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Variation in Grain Yield Losses Due to Fall Armyworm Infestation among Elite Open-Pollinated Maize Varieties under Different Levels of Insecticide Application

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Abstract: Maize is an important food and industrial cereal crop that serves as the main source of energy for millions of low-income people in sub-Saharan Africa (SSA), but its production and productivity are constrained by many constraints, among which the fall armyworm (FAW) is the major one. The use of insecticides is the most effective control measure for the FAW. However, excessive use of chemical insecticides has environmental and health implications, and it can be expensive for resource-poor farmers. The objective of this study was to evaluate the extent of variation in yield losses due to the FAW among some elite maize open-pollinated varieties (OPVs) under two levels of insecticide application and control (0 application). In a two-year field study, 10 elite maize OPVs were evaluated under two levels of emamectin benzoate (5% WDG) applications and the control: 75 and 150 mL of spray solution per 20 L of water. The experimental design was a randomized complete block with three replications. The data were collected on grain yield (GY) and FAW leaf damage rating (LDR). The LDR was conducted on a 1–9 scale and used to categorize the maize varieties as resistant (1–4), moderately resistant (4–6), and susceptible (6–9). Significant varietal differences were obtained for GY and LDRs. The GY of the varieties under control (0 mL), 75 and 150 mL insecticide applications ranged from 3.3 t ha^{-1} (DTSTR-Y SYN-13) to 4.6 t ha^{-1} (PVA SYN-3), from 4.5 t ha^{-1} (DTSTR-Y SYN-13) to 6.4 t ha^{-1} (PVA SYN-13), and from 4.2 t ha^{-1} (DTSTR-Y SYN-13) to 6 t ha^{-1} (DTSTR-Y SYN-14), respectively. No significant differences in GY were found between the application of 75 and 150 mL of insecticide application. The relative loss in GY among the varieties under control (0 mL) differed with an increase in the level of insecticide application. The relative GY loss at the 75 mL insecticide application ranged from 18% (PVA SYN-3) to 38% (DTSTR-Y SYN-15) with a mean of 27%, whereas at the 150 mL insecticide application, it varied from 13% (PVA SYN-3) to 42% (DTSTR-Y SYN-15), with a mean of 26%. All the varieties exhibited moderate resistance to FAW, except DTSTR-Y SYN-14, which was susceptible. The varieties PVA SYN-3 and PVA SYN-13 were the most consistent in GY across the three insecticide treatment levels. The mean performance of the varieties for FAW leaf damage ranged from 4.0 (SAMMAZ-15) to 6.2 (DTSTR-Y SYN-14), from 4.5 (SAMMAZ-15) to 6.3 (PVA SYN-6), from 4.5 (SAMMAZ-15) to 6.3 (DTSTR-Y SYN-14), and from 3.5 (SAMMAZ-15) to 5 (DTSTR-Y SYN-14) for LDR 1, LDR 2, LDR 3, and LDR 4, respectively. The use of moderately resistant varieties, combined with timely spraying of emamectin benzoate at 75 mL provided adequate management for the FAW infestation and sustained high maize grain yield.

Keywords: open-pollinated maize variety; emamectin benzoate; grain yield loss; fall armyworm leaf damage

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1. Introduction

Maize (*Zea mays* L.) is one of the most important food and industrial crops, grown in many developing countries [1]. It belongs to a class of cereals in the grass family (Poaceae) that can be grown in a variety of environments. As a staple crop, maize provides about 30% of the food calories needed to feed over 300 million out of about 4.6 billion people in low-income developing countries [2,3]

Maize is a life-sustaining crop with high grain yield potential in sub-Saharan Africa (SSA), contributing to 7.5% of the total global maize production [4]. The high yield potential of maize and its importance in SSA is reflected in the good expressions of a wide range of traits, such as grain yield, grain characteristics (size, texture, quality, grain type, and color), micronutrient content, maturity period, drought tolerance, and pest and disease resistance [5]. Despite its immense importance in SSA, maize production and productivities are generally very low compared to the world average [2,6]. The low yield can be attributed to different production constraints, which include biotic factors such as weeds, foliar diseases, insect pests including the fall armyworm (*Spodoptera frugiperda* J.E. Smith) and stem borers, as well as abiotic stress factors, including drought, heat, and low soil fertility, which are threatening the food security and economic stability of many countries in SSA.

The fall armyworm (FAW) is a highly invasive pest that threatens global food production and trade [7]. It is native to the tropical and subtropical regions of America [8]. The pest was first identified in Africa in 2016 and spread throughout several Central and Western African countries [9,10]. It has a diverse host range of over 353 plant species and is a serious threat to agricultural production [11]. The rapid spread of the FAW causes significant economic losses worldwide, impacting the food and income security of millions of people [10,12]. Currently, the FAW is one of the most destructive pests of maize crops in SSA, causing widespread damage at different stages of the plant's growth, ranging from early vegetative to physiological maturity [13,14]. It may also attack the basal portion of the maize ear, destroying the grain or promoting infections by microorganisms [15]. The larvae attack and eat the growing points of young maize plants and bore into mature plants' cobs, impairing grain yield and quality [16]. Annual grain yield losses of 21–53%, estimated at 2.5 to 6.2 billion USD per annum due to the FAW in the absence of appropriate control measures, have been reported [17,18].

Chemical treatment is the most widely used method of controlling the FAW. North and South American countries have developed and registered several synthetic pesticides against FAW, with various modes of action [17]. However, many of these synthetic pesticides are becoming ineffective against the FAW due to pesticide resistance [19]. In SSA, insecticides are too expensive and inaccessible for smallholder farmers to consider as a means of FAW control [20]. Furthermore, no single treatment can effectively control a problematic pest like the FAW. Over the years, various technologies and management strategies for the control of the FAW, including host plant resistance, cultural control, biological control, bio-pesticides, mating disruption technologies, synthetic pesticides, and agro-ecological management have been developed [18,21]. However, due to a variety of factors, including legislative barriers, these technologies are not widely available to most African maize farming communities.

Several studies have attempted to estimate the impact of the FAW in Africa by focusing on quantifying yield and production losses caused by the FAW infestation [17,22]. Most of the studies, conducted based on surveys and farmers' estimates in Africa, revealed that failure to control the damage caused by the FAW on maize crops could lead to a significant loss in grain yield [17]. Such economic losses are mainly caused during the larval stage of the insect [17,18]. Similar yield losses due to the FAW in maize were reported in Kenya (47%) and in Zimbabwe (11.6%) [17,23]. The high level of yield losses recorded in different countries of SSA suggests the urgent need to control the FAW infestation in farmers' fields.

Host plant resistance to diseases, drought, and insect pest infestation are critical components of integrated pest management [24]. Research efforts targeted at identifying FAW-resistant maize cultivars are important components towards the development of sustainable strategies for controlling the FAW and reducing yield losses under low-input agriculture [25]. Since the 1950s, maize germplasm has been carefully screened for FAW resistance in America [26]. However, the locally improved maize germplasm for the new geographical distribution of the FAW in Africa still requires a significant amount of screening [27] to identify the genotypes with good levels of resistance/tolerance to the FAW. Diverse maize genetic resources such as landraces, improved open-pollinated varieties (OPVs), synthetic varieties, as well as hybrids must be screened to identify promising genotypes for FAW resistance breeding [7]. Open-pollinated maize varieties are the most important in the marginal areas where the farmers cannot afford to buy hybrid seeds every year; as a result, hybrid recycling is a common practice that negatively affects farmers in SSA. Presently, in some African countries, such as Kenya, numerous maize cultivars from CIMMYT collections have been assessed for resistance to the FAW [28]. Among the CIMMYT cultivars, South Sudan has released and registered two hybrids (Silvestro Meseka, personal communication). However, most of the African maize landraces and OPVs cultivated by smallholder farmers have not been extensively evaluated for resistance against the FAW [27]. Modern technologies are required to successfully manage the FAW and prevent significant yield losses in SSA [29]. A combination of control measures, including the use of tolerant/resistant varieties with chemical insecticides would provide a durable solution and reduce FAW yield losses in farmers' maize fields. Therefore, knowledge of affordable doses of chemical insecticide in controlling the FAW will boost maize productivity and increase the household income of resource-constrained maize farmers in SSA. The present study was conducted to (i) assess the efficacy of half- and full-dose applications of a chemical insecticide on the growth and grain yield of maize, as compared to the trial with no application, and (ii) to estimate the variation in grain yield losses among 10 elite maize OPVs due to FAW infestation.

