Field Response and Genetic Variability Analyses of Maize (*Zea mays* L.) Hybrids and Commercial Varieties Under Natural Fall Armyworm (*Spodoptera frugiperda* (J. E. Smith)) Infestation in Lowland Tropical Ecology

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Abstract

Fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) (FAW) impacts maize (*Zea mays* L.) production. No maize genotype is completely resistant to FAW. This experiment was conducted in Calabar, Cross River State, with twenty maize genotypes using a randomized complete block design with three replications. These maize genotypes varied in responses to FAW scores, plant height, leaf count, plant standability and performance, days to 50% anthesis and silking, anthesis-silking interval, fresh and de-husked cob weight and length, husk proportion, ear rating, grains per cob, 100-seed weight, and grain yield. FAW score perfectly correlated with plant and ear ratings. Grain yield is strongly associated with cobs per plant and grains per cob. The study of this genetic variability showed that while seedling emergence, days to 50% anthesis, and 50% silking showed moderate genetic gain, all other traits showed high genetic gain. This suggests that under FAW pressure, it might be possible to choose maize genotypes that have these traits. FAW score, plant standability and performance, and ear rating were all found to be in the same cluster in the principal component and genotype-by-traits biplot analyses. This proved that they were useful for the identification of maize genotypes that are tolerant to FAW pressure. In one cluster were cobs per plant, husk covering, cob length, and grains per cob with grain yield. This further confirmed the importance of these traits in selecting maize genotypes with high yield potential under FAW pressure. Despite FAW pressure, maize genotypes AS2001-20, AS2001-24, M1628-8, AS2106-63, and FAW 2212 demonstrated high grain yields considerable for inclusion in further FAW-related studies.

Abbreviations

AGG: Accelerating Genetic Gains
BS: Base saturation
CIMMYT: Centro Internacional de Mejoramiento de Maíz y Trigo(International Maize and Wheat Improvement Center)
CRADP: Cross River Agricultural Development Programme
CRBDA: Cross River Basin Development Authority
ECEC: Effective cation exchange capacity
FAW: Fall armyworm
IBPGR: International Board for Plant Genetic Resources
IITA: International Institute of Tropical Agriculture
ITPGRFA: International Treaty on Plant Genetic Resources for Food and Agriculture
OC: Organic carbon
PBTools: Plant Breeding Tools
PCA: Principal Component Analysis
SMTA: Standard Material Transfer Agreement
TN: Total nitrogen
WAE: Weeks after emergence
WAP: Weeks after planting

Introduction

Drought, climate change, and pests like fall armyworm (FAW) (*Spodoptera frugiperda* J. E. Smith) threaten maize (*Zea mays* L.) production (Singh *et al.*, 2021). FAW is native to the tropical western hemisphere from the US to Argentina (Nagoshi *et al.*, 2022). FAW was first reported in West and Central Africa in 2016; two distinct haplotypes were found in maize samples from Nigeria and São Tome, suggesting multiple introductions into Africa (Goergen *et al.*, 2016). FAW is a good colonizer with a prolific reproductive rate (1500–2000 eggs per female), a 30-day generation time, and good dispersal (Otim *et al.*, 2021). Evidence suggests migration is a major part of FAW's life history (Daudi *et al.*, 2021; Johnson, 1987). One of the most mobile noctuid pests in the Western Hemisphere, FAW has had irregular outbreaks in the US (Dinka and Edosa, 2021). The first outbreak affected Georgia grains and grasses in 1797 (Johnson, 1987). Many countries in tropical Africa experience severe outbreaks of larval armyworms in economic crops at the start of the wet season, especially after a long drought (Goergen *et al.*, 2016). As a polyphagous pest, FAW is expected to threaten several important crops in Africa after its accidental introduction (Kumar *et al.*, 2022). In 76 African and Asian countries, FAW has reduced maize production and affected millions of smallholder farmers (Singh *et al.*, 2021; Wan *et al.*, 2021). FAW affects almost 100 plant species in 27 families (Abro *et al.*, 2021; Assefa *et al.*, 2019; De Groote *et al.*, 2020). Maize, millet, sorghum, rice, wheat, and sugarcane are preferred FAW hosts (Matova *et al.*, 2022a; Matova *et al.*, 2022b). Cowpea, groundnut, potato, soybean, and cotton also suffer FAW damage (Assefa *et al.*, 2019; Tepa-Yotto *et al.*, 2022).

Goergen *et al.* (2016) suggest several reasons why S. frugiperda may become more damaging to maize than other African species of the same genus: (a) Adult females of S. frugiperda directly oviposit on maize, unlike most other Spodoptera species in Africa; (b) the caterpillars' mandibles have stronger, serrated cutting edges, which make feeding on high-silica plants easier; (c) older larvae become cannibalistic; and (d) maize is particularly damaged in several tropical American countries where the pest can reproduce continuously. Brazil, the third-largest maize producer after the US and China, considers S. frugiperda its most important pest. In this country, FAW control on maize costs over 600 million dollars annually. The introduction of S. frugiperda to Africa may hurt agricultural production and foreign market access (Abro *et al.*, 2021; De Groote *et al.*, 2020; Goergen *et al.*, 2016). Given its high spreading performance, large reproductive capacity, absence of diapause, and wide host plant range, FAW may soon colonize most of tropical Africa (Day *et al.*, 2017). Identifying ecologically specific maize hybrids that can withstand the FAW without compromising economic yields is urgent. Armyworms were first observed on maize plants in the rainforest zone of southwestern Nigeria and in maize fields at the International Institute of Tropical Agriculture (IITA) at Ibadan and Ikenne in late January 2016, but initial attacks were attributed to indigenous West African Spodoptera Guenée, 1852 (Lepidoptera: Noctuidae) species (Goergen *et al.*, 2016). FAW was later reported in Northern Nigeria, Benin, and Togo; these consistent reports from West and Central African countries about sudden and severe armyworm outbreaks suggested a new regional problem. Reports from the southwest (Ojumoola *et al.*, 2022), FCT (Akhigbe *et al.*, 2021), and northern Nigeria (Kano and Kaduna States) show that FAW has been present in Nigeria since 2016. Besides Obok *et al.* (2021a), there is currently no published research on maize genetic diversity against FAW in Cross River State, one of Nigeria's humid tropical rainforests agroecological areas. Formalized collaboration with 25 national partners in humid and sub-humid sub-Saharan Africa involves IITA in research-for-development under the Accelerating Genetic Gain (AGG) Project's 2023 Stress Resilient Regional Maize Variety and Hybrid Trials. This preliminary trial will determine these improved maize hybrids' natural FAW infestation response and provide pilot data for future trials. Our study is part of the 'Preliminary FAW Hybrid Trial' aimed at screening lowland tropical maize hybrids against natural FAW pressure in the field, which involves the evaluation of the field performance of maize hybrids under natural FAW pressure, the determination of the genetic components and heritability estimates of maize genotypes for agronomic and FAW resistance and/or tolerance traits, and the identification of important agronomic traits in promising maize hybrids for FAW-resistant breeding.

Materials and methods

Site location description

The experiment was conducted in trial plots at the Cross River Basin Development Authority (CRBDA) at Murtala Mohammed Highway, Calabar (5° 2' 49.56" N, 8° 21' 50.4" E). Seasonal agricultural practices dominate CRBDA, largely dependent on rainfed agriculture (Akpabio *et al.*, 2008). The allocated experimental plot area (with three experimental blocks) (30 m × 8 m) was pesticide-free before and during the trial. Adjourning plots (200–300 m surroundings) had never been pesticide-treated prior to the study. Smallholder farmers in the area confirmed historical FAW infestations. Thus, we conducted the study under rainfed conditions and natural FAW pressure during the early cropping season of 2023 (March–July), when FAW peaks in Calabar, based on our previous findings.

Soil sample collection and analysis

Soil samples (20 cm depth) were obtained from each experimental block (top, middle, and bottom sections) utilizing a soil auger. The samples were combined to form a composite soil sample. The composite soil sample was created and examined for physical and chemical parameters as specified by Helrich (1990). The proportions of sand, clay, and silt were evaluated using the hydrometer method of mechanical analysis (Bouyoucos, 1951; Davidson, 1954; Day, 1953). The pH was assessed in H_2O (Bates, 1954; Clark, 1922). Total nitrogen was measured with the traditional macro-Kjeldahl technique (Jackson, 1958). The determination of available phosphorus was conducted using the Bray No. 1 method (Bray and Kurtz, 1945; Jackson, 1958). Potassium, calcium, magnesium, and sodium were examined utilizing a flame photometer and atomic absorption spectrophotometer (Jackson, 1958).

Maize genetic resources

Within the Stress Resilient Regional Maize Variety and Hybrid Trials of the AGG project, overseen by the International Institute of Tropical Agriculture (IITA), 20 intermediate to late maturing maize hybrids (110–120 days) were chosen for the Preliminary FAW Hybrid Trial in lowland tropics subjected to natural FAW infestation. The maize hybrid seeds, designated as 'Plant Genetic Resources for Food and Agriculture,' were obtained via the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) under the Standard Material Transfer Agreement (SMTA) of IITA (International Treaty on Plant Genetic Resources for Food and Agriculture, 2012; Manzella, 2018).

