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ORIGINAL ARTICLE

Damage evaluations of the maize pests' complex: a comparative injuriousness of fall armyworm and stem borers under subsistence maize cultivation techniques

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Abstract

Background Given the perplexity in the maize pest complex which has been exacerbated by the addition of the invasive fall armyworm to the preexisting stem borers, this study was aimed at assessing the damage effects caused by a complex of lepidopterous maize pests under subsistence maize cultivation techniques in order to facilitate appropriate farm-level implementation of effective sustainable control measures of lepidopterous maize pests and improve productivity.

Methods This study was carried out in eighteen subsistence maize farmer's fields, each measuring 50×50 m (2500 m^2) in Buea and Tiko in Cameroon's South West Region. All selected fields used a zero-tillage system, with planting done over 3 years (2020, 2021 and 2022) with 2 cropping seasons per year on the 20 March for the first season and the 25 August for the second season. Data were collected on the incidence (%) of damaged plants per plot, severity of leaf damage (1–9 scale) and degree of damage to stems, tassels and ears. Maize grain yield was recorded, and all data were analyzed with Stat soft version 2022.

Results Throughout the study period, fall armyworm had the highest percentage of damage incidence of 34.8, which was significantly different from 27.4 for stem borers ($p < 0.001$), while stem borers had the highest damage severity (mean 4.5), significantly different from the mean of 3.2 for fall armyworm ($p < 0.001$). Maize grain yields varied significantly between seasons and years ($p < 0.001$). The fall armyworm damage incidence varied considerably between seasons ($p < 0.001$). In contrast to damage incidence, damage severity caused by fall armyworm on maize decreased significantly from 2020 to 2022; the greatest damage severity of 3.2 was observed in 2020, followed by 2.4 in 2021 and 1.8 in 2022. The pattern for stem borers was different, with no significant difference in damage severity ($p < 0.001$) across the years of research, with the lowest mean damage severity observed in 2021 (4.1), followed by 2020 (4.4) and 2022 (4.5). This study found that damage caused by fall armyworm decreased over time, while damage caused by maize stem borers remained nearly constant. Meanwhile, the overall tunnel length in meters and exit holes were significantly greater in the second seasons of the research period than in the first seasons.

Conclusion and recommendation Maize stem borers are the most damaging lepidopterous pests of maize in the study area, drastically reducing maize grain yield during the study period. The high incidence of fall armyworm damage without a corresponding increase in damage severity and maize grain yield reductions throughout the study period clearly demonstrates the pest's low impact on yields when compared to maize stem borers, which feed on maize stems, making them fragile and significantly impeding nutrient uptake and thus plant growth and yields. Due to the severity of injuries caused by the species complex of fall armyworm and stem borers with significant yield reduction, we recommend the use of integrated pest management (IPM) tactics that takes into consideration the control of fall armyworm and stem borers simultaneously.

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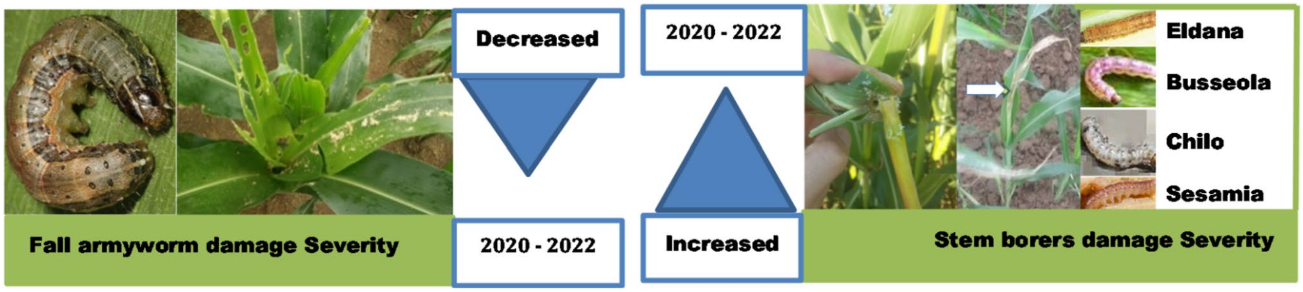
Graphical abstract