2. Materials and Methods

2.1. Description of Experimental Site

Three field trials were conducted for two years at the International Institute of Tropical Agriculture (IITA) (latitude 7°50′37″ N and longitude 3°90′24″ E, 206 masl), Ibadan, Nigeria, during the 2019 wet season and the 2021/2022 dry season.

2.2. Genetic Materials Used for the Experiment

Ten open-pollinated varieties (OPVs) of maize [PVA SYN-2, PVA SYN-3, PVA SYN-6, PVA SYN-9, PVA SYN-13, DTSTR-W SYN-13, DTSTR-Y SYN-14, DTSTR-Y SYN-15, SAMMAZ-15, and TZB-SR (RE)], sourced from the Maize Improvement Programme of IITA, were used.

2.3. Experimental Design, Treatments and Procedures

The trials were arranged in a randomized complete block design (RCBD) with three replications. The land was cleared from the previous season's crop residues, plowed, and harrowed. The experimental field was divided into three main insecticide application rate blocks: 0 mL (no spray), 75 mL (half-dose application), and 150 mL (full-dose application) of spray solution per 20 L of water. The blocks were separated by 5.0 m wide alleys, which were sown with maize at a high density to serve as fillers and trap insecticide spray drifts. The insecticide treatment rates were therefore kept as separate blocks and not randomized. In each block (for each insecticide treatment rate), plots comprised four rows, each 5.0 m long. The rows were spaced 0.75 m apart, while the hills within the rows were spaced 0.5 m. Three seeds were sown per hole. A day after sowing, the pre-emergence application of atrazine was at the rate of 3.0 kg ai ha^{-1} to control weeds before seedling emergence. Two weeks after emergence, the seedlings were thinned to two healthy plants per hill. Compound fertilizer in the form of NPK 15:15:15 was applied at the rate of 60 kg N ha^{-1} three weeks after sowing, while urea (46:0:0) was applied at the rate of 30 kg ha^{-1} five weeks after sowing. Successive weed managements were performed manually and complemented with herbicides. For the trial carried out in the dry season, the experimental field was sprinkler-irrigated to 100% field capacity three times a week, from sowing until harvest maturity. A spray solution of the insecticide emamectin benzoate (5% WDG) prepared following the manufacturer's (GoodJob-Biochemicals Co., Changzhou, China) instructions was used. Insecticide applications were performed using a knapsack sprayer once per week for 3–4 weeks to the half- and full-dose blocks, while the no insecticide application block was left under natural FAW infestation. Emamectin benzoate (5% EDG) was selected in this study, as it is the most commonly available insecticide in the area, being relatively affordable by farmers.

2.4. Data Collection

Data were collected on plot basis for the different insecticide management conditions. The days to 50% anthesis (DA) were recorded as the number of days from the sowing date to the date when half of the plants in a plot shed pollen. The days to 50% silking (DS) were recorded as the number of days from the sowing date to the date when half of the plants in a plot had emerged silks. The anthesis–silking interval (ASI) was computed as the difference between the silking and anthesis dates. Plant height (PLHT) and ear height (EHT) were measured in cm from the soil level to the first tassel branch and from soil level to the upper ear insertion, respectively, on five competitive plants at physiological maturity. Husk cover (HUSK) was rated on a scale of 1 to 5, where 1 = husks tightly arranged and extended beyond the ear tip, and 5 = ear tips exposed. Plant aspect (PASP) was scored on a scale of 1 to 5, where 1 = excellent plant type. and 5 = poor plant type. In addition, ear aspect (EASP) was rated on a scale of 1 to 5, where 1 = clean, uniform, large, and well-filled ears, and 5 = rotten, variable, small, and partially filled ears. The number of ears per plant (EPP) was computed as the ratio of the number of harvested ears to the number of plants standing at harvest. Leaf damage rating (LDR) due to FAW was performed on a 1–9 scale, as described by several researchers [18,30–33]. The scale was used to categorize the maize genotypes as resistant (1–4), moderately resistant (>4–6), and susceptible (>6–9) [34]. Scoring for LDR was performed four times for the entire plants in the plot, at 42, 49, 56, and 63 days after sowing.

Harvesting was conducted manually from the two middle rows of each plot at physiological maturity (black layer at seed base, complete yellowing, and drying of leaves and ears). All harvested ears per plot were weighed to obtain the field weight in kg, and representative samples randomly collected were shelled to determine moisture content using a PM-450 grain moisture tester (Kett electric laboratory). Grain yield (GY), expressed in kg ha^{-1}, was estimated at 15% moisture content and assuming 80% shelling percentage using the following formula:

$$Grain\ yield\left(\frac{kg}{ha}\right) = \frac{FWT(100 - MC)}{85} \times \frac{(10000)}{(2 \times 5 \times 0.75)} \times 80\%$$

where FWT is the field weight per plot and MC is the grain moisture content at harvest.

The yield-loss estimation was calculated based on the yield-over-treatment using the following formula:

$$Yield\ Losses = \frac{(yield\ at\ 150\ ml - yield\ at\ 0\ ml)}{yield\ at\ 150\ ml} \times 100\%$$

$$Yield\ Losses = \frac{(yield\ at\ 75\ ml - yield\ at\ 0\ ml)}{yield\ at\ 75\ ml} \times 100\%$$

2.5. Data Analysis

Data were subjected to analysis of variance (ANOVA) using PROC GLM in SAS (SAS version 9.4, SAS Institute Inc., 2014, Cary, NC, USA). The analysis was carried out separately for the insecticide application rates. Means that were statistically different were separated using the least significant difference (LSD) at $p < 0.05$. Comparison among insecticide application rates was conducted using a one-degree-of-freedom orthogonal contrast.

3. Results

3.1. Variability of Traits among Varieties under the Different Insecticide Applications

The year significantly ($p < 0.001$) affected GY and other agronomic traits in the 10 varieties evaluated under no (0 mL) insecticide application (Table 1). However, the year had no significant effect on the GY under 75 ML and 150 mL (Tables 1 and 2). Under 0 mL and 75 mL, there were significant differences ($p < 0.05$) among the 10 varieties for GY and most agronomic traits, while under the 150 mL application, no significant difference was detected among the varieties for GY, PASP, and EPP. The variety × year interaction effect was significant ($p < 0.05$) only for DA, PLHT, and EHT under the 0 mL insecticide application rate, while under the 75 mL insecticide application rate, the effect was significant ($p < 0.05$) for GY and most of the measured traits. Whereas under the 150 mL insecticide application, the variety × year interaction effect was significant ($p < 0.05$) only for ASI, HUSK, and EASP (Tables 1 and 2).