Table 1 - Maize genotypes used for the 2023 preliminary FAW hybrid trial in Calabar

Entry Number	Name	Origin
1	AS2001-3	IITA, Ibadan
2	AS2001-12	IITA, Ibadan
3	AS2001-19	IITA, Ibadan
4	AS2001-20	IITA, Ibadan
5	AS2001-22	IITA, Ibadan
6	AS2001-24	IITA, Ibadan
7	M1628-10	IITA, Ibadan
8	M1628-8	IITA, Ibadan
9	AS2106-22	IITA, Ibadan
10	AS2106-43	IITA, Ibadan
11	AS2106-63	IITA, Ibadan
12	AS2106-66	IITA, Ibadan
13	FAW2206	IITA, Ibadan
14	FAW2204	IITA, Ibadan
15	FAW2210	IITA, Ibadan
16	FAW2207	IITA, Ibadan
17	FAW2212	IITA, Ibadan
18	OBA SUPER 9	IITA, Ibadan
19	SC719	IITA, Ibadan
20	ZMS623	IITA, Ibadan

Experimental design, treatments and agronomic practices

This trial used a three-replication randomized complete block design. Treatment plots were randomly assigned to 20 maize genotypes per block (replicate) using a table of random numbers (Gomez and Gomez, 1984). The site was manually cleared and lightly pulverized. Experimental blocks were divided by a 1-meter alley. Each treatment plot measured 1.5 m by 2 m and contained 16 stands, arranged as 8 stands per row. The net plot, measuring 2.25 m², comprised 12 stands arranged in 2 rows of 6 stands each, from which data were collected. Agricultural lime ($CaCO_3$) (obtained from the CRADP Office) was uniformly broadcasted on the experimental blocks at the rate of 500 kg ha^{-1} and then worked into the soil by minimal tillage at a depth of 20 cm as described by Obok *et al.* (2022); Obok *et al.* (2023). Each experimental block (30 m x 2 m) received 3 kg of lime (i.e., 150 g per experimental plot). A period of 7 days was allowed between lime application and planting. The maize seeds were planted after rains stabilized. The plant spacing was 0.75 m between rows and 0.25 m between hills, two seeds per hill.

Thinning and gapping (or transplanting) (Adesina *et al.*, 2014; Olabode *et al.*, 2018) were done two weeks after emergence (WAE) to maintain one plant per hill (53,333 plants per hectare). NPK 20:10:10 fertilizer (80 kg N ha^{-1}) was applied by band placements at a depth of 3–5 cm at 2 WAE. Top-dressing with urea fertilizer (46% N) was done at 6 WAE at the rate of 40 kg N ha^{-1}. Weeds were controlled culturally by hand hoeing.

Data collection

Growth and yield data were collected based on CIMMYT/IBPGR crop descriptors for maize (International Board for Plant Genetic Resources, 1991).

Seedling emergence (%):

Seedlings were observed for emergence 5 to 7 days post-planting throughout the whole plot. The germination percentage of seeds that successfully emerged above the earth was determined in relation to the total number of seeds placed in each plot.

Plant height (cm):

The stem length from ground level to the flag leaf was recorded at 4 weeks after planting (WAP), 8 WAP, and at harvest.

Number of leaves per plant (counts):

The count of fully opened leaves was recorded per plant at 4 weeks after planting (WAP), 8 WAP, and at harvest.

Fall armyworm score (rating):

Visual assessments and evaluations of the extent of FAW damage were performed on each leaf per plant within the net plot at 4 WAP, 8 WAP, 12 WAP, and at harvest. Leaf damage was evaluated using a scale from 1 to 9, where 1 indicated no visible damage and 9 represented 80–100% defoliation of the entire leaf area (Davis *et al.*, 1992; Prasanna *et al.*, 2022). A plant receiving a score of 1 to 2 was classified as resistant to FAW; a score between 3 and 5 indicated tolerance, while scores ≥ 5 denoted susceptibilities to FAW (Anyanda *et al.*, 2022).

Plant-standability and performance (scale):

From a scale of 1 to 9, plant aspect was rated based on plant attractiveness, uniformity, disease and insect damage, and lodging. 1 was an outstanding plant type and 9 was a poor plant type. Others were 2 = very good, 3 = good, 4 = satisfactory, 5 = acceptable, 6 = undesirable, 7 = bad and 8 = worse.

Days to 50 % anthesis

Days from seeding to 50% pollen release.

Days to 50 % silking:

Duration from sowing to the emergence of silks on 50% of the plants.

Anthesis-silking interval (days):

The difference between 50% anthesis and silking days was calculated.

Number of cobs per plant (counts):

Per plant, mature cobs were counted.

Fresh cob weight (g):

The husked cobs were weighed using a scale.

De-husked fresh cob weight (g):

The cobs without the husk were weighed using a balance.

Husk proportion (%):

The husk proportion (percentage) was calculated as the weight of the husk (g) relative to the weight of the cob with husk.

De-husked cob length (cm):

Length of a cob without the husk was measured from base to tip.

Ear rating (scale):

At harvest, ear aspect was rated on a scale of 1 – 9, where 1 = 0 %, 2 = 1 – 20 %, 3 = 21 – 30 %, 4 = 31 – 40 %, 5 = 41 – 50 %, 6 = 51 – 60 %, 7 = 61 – 70 %, 8 = 71 –80 %, 9 = 81 – 100 % of the kernels exhibiting visible symptoms of rotten grains (Anyanda *et al.*, 2022; Prasanna *et al.*, 2022).

Number of grains per cob (counts):

The number of grains in each row was counted and summed up.

100-seed weight (g):

The weight of 100 seeds was determined from five groups of 20 seeds each.

Grain yield (t ha^{-1}):

Using the formula of Borrero *et al.* (1992), grain moisture content was determined and grain yield (kg ha^{-1}) was adjusted to 15% moisture content = field weight (kg) ÷ area (m^2) × (100-moisture) ÷ 85 × (10,000 × 0.80).

Data analysis

Using GenStat 16th Edition, version 16.1.0.10916, a two-way ANOVA was performed on the obtained data. Duncan's multiple range test differentiated mean differences after large F-tests with 95% confidence. PBTools (Plant Breeding Tools) version 1.3 was used to calculate phenotypic variance, genetic variance, phenotypic coefficient of variability, genotypic coefficient of variability, broad-sense heritability, genetic gain at 5% selection intensity, and genetic gain as a percentage of the mean values for each trait. Principal Component Analysis (PCA), genotype-trait biplot, and cluster analyses were done using PAST 4.10 (Hammer and Harper, 2001).

Results and Discussion

Soil physical and chemical properties

The soil at the experimental location had loamy sand texture and an average pH value of 5.19, indicating that it was strongly acidic (Table 2). Available phosphorus, potassium, and sodium were 21.33 (mg kg^{-1}), 0.09 (cmol kg^{-1}), and 0.08 (cmol kg^{-1}). Base saturation (BS) was 83.37%, while ECEC was 4.58 cmol kg^{-1}. Light-textured, low-ECEC soils are more leaching-prone. The soil pH is affected continuously. High rainfall and year-round warmth cause acidic soils. These characteristics match Calabar, the experimental site. The parent material determines soil pH. Adding manure, nitrogen, phosphorus, and lime to acidic soil improves its physical and chemical qualities (Anetor and Akinrinde, 2006; Onwonga *et al.*, 2010). Researchers found that maize is highly susceptible to soil acidity and alkalinity. In Calabar, maize should receive 120 kg N ha^{-1} fertilizer and 500 kg ha^{-1} lime. Total nitrogen was 0.10% and soil organic carbon (OC) was 0.83%. Depending on soil texture and precipitation zones, field crops should have 1–2% organic carbon (OC), whereas pasture should have 2 – 5%. The experimental site's soil lacked the 1.0% organic carbon threshold established by Agboola and Ayodele (1987). Increased organic carbon may improve soil cation exchange and nutrient retention, boosting soil production. Organic carbon is highly correlated with soil health rather than yield (Peverill *et al.*, 1999; Slavich and Petterson, 1993).

Total nitrogen (TN) measures soil nitrogen, mostly held in organic matter and hence inaccessible to plants. Low (0.05%) to high (>0.5%) (Hazelton and Murphy, 2016). A low TN of 0.1% was found. Nitrate or ammonia is needed for plants to acquire nitrogen. Nitrogen in organic matter pools is mineralized to form nitrate and ammonia for plant development. Soil is rich in potassium (K). The parent material, weathering and leaching of soil minerals, clay minerals, soil texture, organic matter concentration, and potassium fertilization history determine soil potassium. Thus, soils with high potassium levels may respond to potassium fertilizers since a large amount of potassium is accessible to plants and crops. This investigation found 0.09 cmol kg^{-1} potassium. K threshold values for surface soils are 0.2–0.5 cmol kg^{-1} (Scanlan *et al.*, 2017). Thus, the experimental soil lacked potassium. Extractable aluminum is directly associated with soil pH and becomes a problem below 5.5. As extractable aluminum surpasses 2, sensitive plants will be affected by aluminum toxicity, and too much soluble and/or accessible aluminum (Al^{3+}) may harm plants.

Table 2 - Physical and chemical properties of soil at the experimental site

Soil property	Value
Soil texture (g kg^{-1})	
Sand	889.0
Silt	26.7
Clay	84.3
Textural class (USDA-NRCS, 2016)	Loamy sand
pH (in H_2O)	5.19
Organic carbon (%)	0.83
Total nitrogen (%)	0.10
Available phosphorus (mg kg^{-1})	21.33
Potassium (cmol kg^{-1})	0.09
Sodium (cmol kg^{-1})	0.08
Calcium (cmol kg^{-1})	2.00
Magnesium (cmol kg^{-1})	1.67
Aluminum (cmol kg^{-1})	0.09
Hydrogen (cmol kg^{-1})	0.67
Effective cation exchange capacity (cmol kg^{-1})	4.58
Base saturation (%)	83.37

Effective Cation Exchange Capacity (ECEC) of soil impacts structural stability, nutrient accessibility, pH, and fertilizer and amendment response. Higher clay content increases ECEC (Slavich and Petterson, 1993). Soil pH, organic matter, and clay content affect ECEC. Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and acidity (Al^{3+}, H^{+}) are measured in cmol kg^{-1} as ECEC. Hazelton and Murphy (2016) recommend 5–25 cmol kg^{-1} ECEC. ECEC was below 5 cmol kg^{-1} in the experimental soil, indicating low fertility. Base saturation between 70 and 100% indicates minimal leaching of exchangeable bases (Hazelton and Murphy, 2016). The experimental soil BS was 83.37%.