Keywords Lepidopterous pests · Maize stem borers · Fall armyworm · Maize damage severity · Maize pests · Complex

Abbreviations

FAW	Fall armyworm
SSA	Sub-Saharan Africa
FAO	Food and agriculture organization
CABI	Center for agriculture and bioscience international
WAG	Weeks after germination
SD	Standard deviation
ANOVA	Analysis of variance

Introduction

Smallholder farmers in most African countries struggle to identify damage caused by several lepidopterous pests, as well as which pests have the greatest impacts on maize growth and grain output. The economically important lepidopterous stemborer species in Africa are: (1) the African maize stem borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae); (2) the spotted stem borer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae); (3) the coastal stem borer *Chilo orichalcocillielus* (Strand) (Lepidoptera: Crambidae); (4) pink stem borer *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae); and (5) sugarcane stem borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Adeyinka et al. 2018). However, since the invasion by *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), the number of major lepidopterous pests of maize in Africa has increased. As a result, proper pest identification is critical for redirecting management tactics and ensuring proper farm-level adaptations for effective control of maize pests in smallholder cropping systems (Mankwana et al. 2021) and proper scientific knowledge on the current major lepidopterous pest of maize is required to design sustainable integrated pest management (IPM) techniques that suit smallholder farmers in Africa. Prior to the arrival of *S. frugiperda*, *B. fusca* was regarded as the continent's most serious pest of maize. This has not changed in certain West African nations, such as Nigeria, where *B. fusca* was initially reported (Van den Berg et al. 1991; Kfir et al. 2002; Oyewale et al. 2020). Crop loss estimates vary substantially among regions and agroecological zones. In Kenya, losses due to *B. fusca* damage to maize are estimated at 14% (De Groote. 2002), whereas in Cameroon's humid forest zone, grain losses of 40% are common in monocropped maize fields (Cardwell et al. 1997; Chabi-Olaye et al., 2005; Calatayud et al. 2014). The larvae of the moth can cause up to 100% damage, resulting in the collapse of the maize crop (Oyewale et al. 2020). Larvae inflict damage by feeding inside the maize whorl after which they tunnel into the stems. Larvae can damage growth points during the early phases of crop development, resulting in 'deadhearts' and total crop stand loss. At later stages of growth, significant tunneling of the stems weakens the plants, causing it to break and dislodge. Tunneling larvae may also cause damage to maize ears, allowing the peduncles to shatter.

The invasion of *S. frugiperda* in 2016 (Goergen et al. 2016; Tindo et al. 2017) reduced farmers' attention from *B. fusca* to the fall armyworm due to its characteristic feeding habits which is associated with large quantities of frass due to the voracious larval feeding habits and consequently increasing the visibility of pest damage. *Spodoptera frugiperda*, a native of the Americas' tropical and subtropical regions, has expanded to Asia and, eventually, Africa in early 2016. This pest's destructive feeding habits are currently found in Africa, Asia, Australia, North and South America (Nagoshi et al. 2017; Cock et al. 2017; FAO. 2018; Uzayisenga et al. 2018). In low-input smallholder farming systems, it has been found to cause losses ranging from 21 to 53% (Abrahams et al. 2017). The impact of *S. frugiperda* on maize has been a huge concern for the continent since it poses a serious danger to millions of people's food and nutrition security (Huesing et al. 2018). The pest is present in all of Cameroon's major maize-producing agroecological zones, with the maximum severity and infestation in the Sahelian and Highland savanna zones (Tindo et al. 2017; Kuate et al. 2019).

FAW are destructive caterpillars which feed on young maize leaf whorls, stems, branches and reproductive organs such as tassels and ears, causing significant crop damage and considerable grain yield loss (De Almeida et al. 2002; FAO. 2018). In Africa, the pest is endangering the livelihoods of indigenous smallholder farmers who rely on maize production for revenue and food security (Goergen et al. 2016; Abrahams et al. 2017). FAW destructive caterpillars feed on young maize leaf whorls, stems, branches and reproductive organs such as tassels and ears, causing significant crop damage and considerable grain yield loss (De Almeida et al. 2002; FAO. 2018). In Africa, the pest is endangering the livelihoods of indigenous smallholder farmers who rely on maize production for revenue and food security (Goergen et al. 2016; Abrahams et al. 2017).

