fertilizer was applied at the rate of 40 kg N ha^{-1}. An additional 30 kg N ha^{-1} was applied at 5WAS using urea. The FAW larvae were raised at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. Artificial infestation of the FAW-infested block was done two WAS by using a camel brush to transfer ten second instar FAW larvae into the inner whorl of each maize seedling. To ensure uniformity, infestation of plots was done on the same day. Control of FAW on the FAW-protected block was achieved by spraying the plants weekly for five weeks, starting from the second week after sowing, with the insecticide emamectin benzoate (5% WDG) at the rate of 0.38 g L^{-1} following manufacturer's instructions. The densely sown 10 m strip separating the FAW-infested and FAW-protected blocks was not sprayed and served to harbor FAW larvae and moth.

Data collection

Data were collected on plot basis for all traits under both FAW-infested and FAW-protected conditions. Under each condition, data was recorded for days to anthesis (DA) as the number of days from sowing to the date when 50% of the plants in a plot shed pollen, while days to silking (DS) was recorded as the number of days from sowing to the date when 50% of the plants in a plot have emerged silks. Anthesis-silking interval (ASI) was expressed in days as the difference between DS and DA. Plant height (PH) and ear height (EH) in cm were measured at physiological maturity as the distance from soil level to the collar of the uppermost leaf and upper ear leaf, respectively, of five competitive plants. Plant aspect (PASP) was scored on a scale of 1 to 9 based on uniformity in plant and ear heights, lodging characteristics, reaction to pests and diseases, general appeal etc, where 1 = excellent, and 9 = poor. Husk cover was scored using a scale of 1 to 9, where 1 = husk tightly covers ear tip and extends beyond it, and 9 = poor husk cover with ear tip clearly exposed). Ear aspect (EASP) was also scored on a scale of 1 to 9, where 1 = excellent, clean uniform and well filled ears and 9 = ears with poor phenotypic appearance after harvest. The plants were also scored for streak disease on a scale of 1 to 9, where 1 = all plants excellent, clean with no streak infection and 9 = all plants severely streak infected. At harvest, the number of plants per plot was recorded.

Scoring for FAW leaf damage (FAWLD) and FAW ear damage (FAWED) were done only on the FAW-infested plots at 6WAS and at harvest, respectively. The FAWLD and FAWED were rated on a scale of 1 to 9, where 1 = no visible damage, and 9 = severe damage (Davis et al., 1989, 1992; Prasanna et al., 2018).

Grain yield (GY) was estimated by harvesting all the ears in a plot and shelled. The fresh weight adjusted for number of plants at harvest and percent moisture content of shelled grains were used to estimate GY and reported in kg ha^{-1} adjusted to 15% moisture content using the formula below:

$$\text{Grain yield (kg ha}^{-1}) = \text{grain weight (kg plot}^{-1}) \times \left(\frac{100-\text{moisture}}{85}\right) \times \left(\frac{10000}{3 \times 0.75}\right)$$

Data analyses

All data analyses were conducted separately for the FAW-infested and FAW-protected conditions. Analyses of variance were done using the PROC MIXED procedure in SAS version 9.3 (SAS Institute, 2011). Seasons of evaluation were considered as separate environments. In the model, genotype and genotype × environment were random, while environments and replications within environments were fixed. Significance was declared at 5% level of probability.

Base index (BI) approach by Badu-Apraku et al. (2015) and Oloyede-Kamiyo (2019) was used, with slight modifications to identify FAW tolerant and FAW susceptible genotypes. Traits included in the estimation of BI were GY, FAWLD, FAWED, EASP, and PASP as earlier described. To reduce the effect of differences in scales of measurement of the traits under FAW infestation, all data were standardized prior to integration into the BI equation. The BI values were calculated as:

$$\text{BI} = [(2 \times \text{GY}) - \text{FAWLD} - \text{FAWED} - \text{EASP} - \text{PASP}]$$

A genotype with a positive BI was considered FAW tolerant, whereas negative BI indicated susceptibility to FAW. Correlation analyses were carried out to establish the relationships among measured traits, and between BI and the traits included in the selection criteria using PROC CORR in SAS version 9.3 (SAS Institute, 2011).