Phenotype variations in growth traits of maize genotypes

Seedling emergence percentage

Table 3 shows a significant difference ($p < 0.05$) in maize genotypes by the number of seeds that germinated and emerged seven days after planting (DAP). It was not statistically significant ($p > 0.05$) that maize genotypes AS2001-19, AS2001-22, AS2106-43, and FAW 2206 had the most germinated seeds (95%). Oba super 9, ZMS623, and SC719 had the lowest seedling emergence rates (80–85%), which were not statistically different ($p > 0.05$) from genotypes M1628-10, M1628-8, FAW 2207, FAW 2204, AS2106-63, AS2001-3, and AS2001-20. Nitrogen (N) deficit limits maize production, along with genotype-related seed germination and emergence. Increased nitrogen utilization efficiency through root growth genetics might improve seed germination and seedling emergence. Khaeim *et al.* (2022) reported that temperature and soil moisture also impact maize seed germination and seedling development. The minimal rainfall recorded in March (unpublished weather data) may have adversely affected seed germination and seedling emergence, as well as seed intrinsic germination capabilities, despite the sowing temperature being within the optimal range (10–40°C) for maize sowing and emergence, as noted by Sánchez *et al.* (2014) and Waqas *et al.* (2021).

Plant height

The maize genotype FAW 2206 is significantly taller (75 cm) than other genotypes at four weeks post-planting (p < 0.05). Statistics showed that maize genotypes AS2001-19 (59 cm), AS2001-22 (59 cm), AS2001-3 (64 cm), and FAW 2212 (64 cm) were similar in height. The shortest maize genotype was ZMS623 at 4 WAP (p < 0.05). After 8 weeks after planting, maize genotype FAW 2207 had the highest height (126 cm) compared to other genotypes (p < 0.05). Maize genotypes AS2106-66 (78 cm), AS2106-43 (86 cm), AS2106-22 (87 cm), and AS2001-24 (87 cm) produced the shortest plants (p ≤ 0.05).

Plant height at 8 WAP differed significantly (p ≤ 0.05), while Oba super 9 was equivalent to FAW 2212 (p > 0.05). ZMS623 and AS2001-22 maize genotypes did not vary significantly (p > 0.05). FAW 2204 had the tallest maize at harvest (198 cm) (p < 0.05), whereas FAW 2212 had the shortest plants (103 cm). Plant heights were similar for maize genotypes FAW 2207 and FAW 2206 (p > 0.05). The tallest genotype was ZMS623 at 151 cm, followed by Oba Super 9 at 135 cm and SC719 at 131 cm. According to Job *et al*. (2022), genotype affects maize plant height under natural FAW infestation circumstances in Benin, Mokwa, Lafia, Dutsin Ma, and Zaria, Nigeria.

Number of leaves per plant

At 4 weeks following planting, all maize genotypes had at least five leaves per plant. Among all maize genotypes, AS2001-22, FAW2206, and Oba Super 9 had the maximum leaf count (8), statistically significant (p < 0.05) at 4 weeks post-planting (WAP). Only AS2106-66 and SC719 produced five leaves per plant, whereas other maize genotypes produced 6–7. At 8 weeks after planting (WAP), maize genotype FAW 2206 had the most leaves (12) (p < 0.05), while genotype M1628-8 had the fewest (7). Maize genotypes AS2001-19, AS2001-20, AS2106-63, AS2106-66, FAW 2210, FAW 2212, and M1628-10 had 9 leaves like Oba super 9. At 8 WAP, SC719 had eight leaf counts per plant like maize genotype AS2106-43. ZMS623 and FAW 2207 maize genotypes had similar average leaf counts per plant. AS2001-22, FAW 2204, M168-8, and ZMS623 had the greatest average leaf count per plant (14) at harvest, while AS2106-22 had the lowest (9). Harvested maize genotypes AS2001-19, AS2001-3, FAW 2206, and FAW 2207 had 13 leaves per plant, whereas SC719 and FAW 2212 had 10. Many field, laboratory, and survey investigations have shown that FAW infestation reduces maize growth and leaves' photosynthetic activity.

Fall armyworm score

The fall armyworm score (3) was consistent (p > 0.05) across all maize genotypes at 4 weeks after planting, according to Table 4 and field observations in Fig. 1. Four weeks (8 WAP) later, the fall armyworm score was significantly higher (p ≤ 0.05) for the check genotype, with the highest score being 5. At eight weeks after planting, maize genotypes AS2001-20, AS2001-24, FAW 2204, FAW 2206, FAW 2207, FAW 2210, and M1628-10 had fall armyworm scores comparable (p > 0.05) to SC719. Fall armyworm scores at 12 WAP demonstrated a consistent pattern (p < 0.05), with maize genotype SC719 scoring lowest (3), followed by ZMS623 (4) and Oba super 9 (5). Fall armyworm scores for maize genotypes AS2001-22, AS2106-22, AS2106-43, AS2106-63, AS2106-66, FAW 2206, FAW 2210, and FAW 2212 were equivalent (p > 0.05) to Oba super 9. At 12 weeks after planting, FAW 2204 and M1628-8 maize genotypes had the lowest fall armyworm scores, along with SC719. Despite higher fall armyworm scores, all maize genotypes progressed similarly at harvest as at 12 WAP. Genotype affects leaf damage in maize plants with natural FAW infestation, but not ear damage (Job *et al*., 2022). FAW resistance was not detected in the 20 maize genotypes studied. The acceptability and feeding preferences of FAW larvae to different maize genotypes may explain FAW attacks. These findings were also reported by Morales *et al.* (2021). This analysis confirms Kasoma (2020) and Kasoma *et*

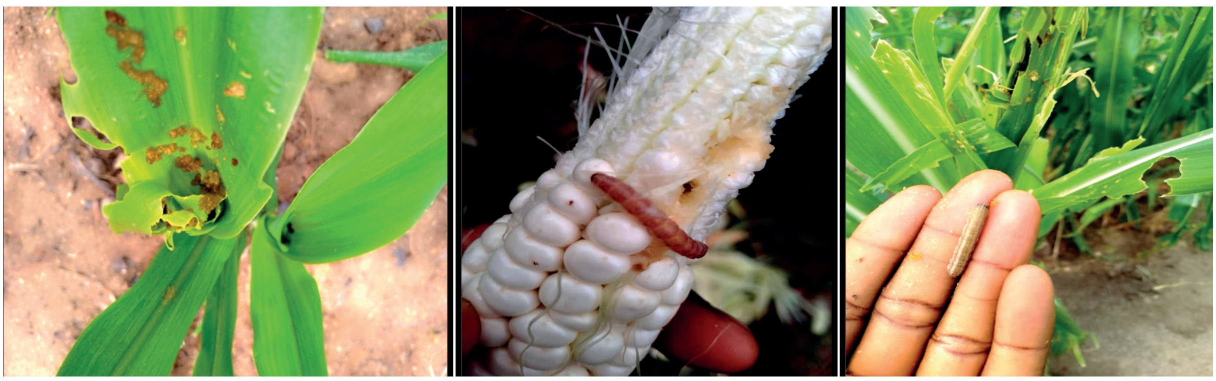

Fig. 1 - Fall armyworm infestations in the field (from left to right) frass in whorls, presence of larva in mature cob and a sampled larva during scouting.

Table 3 - Seedling mergence, plant height, and leaf count of hybrids and commercial maize varieties in Calabar

Genotype	Seedling emergence (%)	Plant height (cm)			Number of leaves per plant		
		4WAP	8WAP	Harvest	4WAP	8WAP	Harvest
AS2001-12	95.0 ab	57.0 j	96.0 g	104.0 p	6.5 c	8.5 e	11.5 d
AS2001-19	100.0 a	59.0 i	92.0 i	145.0 i	7.0 b	9.0 d	13.0 b
AS2001-20	85.0 cd	62.0 g	97.0 f	142.0 j	6.0 d	9.0 d	11.0 e
AS2001-22	100.0 a	59.0 i	95.0 h	174.0 b	8.0 a	10.0 c	14.0 a
AS2001-24	90.0 bc	60.0 h	87.0 m	159.0 e	6.0 d	10.0 c	12.0 c
AS2001-3	80.0 d	64.0 e	105.0 c	128.0 n	7.0 b	10.0 c	13.0 b
AS2106-22	90.0 bc	53.0 m	87.0 m	116.0 o	7.0 b	8.5 e	9.0 g
AS2106-43	100.0 a	63.0 f	86.0 n	153.0 g	6.0 d	8.0 f	11.0 e
AS2106-63	80.0 d	55.0 k	88.0 l	162.0 d	6.0 d	9.0 d	12.0 c
AS2106-66	90.0 bc	53.0 m	78.0 o	139.0 k	5.0 e	9.0 d	12.0 c
FAW 2204	80.0 d	52.0 n	112.0 b	198.0 a	6.0 d	10.0 c	14.0 a
FAW 2206	100.0 a	75.0 a	103.0 e	156.0 f	8.0 a	12.0 a	13.0 b
FAW 2207	80.0 d	69.0 b	126.0 a	156.0 f	7.0 b	11.0 b	13.0 b
FAW 2210	90.0 bc	66.0 d	92.0 i	145.0 i	7.0 b	9.0 d	12.0 c
FAW 2212	90.0 bc	64.0 e	91.0 j	103.0 q	7.0 b	9.0 d	10.0 f
M1628-10	80.0 d	52.0 n	104.0 d	139.0 k	6.0 d	9.0 d	12.0 c
M1628-8	85.0 cd	54.0 l	97.0 f	171.0 c	6.0 d	7.0 g	14.0 a
Checks							
Oba super 9	80.0 d	68.0 c	91.0 j	135.0 l	8.0 a	9.0 d	11.0 e
SC719	85.0 cd	34.0 p	90.0 k	131.0 m	5.0 e	8.0 f	10.0 f
ZMS623	80.0 d	36.0 o	95.0 h	151.0 h	6.0 d	11.0 b	14.0 a

WAP = Weeks after planting. Mean values with the same letter (s) within column are not significantly different ($p > 0.05$) using Duncan's multiple range test

al. (2022) that Africa has no consistent FAW resistance sources. Reports emphasize FAW tolerance over resistance.