Table 1. Mean squares from the analysis of variance of grain yield and agronomic traits of 10 maize varieties, evaluated under 0 and 75 mL levels of emamectin benzoate insecticide application rates for two years (2019 and 2022) in Ibadan.

Source of Variation	DF	GY	DA	DS	ASI	PLHT	EHT	HUSK	PASP	EASP	EPP
0 mL Emamectin benzoate insecticide application											
Year	1	55.24 ***	21.60 ***	3.75	7.35 ***	7504.02 ***	16984.84 ***	5.40 ***	10.00 ***	5.10 ***	0.10 *
Block (Year)	4	0.82	3.2	4.1	0.4	200.67	86.37	0.16	1.25 ***	0.51	0.05 *
Varieties	9	1.29 *	10.55 ***	15.63 ***	0.79	520.98 ***	434.70 **	0.15	0.29	0.4	0.02
Variety × year	9	0.18	3.27 *	2.64	0.39	259.28 *	298.39 *	0.1	0.33	0.2	0.01
Error	36	0.59	1.44	1.9	0.38	114.39	107.59	0.14	0.18	0.26	0.02
CV		19.54	2.13	2.44	247.06	5.72	10.28	16.41	18.35	19.36	14.2
LSD		0.90	1.41	1.61	0.72	12.52	12.15	0.45	0.50	0.60	0.16
75 mL Emamectin benzoate insecticide application											
Year	1	2.2	66.15 ***	112.07 ***	6.02 ***	944.07 **	881.67 *	3.50 ***	0.15	5.58 ***	0.15 **
Block (Year)	4	1.64 *	1.88	4.08 *	0.67	528.93 **	259.27	0	1.15 ***	0.38 *	0.01
Varieties	9	2.00 **	8.08 ***	9.19 ***	2.19 ***	509.07 ***	179.7	0.44 ***	0.20 **	0.50 **	0.02
Variety × year	9	1.66 *	5.78 ***	4.47 **	0.57	305.07 *	212.52	0.24 *	0.40 ***	0.24	0.02
Error	36	0.58	1.05	1.36	0.3	116.21	164.95	0.09	0.06	0.14	0.01
CV		14.1	1.85	2.1	251.23	5.15	11.63	12.69	11.86	16.55	11.85
LSD		0.89	1.20	1.37	0.64	12.62	15.04	0.36	0.29	0.43	0.14

*, **, *** significant at probability levels of < 0.05, 0.01, and 0.001, respectively. GY = grain yield (kg ha^{-1}), DA = days to 50% anthesis, DS = days to 50% silking, ASI = anthesis–silking interval, PLHT = plant height (cm), EHT = ear height (cm), HUSK = husk cover (1–5 rating), PASP = plant aspect (1–5 rating), EASP = ear aspect (1–5 rating), EPP = number of ears per plant.

Table 2. Mean performance from the analysis of variance of grain yield and agronomic traits of 10 maize varieties evaluated under the 150 mL level of emamectin benzoate insecticide application rate for two years in Ibadan.

Source of Variation	DF	GY	DA	DS	ASI	PLHT	EHT	HUSK	PASP	EASP	EPP
150 mL Emamectin benzoate insecticide application											
Year	1	1.12	52.27 ***	98.82 ***	7.35 ***	8283.75 ***	1460.27 ***	7.00 ***	1.07 **	0.34	0.17 **
Block (Year)	4	0.07	1.42	1.47	0.43	178.53	45.87	0.03	1.47 ***	0.06	0.01
Varieties	9	1.49	7.59 ***	12.24 ***	1.56 ***	265.34 *	234.79 *	0.33 **	0.17	0.29 *	0.01
Variety × year	9	0.4	1.97	1.78	0.83 *	76.71	77.53	0.34 **	0.05	0.64 ***	0.03
Error	36	0.75	1.81	1.95	0.38	104.11	104.26	0.09	0.14	0.12	0.02
CV		16.35	2.42	2.51	283.68	4.95	9.73	12.55	17.14	15.1	13
LSD		1.01	1.57	1.63	0.72	11.95	11.96	0.35	0.43	0.40	0.15

*, **, *** significant at probability levels of < 0.05, 0.01 and 0.001, respectively. GY = grain yield (kg ha^{-1}), DA = days to 50% anthesis, DS = days to 50% silking, ASI = anthesis–silking interval, PLHT = plant height (cm), EHT = ear height (cm), HUSK = husk cover (1–5 rating), PASP = plant aspect (1–5 rating), EASP = ear aspect (1–5 rating), EPP = number of ears per plant.

Under combined analysis across the three treatment levels, the year had significant effects on all the measured traits, except PLHT. A significant insecticide application effect was observed among the varieties for GY and most of the agronomic traits. There were significant differences among the varieties for all the measured traits, except PASP and EPP. The variety × insecticide application (IA) interaction was significant ($p < 0.05$) for only DA. The variety × year interaction had a significant effect on all the agronomic traits, except GY and DS. The IA × year interaction had significant effects on all the measured traits, except HUSK, ASI, and EPP. In the three-way interaction, variety × IA × year had a significant effect only on DA and DS (Table 3).

Table 3. Mean squares from the combined analysis of variance of grain yield and agronomic traits of 10 maize varieties, evaluated under 0, 75 and 150 mL levels of emamectin benzoate insecticide application rates for two years (2019 and 2022) in Ibadan.

Source of Variation	DF	GY	DA	DS	PLHT	EHT	HUSK	PASP	EASP	ASI	EPP
Year	1	20.56 ***	38.27 ***	115.20 ***	411.02	4945.51 ***	15.61 ***	7.00 ***	9.02 ***	20.67 ***	0.41 ***
Block (Year)	4	0.84	2.84	4.68 ***	343.12 *	269.9	0.03	1.25 ***	0.3	0.32	0.02
Insecticide Application (IA)	2	41.06 ***	15.42 ***	16.61 ***	8714.91 ***	1386.33 ***	0.09	0.93 *	2.68 ***	0.02	0.03
No Insecticide Vs 75 mL IA	1	65.90 ***	25.21 ***	27.07 ***	14,896.41 ***	2750.42 ***	0.17	1.75 ***	4.33 ***	0.03	0.05
No Insecticide Vs 150 mL IA	1	56.94 ***	20.83 ***	22.53 ***	10,944.30 ***	490.05 *	0.1	0.92 *	3.67 ***	0.03	0
75 mL Insecticide Vs 150 mL IA	1	0.33	0.21	0.21	304.01	918.53 ***	0.01	0.13	0.03	0	0.04
Varieties	9	3.34 ***	19.60 ***	31.77 ***	1043.98 ***	627.44 ***	0.62 ***	0.15	0.67 ***	3.51 ***	0.03
Variety × IA	18	0.72	3.31 **	2.65	125.7	110.87	0.15	0.26	0.26	0.51	0.01
IA × Year	2	19.00 ***	50.87 ***	49.72 ***	8160.41 ***	7190.63 ***	0.15	2.11 ***	1.00 ***	0.02	0
Variety × Year	9	0.98	3.57 **	2.58	280.40 *	307.93 **	0.34 ***	0.46 *	0.69 ***	0.97 **	0.04 *
Variety × IA × Year	18	0.63	3.72 **	3.15 *	180.33	140.25	0.17	0.16	0.19	0.41	0.01
Error	116	0.65	1.46	1.79	123.36	121.13	0.11	0.21	0.18	0.37	0.02
CV		16.58	2.17	2.39	5.53	10.44	13.83	20.8	17.93	266.4	13.14
LSD		0.53	0.80	0.88	7.33	7.27	0.22	0.30	0.28	0.40	0.08

*, **, *** significant at probability levels of < 0.05, 0.01 and 0.001, respectively. GY = grain yield (kg ha^{-1}), DA = days to 50% anthesis, DS = days to 50% silking, ASI = anthesis–silking interval, PLHT = plant height (cm), EHT = ear height (cm), HUSK = husk cover (1–5 rating), PASP = plant aspect (1–5 rating), EASP = ear aspect (1–5 rating), EPP = number of ears per plant.