RESULTS

Trait variability among genotypes

The analysis of variance revealed highly significant ($p \leq 0.01$) differences among the genotypes for all traits measured under both FAW-infested and FAW-protected conditions (Table 2). The effects of environment and genotype × environment interaction were not significant for all traits under both conditions.

Genotype responses under FAW-infested and FAW-protected conditions

Agronomic and fall armyworm damage traits

Under FAW-infested condition, days to anthesis (DA) ranged from 3.7 (FAWTH-3) to 61.9 days (FAWTH-24) with a mean of 57.3 days, while days to silking (DS) ranged from 57.2 (FAWTH-19) to 63.7 days (FAWTH- 20) with a mean of 59.5 days (Table 3). Across genotypes, ASI was 2.3 days. Plant and ear heights ranged from 133.8 cm (FAWTH-8) to 185.1 cm (FAWTH-12) and from 69.4 cm (FAWTH-28) to 105.8 cm (FAWTH-23), respectively. In general, the plant and ear aspects of all the genotypes were good, while the husk cover score ranged from very good to moderate. The highest streak disease score of 6.7 was recorded for genotypes FAWTH-3, FAWTH-9 and FAWTH-14, while genotype FAWTH-4 had the least (3.1). The FAWLD was highest in genotypes FAWTH-5 and FAWTH-8, but least in genotypes FAWTH-13, FAWTH-19 and FAWTH-27. Genotypes FAWTH-6, FAWTH-12 and FAWTH-13 had the least FAWED, while genotypes FAWTH-15 and FAWTH-26 had the highest FAWED (Table 3).

Under FAW-protected condition, DA and DS ranged from 53.6 (FAWTH-12) to 61.7 days (FAWTH-17) with a mean of 54.6 days and from 54.6 (FAWTH-12) to 64.7 days (FAWTH-17) with a mean of 59.7 days. Averaged across genotypes, ASI was 2.2 days (Table 4). Genotype FAWTH-2 (155.1 cm) was the shortest, while genotype FAWTH-24 (194.7 cm) was tallest. Ear height ranged from 75.2 cm for FAWTH-2 to 101.1 cm for FAWTH-18. Plant and ear aspect ranged from 2.0 (FAWTH-12) to 4.0 (FAWTH-25) and from 1.7 (FAWTH-18) to 4.3 (FAWTH-23, FAWTH-25), respectively. Husk cover score among the genotypes ranged from very good to moderate. Genotypes FAWTH-1 had the least streak disease score (2.3), while genotypes FAWTH-12, FAWTH-16 and FAWTH-20 had the highest score of 6.0 (Table 4).

Grain yield performance

Genotypic differences were observed for grain yield (GY) under FAW-infested and FAW-protected conditions (5). Under FAW-infested condition, GY varied from 3.44 (FAWTH-8) to 5.81 t ha^{-1} (FAWTH-1), whereas under FAW-protected condition, GY ranged from 3.42 (FAWTH-25) to 6.85 t ha^{-1} (FAWTH-18). Across genotypes, mean GY under FAW-protected condition (4.86 t ha^{-1}) and FAW-infested condition (4.61 t ha^{-1}) indicated a GY reduction of 5.1% due to FAW infestation.

Under both FAW-infested and FAW-protected conditions, the top 15 genotypes in each case had GY

Table 2. Mean squares from analysis of variance for some agronomic traits and fall armyworm damage parameters of 29 white maize genotypes evaluated under fall armyworm infested and protected conditions for two seasons in Ibadan, Nigeria.