Plant-standability and performance

The average harvest plant aspect assessment of maize genotypes was 5–7. The check, SC719, received the lowest plant aspect rating of 5, followed by ZMS623 with a rating of 6 and Oba Super 9 with a rating of 7. FAW 2206, FAW 2210, FAW 2212, AS2001-22, AS2106-22, AS2106-43, AS2106-63, and AS2106-66 have similar plant aspect ratings ($p > 0.05$) to Oba Super 9. The maize genotypes FAW 2204 and M1628-8 have similar harvest plant aspect ratings to SC719. Job *et al.* (2022) found that the genotypic effect on plant aspect scores remained consistent under natural FAW infestation, contrary to this study.

Variations in grain yield and related traits of maize genotypes under natural FAW pressure.

Days to 50 percent anthesis

Table 5 shows that maize genotypes took 55 to 78 days to reach 50% anthesis. Among maize genotypes, FAW 2210 reached 50% anthesis fastest (55 days) and ZMS623 the slowest (78 days). From planting to 50% anthesis, FAW 2204 and FAW 2206 maize genotypes had similar durations ($p > 0.05$) to Oba super 9 (64 days). To reach 50% anthesis, maize genotypes AS2001-20, AS2001-22, and AS2001-24 took 63 days, like AS2106-66. A highly substantial genetic effect on days to anthesis was shown by Job *et al.* (2022). During flowering, maize undergoes stress, which slows ear growth relative to tassel growth and reduces photosynthate production, according to Edmeades *et al.* (2000).

Days to 50 percent silking

ZMS623 had the longest time to reach 50% silking (87.4 days), followed by SC719 (77 days) and Oba Super 9 (69 days). Other genotypes had varying durations from 65 to 74.5 days ($p \leq 0.05$). This supports Job *et al.* (2022) findings of significant differences in days to silking among maize genotypes assessed under natural conditions.

Anthesis-silking interval

The ASI ranged from 4 to 12 days for all genotypes. ZMS623 (4.4 days) and Oba super 9 (5 days) had ASI equivalent ($p > 0.05$) to maize genotypes AS2001-20, AS2001-22, AS2106-63, AS2106-66, and FAW 2204. Maize genotypes AS2001-19, AS2106-43, FAW 2206, FAW 2207, and M1628-10 had 11-day anthesis-silking intervals (ASI). A broad ASI indicates stress conditions during pollination and silking, which reduces maize yield potential. Job *et al.* (2022) found no genotype

Table 4 - Fall armyworm score and plant aspect of hybrids and commercial maize varieties in Calabar

Genotype	Fall armyworm score (1 – 9)				Plant aspect (1 – 9)
	4WAP	8WAP	12WAP	Harvest	
AS2001-12	3.0 a	4.0 b	4.0 b	5.0 b	6.0 b
AS2001-19	3.0 a	4.0 b	4.0 b	5.0 b	6.0 b
AS2001-20	3.0 a	3.0 c	4.0 b	5.0 b	6.0 b
AS2001-22	3.0 a	4.0 b	5.0 a	6.0 a	7.0 a
AS2001-24	3.0 a	3.0 c	4.0 b	5.0 b	6.0 b
AS2001-3	3.0 a	4.0 b	4.0 b	5.0 b	6.0 b
AS2106-22	3.0 a	4.0 b	5.0 a	6.0 a	7.0 a
AS2106-43	3.0 a	4.0 b	5.0 a	6.0 a	7.0 a
AS2106-63	3.0 a	4.0 b	5.0 a	6.0 a	7.0 a
AS2106-66	3.0 a	4.0 b	5.0 a	6.0 a	7.0 a
FAW 2204	3.0 a	3.0 c	3.0 c	4.0 c	5.0 c
FAW 2206	3.0 a	3.0 c	5.0 a	6.0 a	7.0 a
FAW 2207	3.0 a	3.0 c	4.0 b	5.0 b	6.0 b
FAW 2210	3.0 a	3.0 c	5.0 a	6.0 a	7.0 a
FAW 2212	3.0 a	4.0 b	5.0 a	6.0 a	7.0 a
M1628-10	3.0 a	3.0 c	3.0 c	4.0 c	5.0 c
M1628-8	3.0 a	4.0 b	4.0 b	5.0 b	6.0 b
Checks					
Oba super 9	3.0 a	5.0 a	5.0 a	6.0 a	7.0 a
SC719	3.0 a	3.0 c	3.0 c	4.0 c	5.0 c
ZMS623	3.0 a	4.0 b	4.0 b	5.0 b	6.0 b

WAP = Weeks after planting. Mean values with the same letter (s) within column are not significantly different ($p > 0.05$) using Duncan's multiple range test

effect on ASI. Stress tolerance during flowering is associated with a lower maize ASI (Edmeades *et al.*, 1993). This may be caused by soil fertility, moisture, temperature, or insect pests (Ewansiha *et al.*, 2023). ASI illustrates reproductive success procedures. Edmeades *et al.* (2000) indicated that grain yield (GY) and its component, ears per plant, are contingent upon ASI, represented by the equation $GY = \exp^{(a+b*ASI)}$ (where a denotes the intercept and b signifies the slope). Crop models that forecast grain output under stress must mimic the effects of stress on anthesis-silking interval, grain number, grain yield, and crop growth rate while accounting for genetic differences in parameters interrelationship.

Number of cobs per plant

All maize genotypes averaged 0.68 mature cobs at harvest (AS2001-12) to 1.28 (M1628-8). Analysis of variance showed no significant difference ($p > 0.05$) in maize genotypes' mature cob harvest production. FAW infestation rates of 25 to 30% significantly reduced grain yield, plant height, cob length, cob diameter, number of kernel rows per cob, and number of kernels per row (Kumar *et al.*, 2020; Kumar *et al.*, 2022).

Fresh and de-husked fresh cob weight

Among all maize genotypes, AS2001-3 had the highest harvest weight of fresh mature cobs (300 g). One of the lightest fresh cob weights was Oba super 9, which was comparable to AS2106-63 (100 g). ZMS623 produced the heaviest cobs at 260 g, nearly matching FAW 2204 ($p > 0.05$). Genotypes AS2001-20, AS2001-22, FAW 2212, and M1628-8 had significantly different average harvest weights of fresh cobs than SC719 ($p > 0.05$). At harvest, AS2001-19, AS2001-24, AS2106-43, and FAW 2210 maize genotypes had 250-g fresh cob weights. Due to FAW infestation, fresh maize cobs weigh less. The absence of field FAW management techniques can reduce fresh cob weight by 17.61% (Bakry and Abdel-Baky, 2024).

De-husked fresh cob weight was highest ($p < 0.05$) for AS2106-22 (255 g) and lowest (80 g) for AS2106-63 and Oba Super 9 maize genotypes. De-husked fresh cobs weighed 180 g for the check, SC719, AS2001-22, and AS2106-66 ($p > 0.05$). The de-husked fresh cob weight of maize genotype M1628-8 was 170 g, which was statistically similar ($p > 0.05$) to genotype AS2001-20. De-husked fresh cobs from maize genotypes AS2001-19, AS2001-24, and AS2001-3 weighed 210 g. Statistically significant differences ($p < 0.05$) were observed in the weights of de-husked fresh cobs: ZMS623 (240 g), AS2001-12 (244 g), FAW 2210 (230 g), and FAW 2204 (230 g). Bakry and Abdel-Baky (2024) found that FAW negatively correlates with average plant stem length,

Table 5 - Yield-related traits of hybrids and commercial maize varieties under natural FAW pressure in Calabar