The single-degree orthogonal contrast between the 0 and 75 mL and the 0 and 150 mL insecticide application rates revealed significant differences ($p < 0.001$) among the varieties for all the traits, except HUSK, ASI, and EPP. However, the orthogonal contrast between the 75 and 150 mL insecticide application rates showed no significant differences among the varieties for most of the traits, except EHT (Table 3).

3.2. Performance of 10 Maize Varieties under the Different Insecticide Application Conditions

Under the 0 mL insecticide application, the GY of the varieties varied from 3.3 t ha^{-1} for DTSTR-W SYN-13 and DTSTR-Y SYN15 to 4.6 t ha^{-1} for PVA SYN-3, with a mean grain yield of 3.9 t ha^{-1}. PVA SYN-3, SAMMAZ15, and PVA SYN-9 were the top three high-yielding varieties, with grain yields that were not statistically different from each other (Table 4). The days to 50% anthesis ranged from 55, recorded by four varieties (PVA SYN-2, DTSTR-W SYN13, DTSTR-Y SYN14, and DTSTR-Y SYN-15), to 59 days for TZB-SR. The days to 50% silking ranged from 55 days for three varieties (PVA SYN-2, DTSTR-Y SYN-14, and DTSTR-Y SYN-15) to 60 days for the variety TZB-SR. The ASI for the varieties was less than one day, except for TZB-SR, with an ASI value of 1 (Table 4). DTSTR-W SYN-13 had the shortest plants (174 cm), while PVA SYN-9 and TZB-SR had the tallest (199 cm) plants. Similarly, DTSTR-W SYN-13 had the lowest ear height (86 cm), while TZB-SR had the highest ear placement (117 cm). The scores of HUSK ranged from 2 for DTSTR-Y SYN-14 to 2.6 for PVA SYN-6, while the scores for PASP and EASP ranged from 2.1 for PVA SYN-9 to 2.8 for DTSTR-W SYN-13, and from 2.3 for PVA SYN-3 to 2.9 for DTSTR-Y SYN-14, respectively. The EPP across the varieties under no insecticide application was 1.0 (Table 4).

Table 4. Mean performance of 10 maize varieties evaluated under 0 and 75 mL of emamectin benzoate insecticide application for two years (2019 and 2022) in Ibadan.

Entry	GY	DA	DS	PLHT	EHT	PASP	HUSK	EASP	ASI	EPP
	(t/ha)	(day)	(day)	(cm)	(cm)	(1–5)	(1–5)	(1–5)	(day)	(no)
0 mL emamectin benzoate insecticide application										
PVA SYN-2	4.1	55	55	184	103	2.3	2.3	2.8	0	1
PVA SYN-3	4.6	57	57	187	105	2.3	2.3	2.3	0.2	1
PVA SYN-6	3.6	57	57	178	99	2.2	2.6	2.8	0	0.9
PVA SYN-9	4.3	56	57	199	108	2.1	2.4	2.3	0.5	1
PAV SYN-13	4.2	57	58	198	104	2.3	2.2	2.3	0.5	0.9
DTSTR-W SYN13	3.3	55	56	174	86	2.8	2.3	2.8	0.2	0.9
DTSTR-Y SYN14	3.8	55	55	179	96	2.6	2	2.9	−0.3	1
DTSTR-Y SYN15	3.3	55	55	181	96	2.4	2.3	2.8	0.2	0.9
SAMMAZ15	4.5	58	58	191	96	2.5	2.3	2.4	0.3	1
TZB-SR(RE)	3.5	59	60	199	117	2.1	2.4	2.8	1	1
Mean	3.9	56	57	187	101	2.3	2.3	2.6	0.3	1
CV	19.5	2.13	2.44	5.72	10.28	18.35	16.41	19.36	247.06	14.2
LSD	0.90	1.41	1.61	12.52	12.15	0.50	0.45	0.60	0.72	0.16
75 mL emamectin benzoate insecticide application										
PVA SYN-2	5.1	54	54	208	111	2.1	2.3	2.4	0.5	0.9
PVA SYN-3	5.6	56	55	209	118	2	2.3	2.7	−0.5	1.1
PVA SYN-6	4.8	55	55	195	105	2.3	2.8	2.3	0.3	1
PVA SYN-9	5.9	56	56	217	115	1.9	2.2	2.1	0	1
PAV SYN-13	6.4	56	57	219	113	2	2.3	1.7	0.3	1
DTSTR-W SYN13	4.5	57	57	199	102	2.3	2.1	2.6	0	1
DTSTR-Y SYN14	5.8	55	54	202	111	2.3	2.2	2.3	−0.8	1
DTSTR-Y SYN15	5.3	54	54	212	107	1.8	2.4	2.3	0.3	1
SAMMAZ15	5.7	56	57	208	107	2	2.6	2	0.7	1
TZB-SR(RE)	4.9	55	57	225	118	2.2	2.8	2.2	1.3	1.1
Mean	5.4	55	56	209	110	2.1	2.4	2.3	0.2	1
CV	14.1	1.85	2.1	5.15	11.63	11.86	12.69	16.55	251.23	11.85
LSD	0.89	1.20	1.37	12.62	15.04	0.29	0.36	0.43	0.64	0.14

GY = grain yield (kg ha^{-1}), DA = days to 50% anthesis, DS = days to 50% silking, ASI = anthesis–silking interval, PLHT = plant height (cm), EHT = ear height (cm), HUSK = husk cover (1–5 rating), PASP = plant aspect (1–5 rating), EASP = ear aspect (1–5 rating), EPP = number of ears per plant.

Under the 75 mL insecticide application, the varieties differed for GY and other agronomic traits. PVA SYN-13 had the highest GY (6.4 t ha^{-1}), while DTSTR-W SYN-13 had the lowest GY (4.5 t ha^{-1}), and the mean GY across varieties was 5.4 t ha^{-1}. The top three high-yielding varieties were PVA SYN-13, PVA SYN-9, and DTSTR-Y SYN-14 (Table 4). The days to anthesis ranged from 54 days for two varieties (PVA SYN-2 and DTSTR-Y SYN-15) to 57 days for DTSTR-W SYN-13. The ASI among varieties ranged from −0.8 for DTSTR-Y SYN14 to 1.3 for TZB-SR (Table 4). PVA SYN-6 had the shortest plants (195 cm) and TZB-SR had the tallest plants (225 cm). The ear placement was lowest in DTSTR-W SYN-13 (102 cm), while TZB-SR and PVA SYN–3 had the highest ear placement (118 cm). The scores for HUSK ranged from 2.1 for DTSTR-W SYN-13 to 2.8 for TZB-SR, while the scores for PASP ranged from 1.8 (DTSTR-Y SYN15) to 2.3 (PVA SYN-6, DTSTR-W SYN-13, and DTSTR-Y SYN-14). The EASP rating ranged from 1.7 for PVA SYN-13 to 2.7 for PVA SYN-3. Similarly, the EPP across the varieties was 1.0 under the 75 mL insecticide application (Table 4).