Source of variation	DF	GY (t ha^{-1})	DA	DS	ASI	PH (cm)	EH (cm)	PASP (1 - 9)	EASP (1 - 9)	Streak score (1 - 9)	HCOV (1 - 9)	FAWLD (1 – 9)	FAWED (1 – 9)
							Infested						
Env	1	0.045	0.000	0.006	0.008	58.279	27.006	0.033	0.011	0.059	0.066	0.695	0.002
Rep(Env)	4	1.857***	25.558***	13.078***	2.143*	1779.279***	621.107***	2.313***	0.288	2.487***	0.564	35.889***	3.156***
Geno	28	1.916***	26.803***	28.319***	5.357***	1465.099***	569.899***	0.846***	1.196***	6.113***	1.102***	2.748***	3.618***
Env*Geno	28	0.016	0.118	0.147	0.077	7.480	3.150	0.017	0.015	0.026	0.019	0.086	0.036
Error	112	0.261	1.334	1.697	0.802	68.279	33.689	0.214	0.285	0.327	0.267	0.801	0.468
							Protected						
Env	1	0.273	0.266	0.445	0.023	6.829	0.336	0.002	0.006	0.015	0.001	-	-
Rep(Env)	4	2.053***	19.470**	8.624	3.537*	1957.469***	288.048*	0.984**	0.388	0.533	0.162	-	-
Geno	28	3.557***	15.505***	22.230***	4.668***	738.056***	344.360***	1.230***	2.236***	4.924***	1.100***	-	-
Env*Geno	28	0.022	0.244	0.147	0.110	8.895	5.251	0.015	0.022	0.044	0.019	-	-
Error	112	0.233	4.316	4.389	1.284	122.861	83.281	0.200	0.321	0.716	0.244	-	-

*;**;***: significant respectively at 0.05, 0.01, 0.001 probability levels. Env: Environment; Rep: Replication; Geno: Genotype; DF: Degree of freedom; GY: Grain yield; DA: Days to anthesis; DS: Days to silking; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; PASP: Plant aspect; EASP: Ear aspect; HCOV: Husk cover; FAWLD: Fall armyworm leaf damage; FAWED: Fall armyworm ear damage.

Table 3. Mean performance for some agronomic traits of 29 white maize genotypes evaluated under fall armyworm infested condition for two seasons in Ibadan, Nigeria.

Entry	DA	DS	ASI	PH (cm)	EH (cm)	PASP (1 - 9)	EASP (1 - 9)	Streak score (1 - 9)	HCOV (1 - 9)	Fall army worm damage		
										FAWLD (1 - 9)	FAWED (1 - 9)	Mean
FAWTH-1	56.0	57.3	1.3	171.9	91.4	3.0	2.6	4.6	2.9	4.2	3.4	3.80
FAWTH-2	57.9	60.8	2.9	148.8	76.6	2.7	3.6	5.6	3.0	5.9	4.9	5.40
FAWTH-3	53.7	56.7	3.0	158.5	86.0	3.0	3.3	6.7	3.6	4.9	4.6	4.75
FAWTH-4	57.0	60.0	3.0	172.7	85.9	2.9	3.0	3.1	4.1	4.3	3.3	3.80
FAWTH-5	56.6	60.6	4.0	134.2	70.3	3.0	3.4	6.0	3.3	6.2	4.7	5.45
FAWTH-6	54.8	57.9	3.1	177.4	90.9	2.4	2.4	5.7	3.5	5.9	3.0	4.45
FAWTH-7	57.6	59.8	2.2	167.0	91.7	2.9	3.0	4.3	2.6	4.3	3.6	3.95
FAWTH-8	59.3	62.6	3.4	133.8	73.4	3.0	3.6	6.3	3.6	6.2	4.1	5.15
FAWTH-9	55.2	57.4	2.2	169.2	84.9	3.1	3.7	6.7	3.4	5.6	4.4	5.00
FAWTH-10	55.2	57.5	2.3	166.4	86.5	3.4	2.7	4.6	4.0	4.6	3.4	4.00
FAWTH-11	58.3	61.4	3.2	149.8	78.4	3.4	3.4	6.0	3.3	5.8	4.1	4.95
FAWTH-12	55.6	57.6	2.0	185.1	97.5	3.0	3.0	6.0	3.4	5.1	3.0	4.05
FAWTH-13	57.4	58.6	1.3	181.9	103.6	2.9	2.4	4.0	4.0	4.0	3.0	3.50

Table 3. Contd.