Genotype	Days to 50 % anthesis	Days to 50 % silking	ASI	Number of cobs per plant	Fresh cob weight (g)	De-husked fresh cob weight (g)	Husk proportion (%)	De-husked fresh cob length (cm)
AS2001-12	62.5 e	74.5 d	12.0 b	0.68 a	262.5 c	244.0 b	7.0 k	20.5 c
AS2001-19	62.0 f	73.0 f	11.0 c	0.81 a	250.0 e	210.0 e	16.0 cd	17.0 g
AS2001-20	63.0 d	67.0 k	4.0 j	1.29 a	200.0 i	170.0 j	15.0 ef	22.0 a
AS2001-22	63.0 d	68.0 j	5.0 i	0.77 a	200.0 i	180.0 h	10.0 i	18.0 f
AS2001-24	63.0 d	71.0 g	8.0 f	1.20 a	250.0 e	210.0 e	16.0 cd	21.0 b
AS2001-3	60.0 g	66.0 l	6.0 h	0.83 a	300.0 a	210.0 e	30.0 a	22.0 a
AS2106-22	60.0 g	74.0 e	14.0 a	1.25 a	270.0 b	255.0 a	5.6 l	18.0 f
AS2106-43	62.0 f	73.0 f	11.0 c	0.80 a	250.0 e	200.0 f	20.0 b	17.0 g
AS2106-63	62.0 f	67.0 k	5.0 i	1.27 a	100.0 k	80.0 l	20.0 b	19.0 e
AS2106-66	63.0 d	67.0 k	4.0 j	0.76 a	210.0 h	180.0 h	14.3 f	20.0 d
FAW 2204	64.0 c	68.0 j	4.0 j	1.22 a	260.0 d	230.0 d	11.5 h	18.0 f
FAW 2206	64.0 c	75.0 c	11.0 c	0.79 a	240.0 f	200.0 f	16.7 c	16.0 h
FAW 2207	56.0 k	67.0 k	11.0 c	1.25 a	230.0 g	195.0 g	15.2 de	15.0 i
FAW 2210	55.0 l	65.0 m	10.0 d	0.78 a	250.0 e	230.0 d	8.0 j	18.0 f
FAW 2212	57.0 j	66.0 l	9.0 e	1.26 a	200.0 i	175.0 i	12.5 g	19.0 e
M1628-10	59.0 h	70.0 h	11.0 c	0.77 a	180.0 j	165.0 k	8.3 j	17.0 g
M1628-8	*58.0 i*	*65.0 m*	*7.0 g*	*1.28 a*	*200.0 i*	*170.0 j*	*15.0 ef*	*14.0 j*
Checks								
Oba super 9	64.0 c	69.0 i	5.0 i	0.79 a	100.0 k	80.0 l	20.0 b	14.0 j
SC719	69.0 b	77.0 b	8.0 f	1.25 a	200.0 i	180.0 h	10.0 i	17.0 g
ZMS623	78.0 a	87.4 a	4.4 ij	0.76 a	260.0 d	240.0 c	7.7 jk	17.0 g

ASI = anthesis-silking interval. Mean values with the same letter (s) within column are not significantly different (p > 0.05) using Duncan's multiple range test.

stem diameter, cob weight, number of rows per cob, number of grains per cob, and 1000 grain weight. Bakry and Abdel-Baky (2024) found that natural FAW pressure in field conditions reduced ear weight by 17.61–17.56%.

Husk proportion

The percentages of husk covering (%) reported for the controls were ranked in descending order as follows: 20% (Oba super 9) < 10% (SC719) < 7.7% (ZMS623). The husk yield from the control, ZMS623, was statistically comparable ($p > 0.05$) to the maize genotypes MI628-8 (8.3%), FAW 2210 (8%), and AS2001-12 (7%). AS2001-3 maize genotype had the highest husk-to-cob weight ratio (30%) compared to other genotypes ($p \le 0.05$). Similar to Oba Super 9, maize genotypes AS2106-43 and AS2106-63 had 20% husk. The check, SC719, exhibited an identical husk proportion to maize genotype AS2001-22. The maize genotype FAW 2207 exhibited 15.2% husk, which was statistically comparable ($p > 0.05$) to AS2001-19 (16%), AS2001-24 (16%), AS2001-20 (15%), and M1628-8 (15%). Tight husks have been associated with resistant maize hybrids, as they naturally limit the ingress of pests and diseases into the ear. This additionally reinforces the function of the husk covering as a barrier to FAW infiltration into the maize cobs. The husk helps these maize hybrids resist FAW attacks, but other factors may come into play. Since husk removal affects maize grain yield, plant breeders should select genotypes with higher husk proportions. Miranda *et al.* (2008) reported that the assessment of genetic variability and identification of heterotic groups in maize indicated that both additive and non-additive effects significantly influenced grain yield, plant height, ear height, and husk cover. This corroborated a prior report indicating that alleles promoting reduced husk leaf area were at least partially dominant over those favoring increased husk leaf area and that multiple loci governed the trait (Cantrell and Geadelmann, 1981a; Cantrell and Geadelmann, 1981b). The husk cover, ear rot, anthesis date, and plant height exhibit a strong correlation with FAW tolerance (Matova *et al.*, 2022a; Matova *et al.*, 2022b).

De-husked fresh cob length

After husk removal, maize genotypes AS2001-3 and AS2001-20 had the longest de-husked fresh cobs ($p \le 0.05$), while maize genotype M1628-8 and the control, Oba super 9, had the shortest. SC719 and ZMS623 bore 17-cm fresh cobs like maize genotypes AS2001-19, AS2106-43, and M1628-10. Maize genotype AS2001-22 had a de-husked fresh cob length comparable ($p > 0.05$) to AS2106-22, FAW 2204, and FAW 2210, while AS2106-63 was only comparable to FAW 2212, which had 21 cm. FAW infestation adversely affects maize cob length. According to Bakry & Abdel-Baky (2024), natural infestations lower cob length by 17.19%. FAW-managed maize plants had 14.78% shorter cobs.

Ear rating

ANOVA revealed a significant difference ($p \leq 0.05$) in average ear ratings at harvest among maize genotypes (Table 6). An average of 4–6 was found. The Checks' ear ratings in ascending order were SC719 (4) below ZMS623 (5) and Oba Super 9 (6). Oba super 9 showed no significant difference ($p > 0.05$) from maize genotypes AS2001-22, AS2106-22, AS2106-43, AS2106-63, AS2106-66, FAW 2206, FAW 2210, and FAW 2212. Check ZMS623 showed statistical similarity ($p > 0.05$) to maize genotypes AS2001-12, AS2001-19, AS2001-20, AS2001-24, AS2001-3, FAW 2207, and M1628-8 in ear ratings. Job *et al.* (2022) reported that the genotypic effect on ear aspect scores remained constant under natural FAW infestation, which contrasts with the findings of this investigation. Kasoma (2020) reported extremely significant differences between maize genotypes in terms of FAW leaf damage, FAW cob damage, and agronomic parameters, which is in line with the results of the current study. Regardless of maize reproductive stage, the ear zone affects FAW larval eating preferences and survival. First-instar larvae choose feeding sites, and reproductive-stage maize leaves are unsuitable for early instar development. However, silk and kernel tissues are beneficial to fall armyworm larvae on reproductive-stage maize (Pannuti *et al.*, 2015). Similarly, a maize genotype that tolerates FAW showed non-preference for feeding and lower larval growth rate, suggesting a biochemical function in FAW resistance (Nuambote-Yobila *et al.*, 2023).

Number of grains per cob

The average grain count per cob showed a significant difference ($p < 0.05$) among maize genotypes. Seed counts ranged from 259.5 to 516. The maize genotypes FAW 2210 (308 seeds), FAW 2204 (306.5 seeds), AS2106-22 (302 seeds), AS2001-22 (300.5 seeds), FAW 2207 (297.5 seeds), AS2106-43 (287.5 seeds), AS2001-19 (283.5 seeds), M1628-10 (277.5 seeds), and FAW 2206 (269 seeds) showed no statistically significant difference ($p > 0.05$). AS2001-24 (478.5 seeds), M1628-8 (424 seeds), and AS2106-66 (415.5 seeds) had similar grain counts per cob to Oba super 9 (450.5 seeds). The maize genotype AS2001-20, exhibiting the highest seed count per cob at 516 seeds, was statistically comparable ($p > 0.05$) to the genotypes AS2001-3 (510.5 seeds) and AS2001-24 (478.5 seeds). Furthermore, while maize genotype AS2001-12 (402 seeds) exhibited a significantly higher seed count compared to AS2106-63 (357 seeds) at $p \leq 0.05$, FAW 2212 did not show a significant difference ($p > 0.05$) from either of these maize genotypes. Hybrid maize shows partial FAW resistance due to reduced damage to lower plants and cobs (Ochoa *et al.*, 2023). In maize, genotypic resistance to FAW damage may be linked to physical and chemical variables (Nuambote-Yobila *et al.*, 2023). According to Morales *et al.* (2021), discovering resistant maize genotypes is essential to developing sustainable FAW management techniques. Warm climates and low precipitation favor FAW plant infestations, but rainy season cob damage may be greater than dry season damage.

100-seed weight

Statistical analysis ($p \leq 0.05$) revealed that maize genotype FAW 2212 had the lightest seeds (approximately 0.222 g per seed) from 100 seeds per cob, while SC719 had heavier seeds (approximately 0.481 g per seed). The maize genotypes AS2001-12 (34.7 g) and AS2001-24 (34.5 g) have similar 100-seed weights ($p > 0.05$). Individual seed weight of maize genotypes and the control, Oba Super 9, ranged from 0.2 to 0.3 g, indicating statistical differences ($p \leq 0.05$) and were ordered as follows: FAW 2206 (0.296 g) ≥ AS2106-63 (0.295 g) ≥ AS2106-66 (0.292 g) ≥ FAW 2204 (0.291 g) > FAW 2210 (0.282 g) > AS2106-22 (0.278 g) > Oba super 9 (0.263 g) > FAW 2207 (0.260 g) > M1628-8 (0.249 g) > M1628-10 (0.245 g) > FAW 2212 (0.222 g) The individual seed weights of the remaining nine maize genotypes differed significantly ($p \leq 0.05$) and averaged over 0.3 g. Chanda *et al.* (2021) examined maize farmers' fall armyworm control. Farmers chose maize varieties based on yield, grain weight, germination, drought resistance, cob quantity, grain size, and FAW resistance.