The cereal with the biggest yield worldwide, maize, Zea mays L. (Poaceae), is grown commercially as an industrial and/or food crop. Maize is the primary food crop for over 300 million people in Africa (IPBO. 2017). At the moment, Africa's average maize production is at 1.5 t ha^{-1}, which is much lower than the global average output of 4.9 t ha^{-1}. The crop is grown in a variety of agroecological zones, from wet to hot semiarid regions, and in a variety of soil types (Shiferaw et al. 2011). Maize is the most commonly produced staple food crop in sub-Saharan Africa (SSA), providing food and livelihood for around 208 million people (Parihar et al. 2011; Macauley. 2015) and accounting for 73% of calorific intake (Shiferaw et al. 2011). This research examined the damage caused by lepidopterous maize pests in order to identify the key ones that are negatively impacting maize grain production and recommend appropriate control measures.

Materials and methods

Description of the study site

Buea is located in the Southwest Region of Cameroon, between latitudes 4° 3′ N and 4° 12′ N of the equator and longitudes 9° 12′ E and 9° 20′ E; the soil is composed of weathered volcanic rocks characterized by silt, clay and sand (John et al. 2007). Buea has a monomodal rainfall regime with a less evident dry season and an average relative humidity of 85–90%. The dry season lasts from November through March, with rainfall averaging 2085–9086 mm (Payton. 1993). The average monthly air temperature ranges between 1930 and 15 °C, whereas the soil temperature at 10 cm depth decreases from 25 to 15 °C. Buea is located at an altitude that ranges from 200 to 2200 m above sea level (Payton. 1993; John et al. 2007). Tiko is located at 9° 32′ 2″ N–9° 40′ 9″ N and longitude 9° 25′ 7″ E–9° 55′ 7″ E, 220 m above sea level, with an average temperature of 31 °C and 79% humidity. Agriculture is the principal occupation of Tiko, with plantation crops like as rubber, oil palms and bananas, as well as certain roots and tubers, maize and other vegetable crops, dominating.

Experimental site and setup

This study was carried out in Buea and Tiko in Cameroon's South West Region, where the existence of stem borers has been known for decades and fall armyworm was first detected in 2016. Both locations have fertile volcanic soils that are ideal for maize production.

Eighteen smallholder farmers in the two study sites were selected based on the informed permission of willing farmers to participate in the study. Each farmer was assigned a suitable field plot measuring 50 m × 50 m (2500 m^2) for the study. All fields were planted with zero tillage on the same dates of March 20 for the first season and August 25 for the second season maize planting, and this was repeated throughout the study period of 2020, 2021 and 2022. The UBNMS001 maize variety was planted in the field at 80 × 50 cm inter- and intra-row spacing, with a boundary spacing of 50 cm and a total plant population of 6138 per plot. At 2 weeks following germination, all planted plots were adjusted with the same type and amount of soil applied inorganic fertilizers NPK 20:10:10 + CaO (ADER® Cameroon), 5 g per plant by ringing 5 cm from plants. All plots were rain fed, and weed emergence was monitored on a regular basis and manually weeded when necessary with a hoe.

Sampling and data collection

Data were collected from four cell quadrants delineated within a plot, each spanning 3 × 4 m, in which 20 plants were selected at random and assessed for signs and symptoms of FAW and stem borers at three stages of growth: 4, 8 and 12 weeks after germination (WAG). Border plants were not included in the sampling. Each plant was checked for new signs of fall armyworm or stem borers' infestation. Data on stem borer damage were collected on the leaves, stems (tunnel length), tassels and ears of maize, while data on fall armyworm were collected on leaves, tassels and ears. The presence of larvae and whitish excrement, as well as the leaf feeding pattern, characterized the FAW infestation. The absence of whitish sawdust-like excrements and the distinctive circular holes on the leaves indicated stem borers' infestation. Pest damage occurrences (fall armyworm or stem borers) were determined as a percentage ratio of affected maize plants over the total number of plants under observation:

$$\text{Damage incidence by pest}\,(\%) = \frac{\text{Number of infested plants under observation per plot}}{\text{Total number of plants observed per plot}} \times 100 \quad (1)$$

Stem borers and fall armyworm damage severity were determined at eight and twelve WAG by scoring each affected plant on a scale of 1–9 (where 1 = no visible damage and 9 = entirely injured) (Otim et al., 2022). At harvest (12WAG), 20 infested maize plants were selected, the leaves were pulled off (removed), and stem damage was measured. The number of stem borers exit holes per plant was counted and recorded, and the stems were split open to record tunnel length, larvae count and pupae count. For grain yield, 20 afflicted maize plants were collected per plot for fall armyworm and stem borers, and the ears were threshed, dried to a moisture content of 14% and weighed individually (Otim et al., 2022) .