FAWTH-14	57.1	59.4	2.3	142.7	72.6	2.6	3.9	6.7	3.5	5.8	5.3	5.55
FAWTH-15	54.4	57.3	2.9	166.2	90.9	2.6	3.7	5.7	3.7	4.7	5.7	5.20
FAWTH-16	59.0	60.9	1.9	180.3	94.1	3.5	2.7	5.6	3.7	4.8	4.4	4.60
FAWTH-17	57.3	60.0	2.7	156.4	83.1	2.7	3.7	6.6	3.6	5.3	4.7	5.00
FAWTH-18	56.1	58.3	2.2	176.8	87.1	2.6	2.9	6.0	3.4	4.8	3.5	4.15
FAWTH-19	55.2	57.2	2.0	170.1	85.0	3.0	3.3	5.4	4.4	4.0	3.9	3.95
FAWTH-20	60.5	63.7	3.2	138.6	70.6	3.0	3.4	5.6	4.0	5.2	4.5	4.85
FAWTH-21	53.7	55.5	1.7	147.3	82.0	3.4	3.4	6.4	2.9	5.5	4.1	4.80
FAWTH-22	56.0	57.6	1.6	146.7	70.1	3.3	2.6	5.4	4.0	5.0	4.2	4.60
FAWTH-23	59.9	60.3	0.4	180.5	105.6	3.0	3.0	4.4	4.0	4.2	3.6	3.90
FAWTH-24	61.9	62.3	0.4	185.0	90.9	2.6	3.4	4.4	4.3	5.1	3.9	4.50
FAWTH-25	58.2	58.4	0.3	148.8	75.9	2.3	3.7	3.9	3.6	5.2	4.7	4.95
FAWTH-26	58.4	61.6	3.3	148.2	76.3	3.0	4.0	5.7	3.6	5.5	5.7	5.60
FAWTH-27	59.8	62.2	2.4	170.0	81.5	4.0	3.0	3.6	3.0	4.0	3.6	3.80
FAWTH-28	60.0	63.2	3.2	161.7	69.4	2.6	3.4	6.0	3.6	5.4	3.0	4.20
FAWTH-29	58.4	60.1	1.7	173.0	85.9	3.6	3.4	4.6	3.6	4.5	3.7	4.10
Mean	57.3	59.5	2.3	162.4	84.1	3.0	3.2	5.4	3.6	5.0	4.1	4.55
SED	0.67	0.75	0.52	4.77	3.35	0.27	0.31	0.33	0.30	0.52	0.39	
CV (%)	2.0	2.2	39.5	5.1	6.9	15.5	16.5	9.0	14.4	17.8	16.8	

DA: Days to anthesis; DS: Days to silking; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; PASP: Plant aspect; EASP: Ear aspect; HCOV: Husk cover; FAWLD: Fall armyworm leaf damage; FAWED: Fall armyworm ear damage; BI: Base index; SED: Standard error of the difference; CV: Coefficient of variation.

Table 4. Mean performance for some agronomic traits of 29 white maize genotypes evaluated under fall armyworm protected condition for two seasons in Ibadan, Nigeria.

Entry	DA	DS	ASI	PH (cm)	EH (cm)	PASP (1 - 9)	EASP (1 - 9)	Streak score (1 - 9)	HCOV (1 - 9)
FAWTH-1	56.5	59.7	3.3	184.9	97.3	3.4	2.4	2.3	2.6
FAWTH-2	57.5	61.1	3.6	155.1	75.2	3.0	3.6	5.5	3.4
FAWTH-3	55.8	58.0	2.2	175.4	92.2	3.0	2.6	4.7	3.0
FAWTH-4	56.4	59.7	3.3	194.5	98.6	3.4	3.0	5.1	3.0
FAWTH-5	57.1	58.4	1.3	175.4	91.1	3.0	2.7	5.4	3.1
FAWTH-6	57.6	60.7	3.2	171.4	86.2	2.6	3.4	5.0	3.0
FAWTH-7	57.3	60.8	3.5	183.2	98.5	3.7	3.0	5.3	4.0
FAWTH-8	58.6	60.5	1.8	165.2	80.2	3.0	3.4	4.7	3.6
FAWTH-9	55.4	57.5	2.1	171.5	85.6	3.0	2.6	5.5	3.4

Table 4. Contd.