Grain yield

The maize genotype AS2001-20 yielded the highest average grain output at 4.8 t ha^{-1}, whereas the genotype AS2001-12 produced the lowest average yield at 1.2 t ha^{-1}. The maize genotype AS2001-24 exhibited an average grain yield of 4.5 t ha^{-1}, comparable ($p > 0.05$) to AS2001-20. The five highest-yielding maize genotypes, each exceeding 3 t ha^{-1}, were AS2001-20, AS2001-24, M1628-8, AS2106-63, and FAW 2212. The six lowest-yielding maize genotypes, with grain yields of ≤ 1.5 t ha^{-1}, were AS2001-19, AS2106-43, FAW 2206, M1628-10, ZMS623, and AS2001-12. The grain yields of SC719 (2.8 t ha^{-1}) and Oba Super 9 (2.3 t ha^{-1}) were not significantly different. These were comparable to maize genotypes with grain yields ranging from 2 t ha^{-1} to 3 t ha^{-1}, specifically AS2106-22, FAW 2204, FAW 2207, AS2001-3, AS2106-66, AS2001-22, and FAW 2210. Consistent with the study by Job *et al.* (2022), the genotypic influence of maize hybrids was significant for

Table 6 - Ear rating and grain yield of hybrids and commercial maize varieties under natural FAW pressure in Calabar

Genotype	Ear rating (1 – 9)	Number of grains per cob	100-seed weight (g)	Grain yield (t ha^{-1})
AS2001-12	5.0 b	402.0 de	34.7 b	1.2 c
AS2001-19	5.0 b	283.5 g	30.9 g	1.5 bc
AS2001-20	5.0 b	516.0 a	31.2 f	4.8 a
AS2001-22	6.0 a	300.5 g	31.6 e	1.6 abc
AS2001-24	5.0 b	478.5 ab	34.5 b	4.5 ab
AS2001-3	5.0 b	510.5 a	30.1 h	2.7 abc
AS2106-22	6.0 a	302.0 g	27.8 l	2.9 abc
AS2106-43	6.0 a	287.5 g	32.2 d	1.5 bc
AS2106-63	6.0 a	357.0 f	29.5 i	3.2 abc
AS2106-66	6.0 a	415.5 cd	29.2 j	2.2 abc
FAW 2204	4.0 c	306.5 g	29.1 j	2.9 abc
FAW 2206	6.0 a	269.0 g	29.6 i	1.5 bc
FAW 2207	5.0 b	297.5 g	26.0 n	2.9 abc
FAW 2210	6.0 a	308.0 g	28.2 k	1.6 abc
FAW 2212	6.0 a	360.0 ef	22.2 q	3.2 abc
M1628-10	4.0 c	277.5 g	24.5 p	1.5 bc
M1628-8	5.0 b	424.0 cd	24.9 o	3.9 abc
Checks				
Oba super 9	6.0 a	450.5 bc	26.3 m	2.3 abc
SC719	4.0 c	290.0 g	48.1 a	2.8 abc
ZMS623	5.0 b	259.5 g	33.5 c	1.4 bc

Mean values with the same letter (s) within column are not significantly different ($p > 0.05$) using Duncan's multiple range test

grain yield and various agronomic traits under natural FAW infestation. Chimweta *et al.* (2020) reported that FAW infestation could reach 94%, with leaf, stalk, and tassel damage levels between 25% and 50%, resulting in a grain yield loss of 58% in the absence of pesticide application. The symptoms of FAW damage documented by Baudron *et al.* (2019) varied from 32 to 48%, consistent with other research, yet their assessment of FAW damage's effect on grain yield was 11.57%, significantly lower than the findings of these studies. In general, FAW damage is greater in certain maize varieties, although these varieties do not consistently exhibit the lowest yields (Baudron *et al.*, 2019).

Associations among growth, grain yield and related traits

Table 7 shows the trait bivariate Pearson correlation. A substantial positive connection ($r = 0.706$, $p \leq 0.001$) was found between plant height and leaf count. Magar *et al.* (2021) found that plant height positively correlated with the number of leaves above and below the cob in 10 maize cultivars. The fall armyworm score was positively correlated ($r = 1.000$, $p \leq 0.001$) with both plant and ear ratings. A perfect connection ($r = 1.000$, $p < 0.001$) was found between ear and plant aspect ratings. A significant positive correlation ($r = 0.826$, $p \leq 0.001$) was found between 50% anthesis and 50% silking duration. A significant negative association ($r = -0.449$, $p < 0.05$) exists between the quantity of grains per cob and the days to 50% silking. Weight of 100 seeds positively correlates with 50% anthesis and silking durations ($r = 0.592$, $p \leq 0.05$); fresh cob weight strongly correlates with de-husked cob weight ($r = 0.945$, $p \leq 0.001$); and the number of grains per cob is positively correlated with husk proportion ($r = 0.503$, $p \leq 0.05$) and length ($r = 0.544$, $p \leq 0.05$). According to Magar *et al.* (2021), grain yield and grains per cob were strongly correlated.

Like in our study, Paul and Deole (2020) found no link between leaf damage assessment and plant leaf count. In addition, they found a significant correlation between ear morphology and the length of the central spike, a tassel component, and a significant but negative correlation between cob height and kernel damage rating.

Estimates of variability, heritability and genetic gain

Table 8 shows 20 maize genotypes' growth, yield, and yield-related trait variability, heritability, and genetic gain. For all traits, genotypic variance was lower than phenotypic variance. Limited environmental variance was indicated by narrow margins. Seedling emergence, days to 50% anthesis, and days to 50% silking have less than 10% GCV and PCV. Plant height, number of leaves per plant, de-husked cob length, fall armyworm score, ear rating, and 100-seed weight had GCV and PCV values between 10% and 20%. All traits except the num-

Table 7 - Bivariate Pearson's correlation among growth, yield and yield-related traits

	SE	PH	NL	FAW	PA	DA	DS	ASI	NCP	FCW	DFCW	H%	DCL	EA	NGC	100SW
PH	-0.065															
NL	-0.070	**0.706*** **														
FAW	0.403	-0.137	-0.215													
PA	0.403	-0.137	-0.215	**1.000*** **												
DA	-0.088	0.120	0.165	-0.223	-0.223											
DS	0.105	-0.128	-0.009	-0.198	-0.198	**0.826*** **										
ASI	0.406	-0.426	-0.380	0.041	0.041	-0.415	0.154									
NCP	-0.331	0.188	-0.249	-0.183	-0.183	-0.166	-0.251	-0.102								
FCW	0.280	-0.076	0.173	-0.216	-0.216	0.032	0.275	0.354	-0.173							
DFCW	0.296	-0.101	0.105	-0.234	-0.234	0.087	0.378	0.417	-0.139	**0.945*** **						
H%	-0.115	0.113	0.147	0.188	0.188	-0.149	-0.353	-0.281	-0.046	-0.114	-0.426					
DCL	0.035	-0.291	-0.183	-0.052	-0.052	0.000	-0.140	-0.200	0.010	0.321	0.244	0.126				
EA	0.403	-0.137	-0.215	**1.000*** **	**1.000*** **	-0.223	-0.198	0.041	-0.183	-0.216	-0.234	0.188	-0.052			
NGC	-0.232	-0.183	-0.090	0.013	0.013	-0.160	**-0.449* **	-0.421	0.139	-0.079	-0.235	**0.503* **	**0.544* **	0.013		
100SW	0.169	-0.035	-0.140	-0.366	-0.366	**0.592* **	**0.525* **	-0.077	-0.002	0.172	0.190	-0.113	0.212	-0.366	-0.057	
GY	-0.325	0.148	-0.185	-0.117	-0.117	-0.176	-0.397	-0.322	**0.851*** **	-0.167	-0.221	0.218	0.275	-0.117	**0.597** **	-0.042

SE - Seedling emergence (%), PH - plant height (cm), NL - number of leaves, FAW - fall armyworm score (1 – 9), PA - plant aspect rating (1 – 9), DA - days to 50 % anthesis, DS - days to 50 % silking, ASI - anthesis – silking interval, NCP - number of cobs per plant, FCW - fresh cob weight (g), DFCW - de-husked fresh cob weight (g), H% - husk proportion (%), DCL - de-husked cob length (cm), EA - ear rating (1 – 9), NGC - number of grains per cob, 100SW - 100-seed weight (g), GY - grain yield (t ha-1) (15 % MC). Figures in bold font type are significant bivariate Pearson's correlation coefficients (r): **p* ≤ *0.05*, ***p* ≤ *0.01*, ****p*≤ *0.001*.

Table 8 - Estimates of variability, heritability and genetic gain for growth, yield and yield-related traits

Trait	Range	Mean	SEM	σ^2g	σ^2p	GCV (%)	PCV (%)	H^2b (%)	GA_5	GAM (%)
Seedling emergence (%)	80 – 100	88.17	0.99	54.47	61.14	8.37	8.87	89.10	14.35	16.28
Plant height (cm)	103 – 198	145.33	2.93	533.33	533.34	15.89	15.89	100.00	47.57	32.73
Number of leaves per plant	9 – 14	12.08	0.19	2.10	2.11	11.99	12.04	99.21	2.97	24.60
Fall armyworm score (1 – 9)	4 – 6	5.28	0.10	0.53	0.60	13.79	14.63	88.84	1.41	26.77
Plant aspect rating (1 – 9)	5 – 7	6.28	0.10	0.53	0.60	11.59	12.30	88.84	1.41	22.51
Days to 50% anthesis	55 – 78	62.23	0.63	24.38	24.40	7.93	7.94	99.93	10.17	16.34
Days to 50% silking	65 – 87.4	70.49	0.69	29.09	29.11	7.65	7.65	99.94	11.11	15.76
Anthesis – silking interval	4 – 14	8.00	0.41	10.10	10.17	39.72	39.85	99.35	6.53	81.55
Number of cobs per plant	0.6 – 2	1.16	0.08	0.09	0.18	25.96	36.71	50.00	0.44	37.81
Fresh cob weight (g)	100 – 300	220.67	6.55	2661.53	2661.94	23.38	23.38	99.98	106.27	48.16
De-husked fresh cob weight (g)	80 – 255	190.18	5.85	2125.31	2125.38	24.24	24.24	100.00	94.97	49.93
Husk proportion (%)	5.56 – 30	13.96	0.74	33.91	34.02	41.71	41.77	99.69	11.98	85.78
De-husked cob length (cm)	14 – 22	17.98	0.30	5.47	5.49	13.01	13.03	99.70	4.81	26.76
Ear rating (1 – 9)	4 – 6	5.28	0.10	0.53	0.60	13.79	14.63	88.84	1.41	26.77
Number of grains per cob	256 – 532	351.68	10.66	6704.60	6980.20	23.28	23.76	96.05	165.31	47.01
100-seed weight (g)	22.15 – 48.1	30.19	0.68	28.91	28.92	17.81	17.81	99.97	11.07	36.68
Grain yield (t ha^{-1}) (15% MC)	0.636 - 8.28	3.03	0.29	1.50	2.67	40.29	53.85	55.99	1.88	62.11