Under the 150 mL application, the GY of the varieties ranged from 4.2 t ha^{-1} for DTSTR-W SYN-13 to 6.0 t ha^{-1} for DTSTR-Y SYN-14 with a mean of 5.3 t ha^{-1}. The highest-yielding varieties under the 150 mL insecticide application were DTSTR-Y SYN-14, DTSTR-Y SYN-15, and PVA SYN-13 (Table 5). The DA ranged from 54 days for PVA SYN-2 and DTSTR-Y SYN-15 to 57 days for PVA SYN-13, SAMMAZ-15, and TZB-SR. Similarly, the DS ranged from 54 days for PVA SYN-2, DTSTR-Y SYN-14, and DTSTR-Y SYN-15 to 58 days for TZB-SR. The ASI ranged from -1 day for DTSTR-Y SYN14 to 0.8 day for

TZB-SR (Table 5). PVA SYN-6 had the shortest plants (194 cm), while PAV SYN-13 had the tallest plants (216 cm). Ear height was the lowest for DTSTR-W SYN-13 (97 cm), while PVA SYN-2 had the highest (114 cm) ear placement. The scores for HUSK ranged from 2.0 for DTSTR-Y SYN-14 to 2.8 for PVA SYN-9, while the scores for PASP ranged from 1.9 for DTSTR-W SYN-13 to 2.3 for most of the varieties (TZB-SR, SAMMAZ15, DTSTR-Y SYN15, PVA SYN–9, PVA SYN–6, and PVA SYN–2). The EASP rating ranged from 2.0 for PAV SYN–13 to 2.7 for DTSTR-W SYN-13. As shown in the other insecticide rates, EPP ranged from 0.9 for PVA SYN–9, PAV SYN–13, DTSTR-W SYN13, and SAMMAZ15 to 1.1 for PVA SYN–3 under the 150 mL insecticide application (Table 5).

Table 5. Mean performance of 10 maize varieties evaluated under 150 mL of emamectin benzoate insecticide application for two years (2019 and 2022) in Ibadan.

Entry	**GY**	**DA**	**DS**	**PLHT**	**EHT**	**PASP**	**HUSK**	**EASP**	**ASI**	**EPP**
	(t/ha)	**(day)**	**(day)**	**(cm)**	**(cm)**	**(1–5)**	**(1–5)**	**(1–5)**	**(day)**	**(no)**
150 mL emamectin benzoate insecticide application										
PVA SYN-2	5.5	54	54	210	114	2.3	2.4	2.4	0	1
PVA SYN-3	5.3	56	56	209	105	2	2.2	2.3	0.5	1.1
PVA SYN-6	4.9	55	56	194	108	2.3	2.5	2.5	0.5	1
PVA SYN-9	5.2	56	56	202	98	2.3	2.8	2.2	0	0.9
PAV SYN-13	5.7	57	57	216	110	2	2.2	2	0.5	0.9
DTSTR-W SYN13	4.2	55	55	199	97	1.9	2.3	2.7	0.3	0.9
DTSTR-Y SYN14	6	55	54	207	98	2	2	2.1	−1	1
DTSTR-Y SYN15	5.7	54	54	208	105	2.3	2.4	2	0	1
SAMMAZ15	5.3	57	57	204	102	2.3	2.7	2.3	0.5	0.9
TZB-SR(RE)	5.2	57	58	212	113	2.3	2.4	2.3	0.8	1
Mean	5.3	55	56	206	105	2.2	2.4	2.3	0.2	1
CV	16.3	2.42	2.51	4.95	9.73	17.14	12.55	15.1	283.68	13
LSD	1.01	1.57	1.63	11.95	11.96	0.43	0.35	0.40	0.72	0.15

GY = grain yield (kg ha^{-1}), DA = days to 50% anthesis, DS = days to 50% silking, ASI = anthesis–silking interval, PLHT = plant height (cm), EHT = ear height (cm), HUSK = husk cover (1–5 rating), PASP = plant aspect (1–5 rating), EASP = ear aspect (1–5 rating), EPP = number of ears per plant.

In the combined analysis across insecticide rate applications, the GY of the varieties varied from 4 t ha^{-1} for DTSTR-W SYN13 to 5.4 t ha^{-1} for PAV SYN–13, with a mean yield of 4.9 t ha^{-1} across varieties. PAV SYN–13, SAMMAZ15, DTSTR-Y SYN14, and PVA SYN–3 were the top three high-yielding varieties. The days to anthesis ranged from 54 days for PVA SYN–2 and DTSTR-Y SYN15 to 57 days for TZB-SR, SAMMAZ15, and PAV SYN–13. The days to 50% silking ranged from 54 days, recorded by three varieties (PVA SYN–2, DTSTR-Y SYN14, and DTSTR-Y SYN15), to 58 days for TZB-SR. The ASI of the 10 varieties varied from −0.7 days for DTSTR-Y SYN-14 to 1.1 days for TZB-SR. PVA SYN–6 had the shortest plants (189 cm), while TZB-SR had the tallest plants (212 cm). DTSTR-W SYN13 had the lowest ear height (95 cm), while TZB-SR had the highest ear placement (116 cm). The scores for PASP ranged from 2.1 for PVA SYN–3 to 2.3 for SAMMAZ15. Similarly, the scores for HUSK ranged from 2.1 for DTSTR-Y SYN-14 to 2.6 for TZB-SR(RE) and PVA SYN–6. The EASP rating ranged from 2.0 for PAV SYN-13 to 2.7 for DTSTR-W SYN13. The EPP across the varieties ranged from 0.9 for PAV SYN–13 and DTSTR-Y SYN14 to 1.0 for eight varieties, with a mean of 1.0 across the 10 varieties (Table 6).

Table 6. Combined mean performance of 10 maize varieties evaluated under 0, 75, and 150 mL emamectin benzoate insecticide application for two years (2019 and 2022) in Ibadan.

Entry	GY	DA	DS	PLHT	EHT	PASP	HUSK	EASP	ASI	EPP
	(t/ha)	(day)	(day)	(cm)	(cm)	(1–5)	(1–5)	(1–5)	(day)	(no)
PVA SYN-2	4.9	54	54	201	109	2.2	2.4	2.5	0.2	1
PVA SYN-3	5.2	56	56	202	109	2.1	2.2	2.4	0.1	1
PVA SYN-6	4.5	56	56	189	104	2.3	2.6	2.5	0.3	1
PVA SYN-9	5.1	56	56	206	107	2.1	2.4	2.2	0.2	1
PAV SYN-13	5.4	57	57	211	109	2.1	2.2	2	0.4	0.9
DTSTR-W SYN13	4	56	56	191	95	2.3	2.2	2.7	0.2	0.9
DTSTR-Y SYN14	5.2	55	54	196	101	2.3	2.1	2.4	−0.7	1
DTSTR-Y SYN15	4.8	54	54	200	103	2.2	2.4	2.4	0.2	1
SAMMAZ15	5.2	57	57	201	101	2.3	2.5	2.3	0.5	1
TZB-SR(RE)	4.6	57	58	212	116	2.2	2.6	2.4	1.1	1
Mean	4.9	55.7	55.9	200.8	105.4	2.2	2.4	2.4	0.2	1
CV	16.6	2.2	2.4	5.5	10.4	20.8	13.8	17.9	266.4	13.1
LSD	0.53	0.80	0.88	7.33	7.27	0.30	0.22	0.28	0.40	0.08

GY = grain yield (kg ha^{-1}), DA = days to 50% anthesis, DS = days to 50% silking, ASI = anthesis–silking interval, PLHT = plant height (cm), EHT = ear height (cm), HUSK = husk cover (1–5 rating), PASP = plant aspect (1–5 rating), EASP = ear aspect (1–5 rating), EPP = number of ears per plant.