FAWTH-10	56.9	59.4	2.5	183.1	88.9	3.4	2.7	5.1	2.7
FAWTH-11	56.9	58.2	1.3	171.9	92.2	3.4	2.6	5.4	3.0
FAWTH-12	53.6	54.6	1.0	185.5	93.3	2.0	2.6	6.0	3.0
FAWTH-13	56.9	58.5	1.6	182.0	94.7	2.7	2.4	3.0	3.4
FAWTH-14	58.9	62.4	3.5	183.9	93.7	2.6	3.3	5.7	4.0
FAWTH-15	56.8	58.6	1.8	160.4	80.1	3.3	3.9	5.6	3.4
FAWTH-16	57.4	60.3	2.8	184.5	95.8	2.6	2.4	6.0	3.2
FAWTH-17	61.7	64.7	3.0	166.7	76.8	3.1	3.6	5.0	4.0
FAWTH-18	55.4	56.3	0.9	191.1	101.0	3.6	1.7	3.7	3.4
FAWTH-19	58.8	60.9	2.1	179.3	85.5	3.7	3.0	4.6	2.6
FAWTH-20	56.8	59.9	3.1	163.4	85.2	3.7	3.5	6.0	3.4
FAWTH-21	56.2	59.0	2.8	166.6	87.2	3.3	3.0	4.8	3.0
FAWTH-22	59.3	61.0	1.7	166.2	81.0	2.7	3.5	5.1	3.3
FAWTH-23	59.7	60.1	0.4	156.9	83.9	2.7	4.3	4.2	4.4
FAWTH-24	58.0	60.3	2.4	194.7	97.8	2.6	3.3	4.5	3.5
FAWTH-25	57.8	59.2	1.4	164.3	84.8	4.0	4.3	5.6	3.7
FAWTH-26	56.0	57.7	1.7	184.9	95.8	3.3	2.3	3.7	3.4
FAWTH-27	59.6	61.5	1.9	167.3	79.6	3.6	3.3	5.9	3.0
FAWTH-28	58.3	60.0	1.7	164.2	75.3	2.6	2.6	5.9	2.9
FAWTH-29	58.2	61.0	2.8	180.8	93.1	2.9	2.3	4.6	3.0
Mean	57.4	59.7	2.2	175.0	88.6	3.1	3.0	5.0	3.3
SED	1.20	1.21	0.65	6.40	5.27	0.26	0.33	0.49	0.29
CV	3.6	3.5	50.8	6.3	10.3	14.4	18.8	14.2	15.0

DA: Days to anthesis; DS: Days to silking; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; PASP: Plant aspect; EASP: Ear aspect; HCOV: Husk cover; SED: Standard error of the difference; CV: Coefficient of variation.

higher than the respective means (Table 5).

Using BI as selection criteria, the BI of the maize genotypes ranged from –6.80 (FAWTH-8) to 8.07 (FAWTH-13) (Table 5). The top nine high yielding genotypes had high positive BIs which ranged from 3.16 (FAWTH-28) to 8.07 (FAWTH-13). The GY of the top nine genotypes ranged from 4.90 (FAWTH-18) to 5.81 t ha^{-1} (FAWTH-1) with a mean of 5.27 t ha^{-1}. The bottom five genotypes had negative BIs ranging from -6.80 for FAWTH-8 to -3.16 for FAWTH-20.

Associations of base index with selection indices under FAW-infested condition

Base index had significant positive relationship with GY and significant negative relationships with FAW leaf damage (FAWLD), ear aspect (EASP), and FAW ear damage (FAWED) (Table 6). Negative significant associations were recorded between GY on the one hand, and EASP, FAWLD and FAWED. The associations among FAWLD, FAWED and EASP were positive and significant. However, PASP did not exhibit significant relationships with any of the traits.

DISCUSSION

The raging infestation by FAW is overwhelming

Table 5. Grain yield performance of 29 white maize genotypes evaluated under fall armyworm infested and protected conditions for two seasons in Ibadan, Nigeria.