Statistical analysis

In Microsoft Excel, the means of the various data parameters were determined for each experimental unit (plot). STATISTICA (Statsoft version 2022) was used to assess all data for variance homogeneity and the assumption of normality prior to analysis. MANOVA was used to evaluate all data, using contrasts for pairwise comparisons of fall armyworm and stem borers' damage parameters, seasonal and yearly comparisons, interactions and grain yield. Using the Tukey's HSD method, the means were compared using multiple comparison tests. STATISTICA (Statsoft version 2022) was used for all statistical analyses.

Results

Abundance of fall armyworm and stem borers at various crop growth stages

There was a statistically significant difference in pest occurrence across maize growth stages ($p < 001$). The damage incidence for both fall armyworm and stem borers was highest in 2020, followed by 2021 and lowest in 2022 (Fig. 1). Fall armyworm damage incidence was highest in the early stages of maize plants (4–8 WAG) and lowest at the 12 WAG. In the case of stem borers, damage incidence was lowest at 4–8 WAG and highest toward the end of the crop at 12 WAG. These patterns held true for the years 2020, 2021 and 2022 (Fig. 1).

Fall armyworm exhibited the greatest percentage of mean damage incidence of 34.8 during the study period, which was significantly different from that of 27.4 for stem borers at $p < 0.001$ (Fig. 2).

Annual and seasonal variations in pest damage incidence and severity

Throughout the study period, there was a considerable difference in damage occurrence across seasons (first/rainy and second/dry). The second/dry seasons had the highest damage incidence, which was significantly different from the first/rainy seasons at ($p < 0.001$). The fall armyworm damage incidence varied considerably from 2020 to 2021 and 2022 ($p < 0.001$), with the highest incidence recorded in 2020, followed by 2021 and then 2022 with the lowest damage incidence. In contrast to damage incidence, there was a significant decrease in damage severity produced by fall armyworm on maize from 2020 to 2022; the maximum severity was 3.2 in 2020, followed by 2.4 in 2021 and 1.8 in 2022. However, there was no significant difference in damage incidence and damage severity ($p < 0.001$) across years throughout the study period for stem borers; the lowest damage severity of 4.1 was recorded in 2021, followed by 4.4 in 2020 and the highest damage severity of 4.5 on a scale of 9 occurred in 2022 (Fig. 3).

Annual and seasonal effect of fall armyworm and stem borers on maize grain yield

Plants affected by fall armyworm recorded the highest maize grain yield compared to plants damaged by stem borers at ($p < 0.001$). The largest grain yield for fall armyworm-damaged plants was recorded during the second/dry season of 2022, while the lowest yield was recorded during the second/dry season of 2020. On the other hand, the highest maize grain yield for stem borer-damaged plants was recorded in the first/rainy season of 2020, and the lowest grain yield was recorded in the second season of 2022, with no significant differences in grain yield across seasons and years for stem borer-damaged plants at ($p < 0.001$) (Fig. 4).

Tunnel length and exit hole variations induced by stem borers from 2020 to 2023

Tunnel length and number of exit holes were greatest in 2022, followed by 2021 and 2020. Meanwhile, the tunnel length in meters and exit holes for 2022 were significantly greater in the second seasons of the study period (Table 1).