SEM – standard error of mean, σ^2g – genotypic variance, σ^2p – phenotypic variance, GCV – genotypic coefficient of variation, phenotypic coefficient of variation, H^2b – broad sense heritability, GA_5 – genetic advance at 5 % selection intensity (k = 2.06), GAM – Genetic advance as percentage of mean, MC – moisture content.

ber of cobs per plant (50%) and grain yield (55.99%) had broad sense heritability values above 60% (ranging from 88% to 100%). Predicting selection cycle genetic improvement requires genetic gain. At 5% selection intensity, the number of grains per cob (165.31), fresh cob weight (106.27), and de-husked fresh cob weight (94.97) had the highest genetic progress estimates. At 5% selection intensity, the number of cobs per plant (0.44), fall armyworm score (1.41), plant aspect rating (1.41), ear rating (1.41), and grain yield (1.88), had the lowest genetic gain estimates. Overall, traits genetic gain estimates ranged from 0.44 to 165.31 at 5% selection intensity. When expressed as a percentage of the mean values for each trait, genetic gain varied from 15.76% to 85.78%, with 15.76% for days to 50% silking, 16.28% for seedling emergence percentage, and 16.34% for days to 50% anthesis. The largest genetic progress values, over 50%, were for husk proportion (85.78%), anthesis-silking interval (81.55%), and grain yield (62.11%). Plant aspect rating, number of leaves, de-husked cob length, fall armyworm score, ear rating, plant height, 100-seed weight, number of cobs per plant, number of grains per cob, fresh cob weight, and de-husked fresh cob weight had genetic gain values from 22.51% to 49.93% based on the mean. High grain yield indirect selection will be possible because of high GCV, PCV, heritability, and GAM.

Low genetic progress is below 10% of the mean value of a trait, moderate is 10% to 20%, and high is 20% or more (Johnson, 1987). Only seedling emergence percentage, days to 50% silking, and days to 50% anthesis showed moderate genetic improvement as a percentage of the mean in this study. As a fraction of the mean, all remaining traits had strong genetic gain. Due to the large contribution of environmental factors to variation, direct selection is impractical for traits with moderate heritability and minimal genetic gain as a percentage of the mean. Traits with high heritability and significant genetic gain as a percentage of the mean are dominated by additive gene action. Akbar *et al.* (2008) found that grain yield per plant had a higher genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), while days to 50% tasseling and silking had higher broad-sense heritability. Prakash *et al.* (2019) found high PCV, GCV, heritability, and genetic gain as a percentage of the mean for anthesis-silking interval, tassel branches, kernels per row, grain yield per plant, cob weight, ear height, and kernel rows per cob. Obok *et al.* (2021b) found high PCV and GCV (> 20%) for seedling emergence at 7 days post-planting, cob width, grain count per cob, 1000-grain weight, and grain yield. High GCV and PCV indicate effective selection for a characteristic, affording significant upgrading prospects. This study found considerable broad-sense heritability for grain yield (55.99%), similar to Obok *et al.* (2021b) findings on IPGRI maize accessions in Calabar. Additive gene effects improve heritability and genetic gain, while non-additive gene effects boost heritability but limit genetic gain (Mohana *et al.*, 2009). High heritability estimates for most variables showed that offspring inherited variations, suggesting that high-yielding genotypes may be selected (Magar *et al.*, 2021).

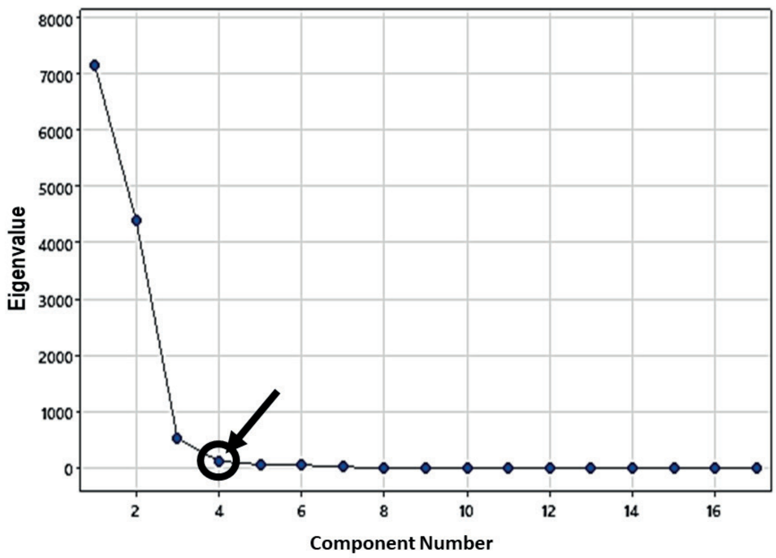

Fig. 2 - Scree plot of eigenvalues vs number of principal components. The "elbow" in the curve indicated by an arrow shows that the first four components were sufficient in describing the variation.

Principal component analysis of traits and genotype by trait biplot

A scree plot (Fig. 3) and eigenvalues (Table 9) showed that four principal components were adequate. PC 1 represented the linear combination of attributes with the greatest variation. The linear combination of features in the second principal component (PC 2) maximized the residual variation if the correlation between the first and second components was zero. All subsequent principal components (PC 3 and PC 4) were linear combinations that maximized residual variation explanation and were uncorrelated. The principal components were evaluated using attributes most strongly connected with each component, specifically those values farthest from zero (positive or negative). A cut-off value of 0.05 was used. PC 1 was negatively correlated with fresh and de-husked fresh cob weight and positively correlated with grains per cob. PC 1 was primarily used to measure grain count per cob and, to a lesser extent, fresh cob weight. PC 2 increased with fresh cob weight, de-husked fresh cob weight, and grain count per cob and decreased with plant height. This suggested that shorter maize genotypes produce better fresh cobs and higher grain yields. PC 3 measured increased plant height, leaf production, fresh cob weight, and husk proportion. However, PC 3 focused on plant height. PC 4 evaluated fresh cob and husk ratio, seedling emergence, and anthesis-silking interval to a lesser extent. PC 4 was, however, correlated with reduced plant height, a decrease in days to 50% anthesis and silking, a reduction in the weight of de-husked fresh cobs, grain yield, and 100-seed weight.

Figure 3 shows a genotype by traits (GT) biplot of 20 maize genotypes and their agronomic properties. The first principal component covers 58.1% of the data variance, whereas the second covers 35.7%, according to the polygon diagram. The genotypes AS2001-3, AS2001-20, Oba Super 9, AS2106-63, M1628-10, ZMS623, and AS2106-22 were the farthest from the diagram's origin at the polygons' vertices. Each sector's vertex genotype is the winner, with the highest characteristic value. Traits and genotype trait profiles were shown using the GT biplot. Trait-standardized GT data and trait-focused singular value partitioning were utilized for deductions. Pearson correlation coefficient is approximated by the cosine of the angle between trait vectors. Thus, an angle less than 90° indicates a positive correlation, greater than 90° a negative correlation, and 90° no association. The angle between a genotype and a trait also indicates the genotype's relative level for that characteristic. Acute angles imply that a genotype's performance surpasses the average for that attribute, obtuse angles indicate below average performance, and right angles indicate average performance. A short vector indicates that the trait is variation across genotypes is either minimal or inadequately represented in the biplot due to its weak or nonexistent correlation with other traits. The vector length of a genotype

Table 9 - Eigenvectors

Trait	PC 1	PC 2	PC 3	PC 4
Seedling emergence (%)	-0.0259	0.0222	-0.0275	0.0960
Plant height at harvest (cm)	-0.0424	-0.0629	0.9834	-0.1245
Number of leaves at harvest	-0.0022	0.0020	0.0466	0.0089
Fall armyworm score at harvest (1 – 9)	0.0006	-0.0024	-0.0053	0.0138
Plant aspect rating (1 – 9)	0.0006	-0.0024	-0.0053	0.0138
Days to 50% anthesis	-0.0097	-0.0008	0.0190	-0.1066
Days to 50% silking	-0.0320	0.0115	-0.0458	-0.0812
Anthesis – silking interval	-0.0183	0.0106	-0.0664	0.0483
Number of cobs per plant	0.0006	-0.0005	0.0026	-0.0071
Fresh cob weight (g)	-0.2006	0.7281	0.1150	0.5730
De-husked fresh cob weight (g)	-0.2584	0.6026	-0.0575	-0.6605
Husk proportion (%)	0.0370	-0.0042	0.0620	0.4229
De-husked cob length (cm)	0.0119	0.0179	-0.0143	-0.0099
Ear rating (1 – 9)	0.0006	-0.0024	-0.0053	0.0138
Number of grains per cob	0.9420	0.3187	0.0473	-0.0817
100-seed weight (g)	-0.0065	0.0128	-0.0070	-0.0579
Grain yield (t ha^{-1}) (15% MC)	0.0098	0.0009	0.0148	-0.0254
Eigenvalue	7154.5	4390.4	517.9	117.0
Proportion	0.581	0.357	0.042	0.010
Cumulative	0.581	0.938	0.980	0.989

PC – principal component, MC – moisture content.