3.3. Foliar Fall Armyworm Damage of the 10 Maize Varieties under Natural Infestation (No Emamectin Benzoate Insecticide Treatment)

Significant year effects were observed among the varieties for LDR1, LDR3, and LDR4. Highly significant *($p < 0.01$)* differences were observed among the varieties for FAW leaf damage, scored at 42 (LDR 1) and 56 (LDR 3). However, there was no significant variety × year interaction effect detected for the FAW leaf damage among the 10 varieties (Table 7).

Table 7. Mean squares from the analysis of variance of leaf damage scores of 10 maize open-pollinated varieties evaluated for two years in Ibadan.

Source of Variation	DF	LDR1	LDR2	LDR3	LDR4
Year	1	123.27 ***	1.67	5.4 *	166.67 ***
Block (Year)	4	0.87	1.87	2.28	2.57
Variety	9	3.12 **	1.84	2.21 *	1.45
Variety × year	9	0.75	1.11	0.99	1.74
Error	36	0.87	0.92	0.99	1.03
CV		17.79	17.36	18.17	23.97

*, **, *** significant at probability levels of < 0.05, 0.01 and 0.001, respectively. LDR1 = leaf damage rating 1 (1–9 rating 42 days after planting), LDR2 = leaf damage rating 2 (1–9 rating 49 days after planting), LDR3 = leaf damage rating 3 (1 to 9 rating 56 days after planting), LDR4 = leaf damage rating 4 (1 to 9 rating 63 days after planting).

The mean performance of the varieties for FAW leaf damage ranged from 4.0 (SAMMAZ-15) to 6.2 (DTSTR-Y SYN-14), from 4.5 (SAMMAZ-15) to 6.3 (PVA SYN-6), from 4.5 (SAMMAZ-15) to 6.3 (DTSTR-Y SYN-14), and from 3.5 (SAMMAZ-15) to 5 (DTSTR-Y SYN-14) for LDR 1, LDR 2, LDR 3, and LDR 4, respectively (Table 8). The mean FAW leaf damage scores for the varieties across the period of assessment ranged from 4.1 (SAMMAZ-15) to 5.9 (DTSTR-Y SYN-14). All the varieties exhibited marginal resistance to FAW infestation, except DTSTR-Y SYN-14, which exhibited a significant level of susceptibility to FAW (Table 8).

Table 8. Mean performance for leaf damage rating of 10 maize varieties evaluated under 0 mL insecticide application for two years in Ibadan.

Entry	LDR1	LDR2	LDR3	LDR4	Overall Mean	Response
	(42 DAP)	(49 DAP)	(56 DAP)	(63 DAP)		
			(1–5)			
PVA SYN-2	5.7 abc	5.8 abc	6 abc	4.5 abc	5.5	MR
PVA SYN-3	5.8 ab	5.7 abc	5.5 abcde	4.3 abc	5.3	MR
PVA SYN-6	5.8 ab	6.3 a	5.8 abcd	4.8 ab	5.7	MR
PVA SYN-9	5 bcde	5.3 abcd	4.8 de	3.7 bc	4.7	MR
PVA SYN-13	5.7 abc	5.5 abcd	5.3 abcde	4 abc	5.1	MR
DTSTR-W SYN-13	4.3 de	5.2 bcd	6.2 ab	4.5 abc	5	MR
DTSTR-Y SYN-14	6.2 a	6.2 ab	6.3 a	5 a	5.9	S
DTSTR-Y SYN-15	5.2 abcd	5.8 abc	5 cde	4.2 abc	5	MR
SAMMAZ-15	4 e	4.5 d	4.5 e	3.5 c	4.1	MR
TZB-SR(RE)	4.7 cde	5 cd	5.2 bcde	3.8 abc	4.7	MR
Mean	5.2	5.5	5.5	4.2	-	-
CV	17.79	17.36	18.17	23.97	-	-
LSD	1.09	1.12	1.16	1.19	-	-

Means with the same letters within columns did not differ significantly at $p \leq 0.05$. MR = moderately resistant.

3.4. Yield Loss Estimates

The estimates of yield loss due to FAW infestation in the untreated (0 mL insecticide application) and treated (75 mL or 150 mL of the insecticide) conditions are presented in Table 9. The percentage-relative losses in GY due to FAW infestation when 75 mL of insecticide was applied ranged from 18% for PVA SYN-3 to 38% for DTSTR-Y SYN-15, with a mean of 27%. On the other hand, when 150 mL insecticide was applied, relative loss in GY varied from 13% for PVA SYN-3 to 42% for DTSTR-Y SYN-15 with a mean of 26% (Table 9).

Table 9. Estimates of relative grain yield losses of 10 maize varieties evaluated under three levels of insecticide application for two years in Ibadan.

Entry	Grain Yield (t ha^{-1})			Yield Loss (%)	
	0 mL	75 mL	150 mL	75 mL	150 mL
PVA SYN-2	4.1	5.1	5.5	20	25
PVA SYN-3	4.6	5.6	5.3	18	13
PVA SYN-6	3.6	4.8	4.9	25	27
PVA SYN-9	4.3	5.9	5.2	27	17
PVA SYN-13	4.2	6.4	5.7	34	26
DTSTR-W SYN-13	3.3	4.5	4.2	27	21
DTSTR-Y SYN-14	3.8	5.8	6	34	37
DTSTR-Y SYN-15	3.3	5.3	5.7	38	42
SAMMAZ-15	4.5	5.7	5.3	21	15
TZB-SR(RE)	3.5	4.9	5.2	29	33
Mean	3.9	5.4	5.3	27	26

4. Discussion

To address the challenge posed by the severity of grain yield losses due to FAW infestation and its implications on the socio-economic livelihoods of resource-limited farmers in SSA, one of the economically sustainable long-term control measures is the identification of the sources of FAW resistance and the use of the recommended insecticide rates. The highly significant differences among the varieties for grain yield, FAW leaf damage parameters, and most of the traits recorded in this study under each test condition revealed the existence of adequate genetic variation among the varieties, which can be exploited as sources of novel alleles for developing FAW-resistant varieties in a breeding program.

The observed gain in grain yield in the treatments sprayed with 75 mL and 150 mL of insecticide over plots left to natural FAW infestation (zero application) is consistent with previous results [35–37], indicating that spraying insecticides resulted in higher grain yields compared to untreated fields. In the present study, the average maize grain yields from the plots sprayed with 75 mL (5.4 t ha^{-1}) did not differ significantly from the average grain yield obtained from 150 mL (5.3 t ha^{-1}) insecticide application. This finding is in agreement with the grain yield under FAW treatment reported by [38], revealing that increased rates of insecticide applications were not always associated with higher grain yields.

The significant differences among the 10 varieties for leaf damage scores at the four different periods of data collection indicated the presence of variable levels of tolerance to FAW among the maize varieties, depending on the crop's growth stage, when the assessment was conducted. It also suggested that there is sufficient genetic variability among the varieties for effective FAW tolerance breeding. Three varieties, DTSTR-Y SYN-14, PVA SYN-6, and PVA SYN-3, recorded the highest FAW leaf damage score at 42 days after emergence, indicating their susceptibility to FAW attacks at the early growth stage. At 49 and 56 days after emergence, PVA SYN-6, DTSTR-Y SYN14, DTSTR-W SYN-13, PVA SYN-2, and DTSTR-Y SYN-15 suffered the most FAW injury. However, the highest leaf damage was recorded in DTSTR-Y SYN-14, PVA SYN-6, and DTSTR-W SYN-13 at 63 days after emergence. Although the varieties exhibited some level of consistency in their leaf damage response to FAW, the relative change in ranking of the varieties to leaf damage suggested that some varieties that were vulnerable to FAW attacks at the early vegetative stage recovered with time, whereas other varieties, which sustained low levels of FAW attack at an early vegetative stage became less tolerant at later stages of growth. Generally, FAW damages decreased at 63 days after planting, suggesting that most of the varieties that suffered FAW attacks at earlier vegetative stages recovered from the FAW attacks at their later vegetative and reproductive stages. The study [39] had earlier reported that FAW infestation at the early vegetative stage causes more damage than at the later growth stages. We observed highly significant variety effects for LDR1 at 42 days after emergence, suggesting that this stage is the most appropriate time to characterize maize germplasm for tolerance to FAW.