Entries	Grain yield (t ha^{-1})		Yield reduction (%)	BI
	Protected	Infested		
FAWTH-13	5.26	5.48	-4.2	8.07
FAWTH-1	5.4	5.81	-7.6	7.71
FAWTH-4	4.41	5.46	-23.8	5.82
FAWTH-6	5.24	5.13	2.1	5.34
FAWTH-23	3.97	5.2	-31	4.39
FAWTH-10	4.97	5.28	-6.2	3.97
FAWTH-18	6.85	4.9	28.5	3.85
FAWTH-12	5.67	5.11	9.9	3.52
FAWTH-28	4.73	5.09	-7.6	3.16
FAWTH-7	4.52	4.69	-3.8	2.7
FAWTH-22	4.19	4.77	-13.8	1.02
FAWTH-19	6.71	4.36	35.0	0.65
FAWTH-27	4.16	4.78	-14.9	0.57
FAWTH-16	5.43	4.68	13.8	-0.01
FAWTH-3	5.12	4.69	8.4	-0.42
FAWTH-29	5.02	4.46	11.2	-1.28
FAWTH-24	5.02	3.97	20.9	-1.53
FAWTH-2	3.84	4.78	-24.5	-1.86
FAWTH-17	4.79	4.45	7.1	-2.1
FAWTH-15	4.02	4.43	-10.2	-2.32
FAWTH-25	3.42	3.99	-16.7	-2.53
FAWTH-20	3.78	4.07	-7.7	-3.16
FAWTH-9	4.64	4.43	4.5	-3.28
FAWTH-21	4.88	4.22	13.5	-3.6
FAWTH-11	4.78	4.09	14.4	-4.51
FAWTH-5	5.22	4.1	21.5	-4.79
FAWTH-26	5.14	4.14	19.5	-6.26
FAWTH-14	5.17	3.75	27.5	-6.29
FAWTH-8	4.51	3.44	23.7	-6.8
Mean	4.86	4.61	5.1	
SED	0.28	0.29		
CV	9.9	11.1		

BI: Base index; SED: Standard error of the difference; CV: Coefficient of variation.

and has become a major yield-limiting factor to maize production in SSA. Depending on extent of infestation, susceptibility of genotype and in the absence of appropriate control measures, FAW can cause up to 100% loss in maize grain yield (Prasanna et al., 2018). Host-plant resistance is the most sustainable management strategy to FAW infestation on maize in SSA. Stem borers (SB) are Lepidopteran pests like FAW, and exhibit similar mode of infestation on maize. Therefore, a search into maize germplasm exhibiting SB resistance could be a ready source of genes for tolerance to FAW infestation. In this study, 29 white maize genotypes with varying levels of resistance to SB were evaluated under artificial FAW- infested and FAW-protected conditions.

The observed genotypic differences, coupled with the enormous contribution of the sum of square for genotype to the total sum of squares for all the traits under both FAW-infested and FAW-protected environments demonstrated the existence of sufficient genetic variability among the test genotypes, which could be exploited for FAW tolerance breeding. Also, the main effects of environment, and genotype × environment interaction were non-significant, with very low contributions to the total sum of squares for all the traits under both FAW-infested and FAW-protected conditions. This indicated

Table 6. Linear relationships between base index and selection indices in 29 white maize genotypes evaluated under fall armyworm infested condition.

Genotype	GY	FAWLD	EASP	FAWED	PASP
BI	0.932***	-0.660***	-0.835***	-0.784***	-0.057
GY		-0.583***	-0.747***	-0.644***	0.059
FAWLD			0.493**	0.405*	-0.290
EASP				0.739***	-0.217
FAWED					-0.137

*;**;***: significant respectively at 0.05, 0.01, 0.001 probability levels. BI: Base index; GY: Grain yield; FAWLD: Fall armyworm leave damage; EASP: Ear aspect; FAWED: Fall armyworm ear damage; PASP: Plant aspect.

that the performance of the test genotypes was essentially due to their genetic make-up and little influenced by environmental factors. Similar observations were reported by Kamweru et al. (2023) and could be an indication of the preponderance of additive gene effects for the traits. It is pertinent to note that the test genotypes in this study had varying levels of tolerance to SB. In studies involving artificial SB infestation, Karaya et al. (2009), Beyene et al. (2011) and Olayiwola et al. (2021) reported the preponderance of additive gene effect in the inheritance of GY and SB damage traits in maize. Averaged across genotypes, a comparison of the grain yields under FAW-infested and FAW-protected condition revealed a 5% reduction, which suggests that SB resistance could confer tolerance to FAW infestation.