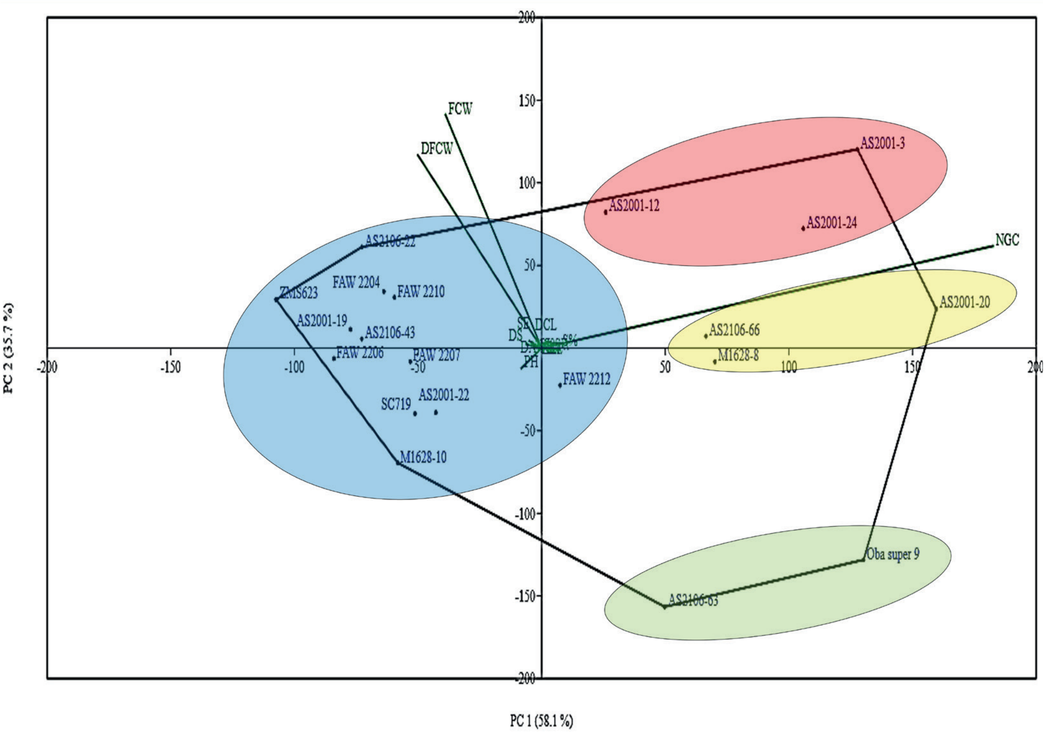

Fig. 2 - The genotype by trait (GT) biplot highlights genotypes with outstanding profiles.
SE–Seedling emergence (%), PH–plant height (cm), NL–number of leaves, FAW–fall armyworm score (1-9), PA–plant aspect rating (1-9), DA–days to 50% anthesis, DS–days to 50% silking, ASI–anthesis-silking interval, NCP–number of cobs per plant, FCW - fresh cob weight (g), DFCW - de-husked fresh cob weight (g), H% - husk proportion (%), DCL - de-husked cob length (cm), EA–ear rating (1-9), NGC–number of grains per cob, 100SW–100-seed weight (g), GY–grain yield ($t\ ha^{-1}$) (15% MC).

indicates whether it is intermediate across all characteristics or has distinct strengths and weaknesses in its trait profile. The GT biplot in Fig. 3 has a goodness-of-fit of 93.8%. Using GT biplot analysis, genotypes were evaluated across various variables to find superior genotypes for future breeding operations to enhance target traits.

According to these principles, the subsequent observations were noted (Fig. 3): fresh cob weight (FCW) exhibited a positive correlation with de-husked fresh cob weight (DFCW) and was strongly associated with seedling emergence (SE), days to 50% anthesis (DA), and days to 50% silking (DS). Consequently, seedling emergence was significant for flowering characteristics and elevated cob yield. FCW exhibited a positive correlation with DFCW, while demonstrating a negative correlation with the number of grains per cob (NGC) and husk percentage (H%). This suggests that larger cobs do not inherently correlate with a greater number of grains; fresh cobs (with or without husk) exhibiting larger grain sizes may possess fewer but denser grains. NGC exhibits a negative correlation with plant height (PH), days to silking (DS), and days to anthesis (DA), indicating that shorter and early flowering genotypes typically possess a greater number of grains per cob. Typically, traits characterized by shorter vectors exhibited weak correlations with other traits. The correlation table (Table 7) can validate these reports, despite the biplot's goodness of fit being more than adequate (93.8%). This study revealed that the genotypes FAW 2212, AS2106-63, AS2001-12, AS2001-3, AS2001-24, AS2106-66, AS2001-20, M1628-8, and Oba super 9 (control) exhibited acute angles with the number of grains per cob, signifying their superior performance for this trait. The cluster membership summary indicates that traits were categorized into four clusters, while genotypes were grouped according to their performance superiority based on the assessed traits (Table 10). Khan *et al.* (2019) indicated that the days to male flowering, the number of rows per cob, the number of seeds per cob, and the 100-seed weight influenced the cluster mean performance. This partially corroborates the findings of the current study, wherein days to 50% anthesis and 100-seed weight were grouped together. The findings from our study, utilizing cluster analysis and PCA biplot, confirmed the variability indicated by the analysis of variance concerning growth and yield traits of the 20 maize genotypes under fall armyworm pressure. This confirmation aligned with a study by Asare *et al.* (2023) that screened maize inbred lines and

Table 10 - Cluster membership summary

Cluster	
Trait	
1	Seedling emergence (%), anthesis – silking interval, fresh cob weight (g), de-husked fresh cob weight (g)
2	Plant height at harvest (cm), number of leaves at harvest, days to 50% anthesis, days to 50% silking, 100-seed weight (g)
3	Fall armyworm score at harvest (1 – 9), plant aspect rating (1 – 9), ear rating (1 – 9)
4	Number of cobs per plant, husk proportion (%), de-husked cob length (cm), number of grains per cob, grain yield (t ha^{-1})
Genotype	
1	AS2001-12, AS2001-24, AS2001-3
2	AS2001-19, AS2001-22, AS2106-22, AS2106-43, FAW 2204, FAW 2206, FAW 2207, FAW 2210, FAW 2212, M1628-10, SC719, ZMS623,
3	AS2001-20, AS2106-66, M1628-8
4	AS2106-63, Oba super 9

hybrids for resistance to fall armyworm. Consistent with our findings, Oluwaranti *et al.* (2022) indicated that cluster analysis successfully categorized 100 maize germplasm assessed during the late cropping season of 2018 in Osun State according to their responses to fall armyworm and stem borer in field conditions.

Conclusions

The study site was affected by enough natural FAW pressure to test maize genotypes responses to FAW pressure. FAW affected the 20 maize genotypes in our study under natural field infestation conditions, but some showed partial resistance. Except for the number of cobs per plant, these maize genotypes differed in seedling emergence, plant height, number of leaves, fall armyworm score, plant aspect rating, days to 50% anthesis, days to 50% silking, anthesis-silking interval, and fresh cob weight. de-husked fresh cob weight, husk proportion, length, ear rating, grains per cob, 100-seed weight, and grain yield. The maize genotypes showed diversity in agronomic traits and FAW responses, providing genetic variation for maize improvement. High heritability means a trait is less environment dependent. Thus, phenotypic expression of these traits in the plant can be used to select. In our study, traits with high genetic gain and heritability were found to be useful in predicting the effect of selecting a superior maize genotype. High-heritability traits with moderate genetic gain can also be improved. This study found that maize genotypes AS2001-20, AS2001-24, M1628-8, AS2106-63, and FAW 2212 had high grain yield potential (≥ 3 t ha^{-1}) in Calabar, despite FAW pressure (5-6 points). FAW was perfectly positively correlated with plant and ear aspects, while grain yield was strongly correlated with cobs per plant and grains per cob. Traits can be indirectly selected for each other. Cluster analysis showed that FAW score, plant aspect, and ear aspect were in the same cluster, confirming the selection of FAW-resistant and/or tolerant plants. The following traits—number of cobs per plant, husk covering, cob length, and number of grains per cob—were in the same cluster with grain yield, confirming their importance in selecting maize genotypes with promising yield potential under FAW pressure. Since FAW arrived in Nigeria in 2016, its effects on maize fields in Cross River State have been speculated.

The only Calabar FAW infestation study was a four-week preliminary study (Obok *et al.*, 2021a). To the best of our knowledge and available literature, this is the first attempt in Calabar to study the effect of FAW on newly developed IITA maize genotypes from seed to harvest as part of the African-wide Accelerating Genetic Gains project. This study will soon enrich FAW literature and guide plant breeding goals for Calabar and its environments. In this study, we can consider these suggestions: (1) In Calabar, maize genotypes AS2001-20, AS2001-24, M1628-8, AS2106-63, and FAW 2212 were chosen for low FAW damage and high grain yield; the selected genotypes could improve FAW resistance breeding populations. (2) This study evaluated only 20 IITA maize genotypes following the accelerated genetic gain project's experimental guidelines; however, control experimental plots—treatments with indigenous maize varieties and FAW control measures—should be included in future field trials to provide additional comparisons, report economic injury levels and action thresholds, and assess cost-benefit implications.

Author contribution

Ekemini OBOK, Justina ULAFOR, Godfrey IWO: conceptualization, methodology. Ekemini OBOK, Justina ULAFOR: data collection and analysis, writing-original draft manuscript. Ping AN, Jia LIU, Anthony ENEJI: corrections, suggestions, and input for improvements of the final manuscript.

Conflicts of Interests

We have no conflicts of interest to disclose as authors and co-authors.

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