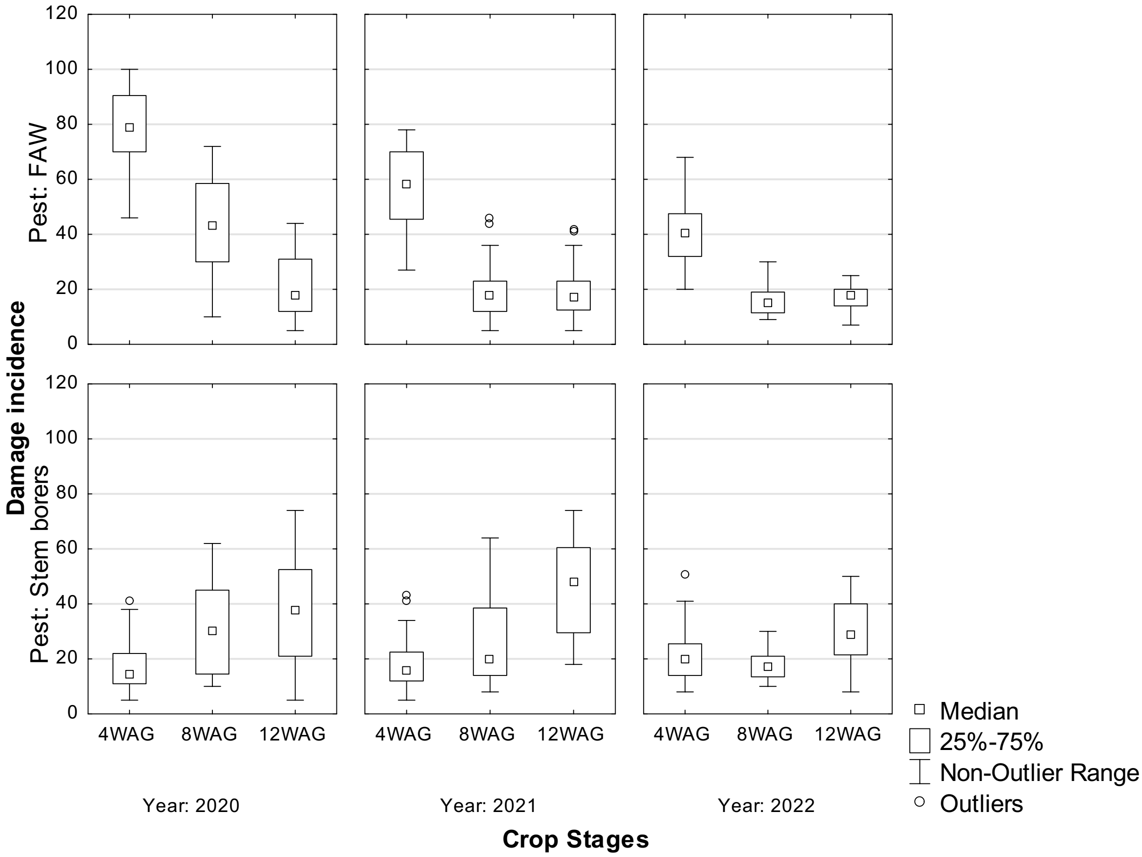


Fig. 1 Box plot depicting the annual damage incidence at various weeks after germination (WAG) from 2020 to 2022