The level of resistance to FAWLD and FAWED exhibited by most of the test genotypes in this study was moderate. None of the genotypes was highly resistance or highly susceptible to both FAW damage parameters. Cultivation of partially resistant genotypes could serve as an interim management strategy for farmers as well as valuable genetic resource for breeding programs targeted at the development maize genotypes with resistance to the twin effects of FAW and SB infestation. Other studies (Ni et al., 2014; Abel et al. 2020; Kasoma et al., 2020, 2021b; Kamweru et al. 2023) have also found maize genotypes expressing moderate resistance to FAW.

Results from this study revealed that GY was significantly but negatively correlated with FAWLD and FAWED, which implied FAW infestation reduced maize GY. Similar negative relationships between GY and FAW damage parameters had been reported by previous studies (Assefa and Ayalew, 2019; Overton et al., 2021; Job et al. 2022; Kamweru et al., 2023). Grain yield is directly impacted by FAWLD. The FAW larvae's leaf feeding and whorl damage causes a reduction in the plant's capacity to photosynthesize, leading to a disruption in assimilate translocation and partitioning, which results in impaired growth, poor grain filling and yield. The older caterpillars burrow into the maize cob, damaging the maize ear and kernels, and predisposing the kernels to secondary infections (Buntin, 1986; Anjorin et al., 2022). Additionally, FAWED leads to a reduction in seed and grain quality by predisposing the kernels to fungal attack, rot and mycotoxin accumulation (Williams et al., 2018). The positive and significant association among FAWLD, FAWED and EASP suggests that any one of the traits could be used to predict the other two. Matova et al. (2022) also reported similar positive correlations among FAW damage parameters.

In the present study, a BI which included five traits (GY, EASP, FAWLD, FAWED and PASP) was used as a selection criterion. The highly significant correlations between BI and GY (r=0.93), EASP (r=-0.84), FAWLD (r=-0.66) and FAWED (r=-0.78) indicated that high BI could be effectively used to select genotypes that combined high grain yield with FAW tolerance/resistance. Oloyede-Kamiyo (2019) has shown the effectiveness of base index in the selection of desirable maize genotypes under stem borer infestation.

Conclusion

Fall armyworm has assumed the status of the most destructive yield-limiting insect pest of maize in sub-Saharan Africa. Cultivation of varieties with resistance to fall armyworm is most economical, sustainable and compatible with other management options targeted at enhancing maize grain yields in sub-Saharan Africa. In this study, some white maize genotypes with varying levels of tolerance to stem borer were evaluated for their agronomic performance under artificial fall armyworm infestation.

The genotypes evaluated varied widely for grain yield, agronomic traits and fall armyworm damage traits. Our study revealed the utility of stem borer resistant germplasm as reservoir for fall armyworm tolerant genes. Averaged across genotypes, grain yield reduction under fall armyworm infestation was low (5.1%) suggesting that resistance to stem borer could also confer tolerance to fall armyworm damage. Grain yield was negatively and significantly related with fall armyworm damage parameters, indicating that low fall armyworm damage scores can be used to identify tolerant and high yielding genotypes. Highly significant correlations were also found between base index and grain yield, ear aspect, fall armyworm leaf damage and fall armyworm ear damage indicating it could be effective as selection criteria for combined fall armyworm tolerance and high grain yield. Genotypes FAWTH-1, FAWTH-13, FAWTH-4, FAWTH-10, FAWTH-23 and FAWTH-6 with positive base index ≥ 4.0 and grain yield ≥ 5.13 t ha^{-1} under fall armyworm infested condition were identified as promising candidates that combined tolerance to fall armyworm with high grain yields.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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