Reports from previous studies [40,41] have shown that the FAW can cause yield losses of up to 100% in the absence of control measures. In the present study, the average yield loss across the 10 varieties due to FAW infestation under 75 mL (27%) and 150 mL (26%) insecticide application were similar. The similarity in average yield loss under both insecticide treatments is consistent with the non-significant difference observed in the average grain yields under these treatment conditions. A study in Kenya [23] reported an average economic loss of 47%, while in Zimbabwe, [17] reported a loss of 11.6%. Generally, the grain yield loss of maize varieties increased with a reduction in FAW infestation. These findings are in close agreement with the results obtained by [42], who reported that yield loss was higher in the untreated plots compared to the plots treated with insecticides.

5. Conclusions

Our study demonstrated the existence of genetic variability for tolerance to the FAW among the 10 elite maize varieties evaluated under three levels of insecticide treatments (0, 75, and 150 mL). Most of the varieties exhibited moderate resistance/tolerance to the FAW, with the exception of DTSTR-Y SYN-14, which exhibited susceptibility to the FAW at all treatment levels. Leaf damage recorded at early vegetative stages provided the best opportunity for identifying the varieties with good levels of tolerance to FAW. The application of emamectin benzoate at half the manufacturer's recommendation (75 mL) provided good protection for maize growth, and hence high grain yields. However, increasing the dose to 150 mL had no significant effect on increasing grain yield. The average grain yield loss was 27% and 26% under 75 mL and 150 mL, respectively. Four varieties, PVA SYN-13, PVA

SYN-9, DTSTR-Y SYN-14, SAMMAZ-15, and PVA SYN-3, had grain yields above the mean under 75 mL. However, PVA SYN-3 and PVA SYN-13 were the most consistent varieties, producing high grain yields across all insecticide treatment levels. These two varieties can be further tested under naturally FAW infested fields by partners in West Africa to confirm their yield performance and the level of their resistance to the FAW. We conclude that the use of moderately resistant varieties, combined with timely spraying of emamectin benzoate at 75 mL, provides adequate protection against FAW infestation, leading to a high grain yield in maize. This would provide an opportunity for smallholder farmers to boost their production in areas infested with FAW.

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Abbreviations

Anthesis–silking interval (ASI), days to 50% anthesis (DA), days to 50% silking (DS), ear aspect (EASP), ear height (EHT), grain yield (GY), husk cover (HUSK), leaf damage rating (LDR), number of ears per plant (EPP), plant aspect (PASP), plant height (PLHT).

References

1. Shiferaw, B.; Prasanna, B.M.; Hellin, J.; Bänziger, M. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Sec.* **2011**, *3*, 307. [CrossRef]
2. FAOSTAT. Crop Yields FAOSTAT. 2020. Available online: https://ourworldindata.org/crop-yields (accessed on 15 February 2024).
3. Beyene, Y.; Semagn, K.; Crossa, J.; Mugo, S.; Atlin, G.N.; Tarekegne, A.; Meisel, B.; Sehabiague, P.; Vivek, B.S.; Oikeh, S.; et al. Improving maize grain yield under drought stress and non-stress environments in sub-Saharan Africa using marker assisted recurrent selection. *Crop Sci.* **2016**, *56*, 344–353. [CrossRef]
4. IITA. 2017 Annual Report: Serving the African Farmers and Communities. 2017. 124. Available online: http://www.iita.org/wp-content/uploads/2019/01/2017-IITA-annual-report.pdf (accessed on 15 February 2024).
5. Ekpa, O.; Palacios-Rojas, N.; Kruseman, G.; Fogliano, V.; Linnemann, A.R. Sub-Saharan African maize-based foods: Technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. *Glob. Food Secur.* **2018**, *17*, 48–56. [CrossRef]
6. Grote, U.; Fasse, A.; Nguyen, T.T.; Erenstein, O. Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia. *Front. Sustain. Food Syst.* **2021**, *4*, 617009. [CrossRef]
7. Kasoma, C.; Shimelis, H.; Laing, M.D. Fall armyworm invasion in Africa: Implications for maize production and breeding, *J. Crop Improv.* **2021**, *35*, 111–146. [CrossRef]
8. FAO. Fall Armyworm Forecasting. 2020. Available online: https://www.fao.org/food-chain-crisis/how-we-work/plant-protection/fallarmyworm/en/ (accessed on 2 February 2024).
9. Goergen, G.; Kumar, P.L.; Sankung, S.B.; Togola, A.; Tamò, M. First Report of Outbreaks of the Fall Armyworm *Spodoptera Frugiperda* (J.E. Smith) (*Lepidoptera*, *Noctuidae*), a New Alien Invasive Pest in West and Central Africa. *PLoS ONE* **2016**, *11*, e0165632. [CrossRef] [PubMed]
10. Tepa-Yotto, G.T.; Tonnang, H.E.; Goergen, G.; Subramanian, S.; Kimathi, E.; Abdel-Rahman, E.M.; Sæthre, M.G. Global habitat suitability of *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae): Key parasitoids considered for its biological control. *Insects* **2021**, *12*, 273. [CrossRef]