Fig. 2 Mean plot of damage Incidence by Pest in 2020, 2021 and 2022

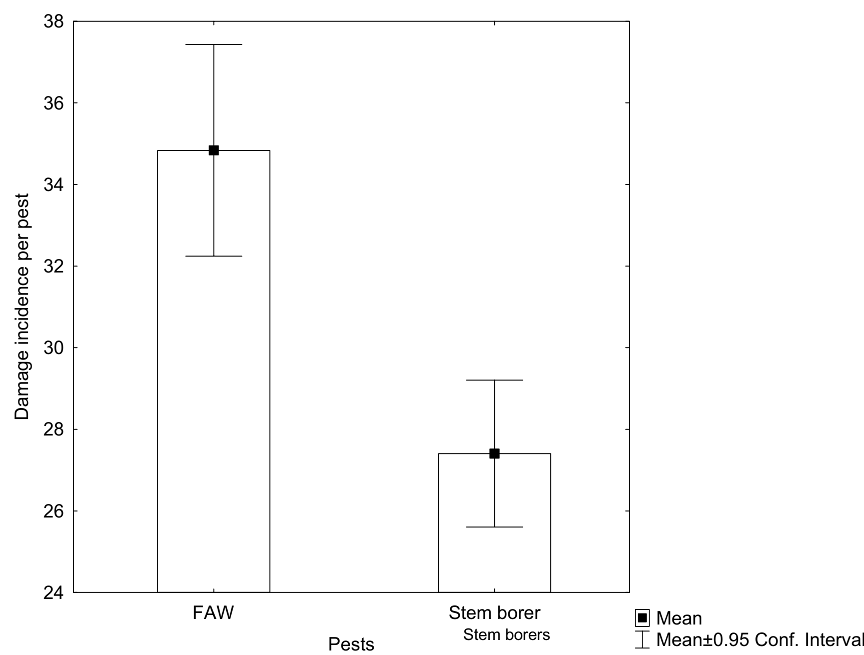
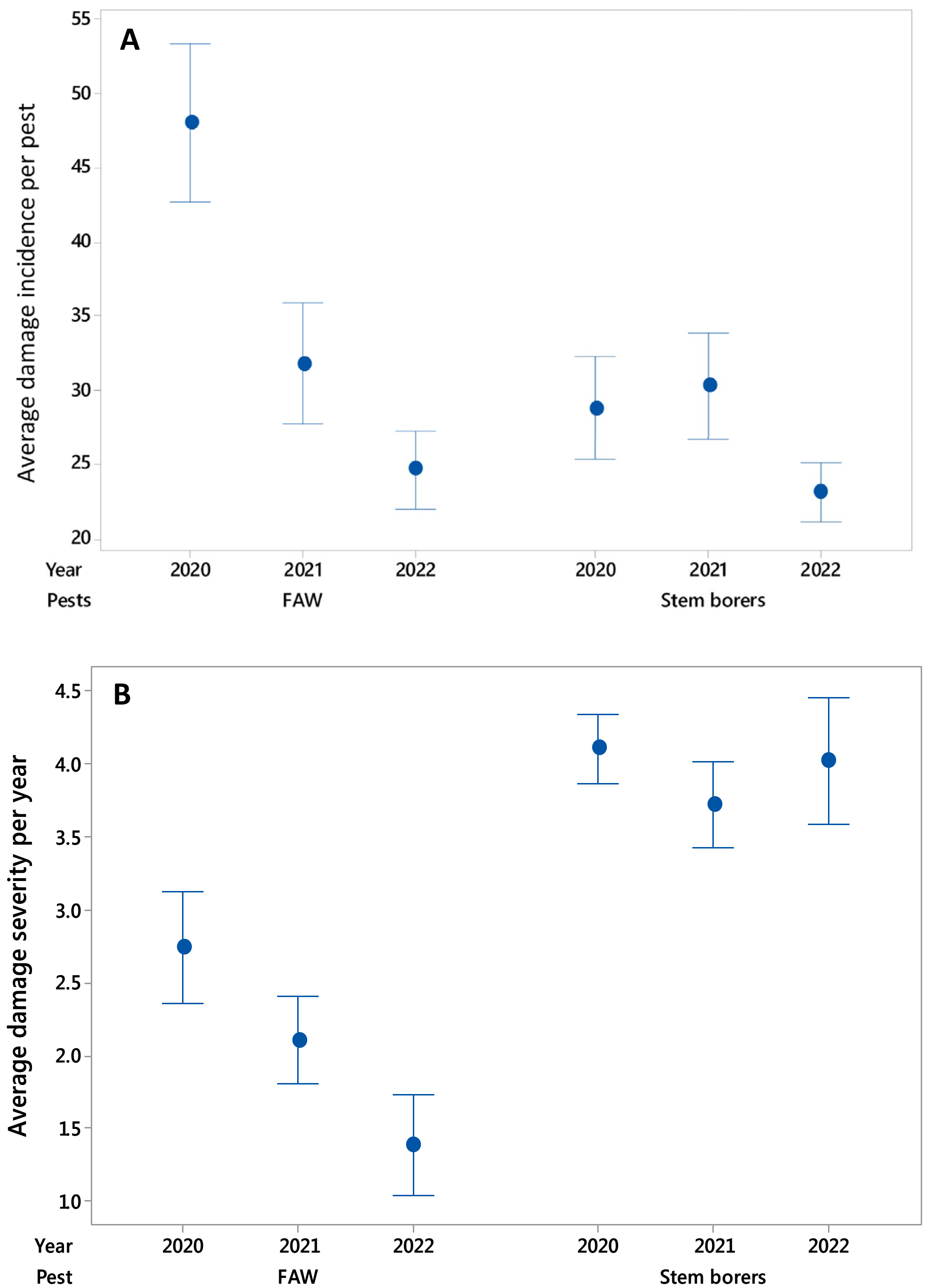


Fig. 3 Average damage severity (**A**) and damage incidence (**B**) caused by fall armyworm (FAW) and stem borers from 2020 to 2022



Pests damage to tassels and ears

The number of maize ears infested with stem borers varied significantly among seasons ($p<0.001$), with the dry season having the largest percentage mean of 45 and the rainy season having the lowest percentage mean of 21. Fall armyworm damage severity on maize tassel was 5.3, which was substantially higher than 2.1 for stem borers ($p<0.001$).

Discussion

Pest damage frequency and crop stage

Fall armyworm produced more damage than stem borers at 4 WAG and 8 WAG, which is consistent with the findings of (Mutyambai et al. 2022). The leaves and stems

Fig.4 Impact of fall armyworm and stem borers on maize grain yield on an annual and seasonal basis

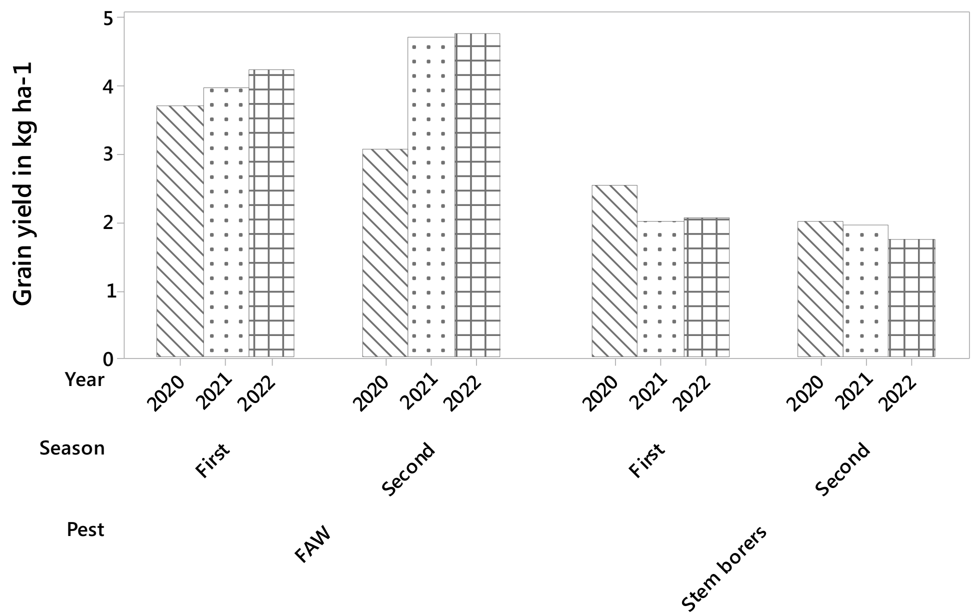


Table 1 Tunnel length (cm) and number of exit holes per plant vary seasonally and annually from 2020 to 2022

Parameters	Seasons	Years		
		2020	2021	2022
Tunnel length (cm)	S1	1.6 ± 0.5aA	1.6 ± 0.5aA	2.2 ± 0.6aA
	S2	1.6 ± 0.5aA	1.6 ± 0.5aA	3.8 ± 1.3bB
No. of exit holes per plant	S1	3.9 ± 0.8aA	3.1 ± 0.8aA	2.3 ± 0.8aA
	S2	2.6 ± 0.8aA	4.4 ± 0.6aB	5.3 ± 2.9bC