11. Wan, J.; Huang, C.; Li, C.; Zhou, H.; Ren, Y.; Li, Z.; Xing, L.; Zhang, B.; Qiao, X.; Liu, B.; et al. Biology, invasion and management of the agricultural invader: Fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J. Integr. Agric.* **2021**, *20*, 646–663. [CrossRef]
12. Virla, E.G.; Álvarez, A.; Loto, F.; Pera, L.M.; Baigorí, M. Fall Armyworm Strains (Lepidoptera: Noctuidae) in Argentina, Their Associate Host Plants and Response to Different Mortality Factors in Laboratory. *Fla. Entomol.* **2008**, *91*, 63–69. [CrossRef]
13. CABI. Invasive Species Compendium. 2018. Available online: www.cabi.org/isc/fallarmyworm (accessed on 18 January 2024).
14. FAO. *Fall Armyworm Management—Farmer Field School Experiences in Africa*; FAO: Addis Ababa, Ethiopia, 2021.
15. de la Cruz, J.; Kressler, D.; Linder, P. Unwinding RNA in Saccharomyces cerevisiae: DEAD-box proteins and related families. *Trends Biochem. Sci.* **1999**, *24*, 192–198. [CrossRef]
16. FAO. *Briefing Note on FAO Actions on Fall Armyworm in Africa*; FAO: Rome, Italy, 2018; Available online: http://www.fao.org/3/a-bt415e.pdf (accessed on 15 February 2024).
17. Day, R.; Abrahams, P.; Bateman, M.; Beale, T.; Clottey, V.; Cock, M.; Colmenarez, Y.; Natalia, C.; Early, R.; Godwin, J.; et al. Fall Armyworm: Impacts and Implications for Africa. *Outlooks Pest Manag.* **2017**, *28*, 196–201. [CrossRef]
18. Prasanna, B. *Breeding for Native Genetic Resistance to Fall Armyworm*; CGIAR Research Programme on Maize: Hohenheim, Germany, 2018.
19. Fatoretto, J.C.; Michel, A.P.; Filho, M.C.S.; Silva, N. Adaptive potential of fall armyworm (Lepidoptera: Noctuidae) limits Bt trait durability in Brazil. *J. Integr. Pest Manag.* **2017**, *8*, 17. [CrossRef]
20. Kasoma, C.; Shimelis, H.; Laing, M.; Shayanowako, A.I.T.; Mathew, I. Screening of inbred lines of tropical maize for resistance to fall armyworm, and for yield and yield-relatedtraits. *Crop. Prot.* **2020**, *136*, 105218. [CrossRef]
21. Prasanna, B.M.; Huesing, J.E.; Peschke, V.M.; Nagoshi, R.N.; Jia, X.; Wu, K.; Trisyono, Y.A.; Tay, T.; Watson, A.; Day, R.; et al. Fall armyworm in Asia: Invasion, impacts, and strategies for sustainable management. In *Fall Armyworm in Asia: A Guide for Integrated Pest Management*; Prasanna, B.M., Ed.; CIMMYT: Cdmx, Mexico, 2021; pp. 1–20.
22. Chisanga, B. IMPACT of the Fall Armyworm (FAW) on the FOOD Security of Children and Mothers in Eastern Uganda. In Proceedings of the 2021 Conference, Virtual, 17–31 August 2021; p. 315223.
23. Kumela, T.; Simiyu, J.; Sisay, B.; Likhayo, P.; Mendesil, E.; Gohole, L.; Tefera, T. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm *(Spodoptera frugiperda)* in Ethiopia and Kenya. *Int. J. Pest.* **2018**, *65*, 1–9. [CrossRef]
24. Mihm, J.A. *Insect Resistant Maize-Recent Advances and Utilization*; Mihm, J.A., Ed.; CIMMYT: El Batan, Mexico, 1997; p. 304.
25. Mihm, J.A.; Smith, M.E.; Deutsch, J.A. Development of Open-Pollinated Varieties, Non-Conventional Hybrids and Inbred Lines of Tropical Maize with Resistance to Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), at CIMMYT. *Fla. Entomol.* **1988**, *71*, 262–268. [CrossRef]
26. Wiseman, B.R.; Davis, F.M. Plant Resistance to Insects Attacking Corn and Grain Sorghum. *Fla. Entomol.* **1979**, *62*, 123–130. Available online: http://www.jstor.org/stable/3495461 (accessed on 2 April 2024). [CrossRef]
27. Chiriboga Morales, X.; Tamiru, A.; Sobhy, I.S.; Bruce, T.J.A.; Midega, C.A.O.; Khan, Z. Evaluation of African Maize Cultivars for Resistance to Fall Armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) Larvae. *Plants* **2021**, *10*, 392. [CrossRef]
28. Prasanna, B.P. Host Plant Resistance to Fall Armyworm: Status and Prospects WTO Meeting. 2019. Available online: https://www.wto.org/english/tratop_e/sps_e/faw_2_c_prasanna_thematic_session_faw_19march2019.pdf (accessed on 5 April 2024).
29. Tambo, J.A.; Day, R.K.; Lamontagne-Godwin, J.; Silvestri, S.; Beseh, P.K.; Oppong-Mensah, B.; Phiri, N.A.; Matimelo, M. Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: An analysis of farmers' control actions, *Int. J. Pest Manag.* **2020**, *66*, 298–310. [CrossRef]
30. Williams, W.; Bukclye, P.; Davis, F. Combining ability for resistance in corn to fall armyworm and to southwestern corn-borer. *Crop Sci.* **1989**, *29*, 913–915. [CrossRef]
31. Davis, F.M.; Williams, W.P. *Visual Rating Scales for Screening Whorl-stage Corn for Resistance to Fall Armyworm*; Starkville, MS: Mississippi Agricultural and Forestry Experiment Station, Technical Bulletin 186; Mississippi State University: Starkville, MS, USA, 1992.
32. Ni, X.; Chen, Y.; Hibbard, B.E.; Wilson, J.P.; Williams, W.P.; Buntin, G.D.; Ruberson, J.R.; Li, X. Foliar resistance to fall armyworm in corn germplasm lines confers resistance to root and ear-feeding insects. *Fla. Entomol.* **2011**, *94*, 971–981. [CrossRef]
33. Toepfer, S.; Fallet, P.; Kajuga, J.; Bazagwira, D.; Mukundwa, I.P.; Szalai, M.; Turlings, T.C.J. Streamlining leaf damage rating scales for the fall armyworm on maize. *J. Pest Sci.* **2021**, *94*, 1075–1089. [CrossRef]
34. Soujanya, P.L.; Sekhar, J.C.; Yathish, K.R.; Karjagi, C.G.; Rao, K.S.; Suby, S.B.; Jat, S.L.; Kumar, B.; Kumar, K.; Vadessery, J.; et al. Leaf Damage Based Phenotyping Technique and Its Validation Against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith), in Maize. *Front. Plant Sci.* **2022**, *13*, 906207. [CrossRef] [PubMed] [PubMed Central]
35. Singh, D.P.; Sarao, P.S. Efficacy of different insecticides for the control of stem borer, Scirpophaga incertulas (Walker). *Pestology* **2001**, *25*, 39–40.
36. Barman, H.K.; Barat, A.; Yadav, B.M.; Banerjee, S.; Meher, P.K.; Reddy, P.V.G.K.; Jana, R.K. Genetic variation between four species of Indian major carps as revealed by random amplified polymorphic DNA assay. *Aquaculture* **2003**, *217*, 115–123. [CrossRef]
37. A Magdy, M.; A Osman, Z.; S Ahmed, B.; M Ahmed, E.; A Abou-gleel, A. Assessment of Maize Yield Loss to Determine Economic Injury Levels (Eils) Due To the Infestation by Stem Borers with Insecticidal Control under the Egyptian Conditions. *Alex. Sci. Exch. J.* **2016**, *37*, 729–737.

38. Pogetto, M.H.F.A.D.; Prado, E.P.; Gimenes, M.J.; Christovam, R.S.; Rezende, D.T.; Junior, H.O.A.; Costa, S.I.A.; Raetano, C.G. Corn yield with reduction of insecticidal sprayings against Fall Armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J. Agron.* **2012**, *1*, 17–21. [CrossRef]
39. Buntin, G.D. A review of plant response to fall armyworm, *Spodoptera frugiperda* (J. E. Smith), injury in selected field and forage crop. *Fla. Entomol.* **1986**, *69*, 549–558. [CrossRef]
40. de Oliveira, N.C.; Suzukawa, A.K.; Pereira, C.B.; Santos, H.V.; Hanel, A.; de Albuquerque, F.A.; Scapim, C.A. Pop-corn genotypes resistance to fall armyworm. *Ciência Rural* **2018**, *48*, 5–10. [CrossRef]
41. De Groote, H.; Kimenju, S.C.; Munyua, B.; Palmas, S.; Kassie, M.; Bruce, A. Spread and impact of fall armyworm (*Spodoptera frugiperda* J.E. Smith) in maize production areas of Kenya. *Agric. Ecosyst. Environ.* **2020**, *292*, 106804. [CrossRef]
42. Pandya, H.V.; Shah, A.H.; Purohit, M.S.; Patel, C.B. Estimation of losses due to rice stem borer (Scirpophaga incertulas Wlk.). *Gujarat Agric. Univ. Res. J.* **1994**, *20*, 164–166.