Values within columns with different letters (lowercase) per parameter are significantly different ($p < 0.05$), while values within rows with different letters (uppercase) are significantly different ($p < 0.05$)

of maize plants are softer and more susceptible to larvae at these early growth stages than older plant parts, which are more lignified and hence harder. Furthermore, the higher damage incidence found for fall armyworm larvae than stem borers may be attributed to the pest's more visible eating features, as opposed to stem borers, which feed inside the stems. As a result, fall armyworm damage is more quickly discovered by farmers and crop security agencies than stem borers known for their hidden stem tunneling damage, with the exception of early leaf infestation (Matova et al. 2020). Early leaf infestations by stem borers are sometimes misinterpreted for damage caused by fall armyworm. The high damage severity caused by stem borers, despite their low damage incidence, can be attributed to the tunneling nature of its damage, which disrupts the movement of water and nutrients required for optimum crop growth; tunneling of the stems also renders infested maize plants very fragile and easily toppled with the slightest breeze or wind (Oyewale et al. 2020). There is a substantial positive relationship between the severity of maize damage produced by stem borers and the number of toppled maize plants as reported by Oyewale et al. 2020. The significant damage severity documented in 2020 and 2022 for plants infested by stem borers, as well as the corresponding drop in maize grain yields, demonstrates that stem borers are the dominant maize field pests in the study area. The high incidence of fall armyworm damage without a corresponding increase in damage severity and maize grain yield reductions throughout the study period clearly demonstrates the pest's low impact on yields when compared to maize stem borers, which feed on maize stems, thereby significantly impeding nutrient uptake and thus plant growth and yields. The high damage incidence caused by the fall armyworm but with less negative effects on maize yields may be due to the numerous maize functional leaves capable of supporting normal physiological processes and photosynthesis (Oyewale et al. 2020), allowing the crop to maintain yields despite the fall armyworm damage to leaves. A healthy maize plant has many functional leaves; therefore, if only a few of these leaves are injured by the fall armyworm, the crop's growth and yields will not suffer much.

Pest damage incidence and severity vary seasonally

The year 2020 had the highest damage incidence caused by fall armyworm and stem borers, followed by 2021, while the year 2022 had the lowest incidence. These findings are compatible with the research work of Adeyinka et al. (2018) and Tanyi et al. (2022). The second (dry) seasons had the highest pest incidence, which was significantly different from the first (rainy seasons). Tanyi et al., (2018) obtained similar results for cabbage pests in the same study region. Damage incidence for fall armyworm varied substantially between 2020 and 2022. The fall armyworm caused the most damage in 2020, followed by 2021 and the least damage in 2022. The insect's decreasing influence over time may be attributable to an increase in the number of indigenous natural enemies such as ear wigs, along with the dramatic synthetic chemical control reaction used by maize producers as a strategy to effectively combat the foreign invasive pest (FAW). The fall armyworm caused the most severe damage in 2020, followed by 2021 and the least severe in 2022. The lowest damage severity was recorded for stem borers in 2021, followed by the highest damage severity in 2020 and 2022.

Pest impact on maize grain yields

Maize stem borers reduced maize yields more than fall armyworm larvae. This could be because the larvae of maize stem borers are known to create the most stem tunneling (Félix et al., 2009; Oyewale et al. 2020), which disrupts the transport of water and nutrients to the top part of the crop, resulting in low fruit setting and a loss in maize grain yields (Oyewale et al. 2020). The significant increase in maize grain yields across years throughout the study period, with lowest yields recorded in 2020 and highest yields recorded in 2022 for maize crops infested with fall armyworm, could be attributed to farmers' prophylactic use of synthetic insecticides since the pest's invasion in the study area, as well as an increase in the number of pesticides used.

Recommendations

Due to the severity of injuries caused by the species complex of fall armyworm and stem borers with significant yield reduction, we recommend the use of integrated pest management (IPM) tactics that takes into consideration the control of fall armyworm and stem borers simultaneously. Appropriate cultural practices such as clearing all remains of the previous maize crop after harvest, plow deeply, early planting at the beginning of the rains and seed treatment with imidacloprid 70 WS 10 g/kg of seeds may help to reduce early infestation by stem borers and fall armyworm.

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Authors' contributions This work was carried out in collaboration between all authors. CBT designed, established and managed the experiment, prepared traps and baits, performed data collection, processed and analyzed data, performed literature searches and wrote the first manuscript draft, TEN contributed to literature search and manuscript preparation, and NNN contributed to the experimental design, coordinated the field experimentation and data collection, and supervised manuscript preparation and the overall study. All authors read and approved the final manuscript.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests. The authors have no relevant financial or non-financial interests to disclose.

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