

Effect of Fall Armyworm (*Spodoptera frugiperda*) Damage on the Yield of Four Maize Cultivars in the Coastal Lowland and Western Highland of Cameroon

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ABSTRACT

Maize (*Zea mays* L.) production in Africa is threatened by the invasive fall armyworm – FAW (*Spodoptera frugiperda*), and information on its agro-ecological variation and adaptation of different maize cultivars is scarce. The effect FAW was assessed on three hybrid maize cultivars (PAN-12, PAN-53, CMS-8704) and one Landrace in two agro-ecological zones (Coastal Lowland and Western Highland) of Cameroon. Maize cultivars were not fully resistant to FAW feeding and differences occurred in infestation severity and damage incidence between hybrid cultivars and landrace, but no significant yield differences was recorded. FAW infestation

severity (IS) and damage incidence (DI) differed ($P<0.001$) significantly between cultivars in each agro-ecological zone. The highest IS occurred in hybrid maize cultivars as compared to the Landrace. Maize DI differed between cultivars in the Coastal Lowland with the highest in hybrid PAN-12 and PAN-53 as compared to CMS-8704 and Landrace ($P<0.001$). For the Western Highland, the highest damage incidence occurred in hybrid PAN-53 with the lowest in Landrace ($P<0.05$). Maize yield differed ($P<0.001$) significantly across cultivars within each agro-ecological zone. Significantly ($P<0.001$) higher maize yield occurred in the Coastal Lowland (ranging from 4.2–5.5 tons/ha) as compared to the lowest in the western highland (ranging from 3.2–4.6 tons/ha). The highest yield occurred in PAN-12 and PAN-53 as compared to CMS-8704 and Landrace for each agro-ecological zone. Overall, maize yield could not be predicted from FAW damage since the maize hybrids PAN-12 and PAN-53 recorded the highest damage and the highest yield, which implies high cultivar-specific defensive and yield-producing traits than the effect of FAW damage.

Keywords: Agroecology; Cultivars; Fall armyworm; Maize yield; Pest damage

INTRODUCTION

Maize (*Zea mays* L.) is the most important cereal in Sub-Saharan Africa (SSA) and maize production contributes to food security while generating income for many smallholder farmers. However, maize production is constrained by combinations of biotic and abiotic factors (Gunes et al., 2007; Abu et al., 2011). Accordingly, the recent invasion of African maize fields by fall armyworm – FAW (*Spodoptera frugiperda*, Lepidoptera: Noctuidae) represents a major production challenge (Goergen et al., 2016). FAW is an important economic pest of maize in its native Americas that has recently extended its ecological niche by invading Africa (Cock et al., 2017; Nagoshi et al., 2018). FAW herbivory causes substantial crop damage with occasional total yield loss (Barros et al., 2010). Recent studies reported FAW in maize fields across all ecological zones in Cameroon, with the highest infestation severity and damage incidence recorded in the Sahelian Regions and Western Highlands (Kuate et al., 2019). This has necessitated urgent attention to devise appropriate management strategies (Siazemo and Simfukwe, 2020). Accordingly, Tanyi et al. (2020) recently evaluated different management strategies against FAW damage on maize in the Coastal Lowland of Cameroon, but so far, the extent of ecological niche differentiation of FAW and maize damage has not been quantified. The lack of information on agro-ecological differentiation could limit the deployment of appropriate control strategies against FAW damage (Midega et al., 2018).

Some inherent plant defensive traits including morphological and structural characteristics associated with different crop cultivars can be explored to control FAW (Williams et al., 2000). Different maize cultivars may release important volatile compounds that initiate plant defence mechanisms against insect pests (Carvalho et al., 2018; Acevedo et al., 2019). Hence, maize cultivars with desirable resistant traits can be integrated into conventional pest management strategies (Santiago et al., 2011). Accordingly, damage incidence of some maize genotypes reduced the natural metabolite chlorogenic acid that is a deterrent against FAW (Ibanez et al., 2012). Meanwhile, maize yield is affected by the interaction of genotypic and environmental variables (Kumar et al., 2017). This study evaluated the interactions ($G \times E$) between four maize genotypes (one landrace and three hybrid cultivars) and environment (two agro-ecological zones) on the dynamics of FAW in maize fields in Cameroon. It was hypothesised that FAW

effects will vary across the two agro-ecological zones in Cameroon, with cultivar-specific maize resistance dominated by hybrid maize as compared to the landrace.

MATERIALS AND METHODS

Study sites

This study was conducted between March and July 2019 in two major agro-ecological zones of Cameroon (e.g. Coastal Lowland–Buea and Western Highland–Bamenda). Buea is located in the Coastal Lowland at elevation of 1000 m a.s.l. on an active mount Cameroon (4095 m) volcano situated at 4.1560° N, 9.2632° E. The area has humid tropical climatic conditions with two distinct seasons and rich volcanic soils (Proctor et al., 2007). The dry season starts from November to February with mean monthly air temperature ranging from 19–30°C. Soil temperature at 10 cm depth decreases from 25–15°C with increasing elevation from 200–2200 m, respectively, above sea level. The rainy season ranges from March to October with mean annual rainfall of 2,800 mm. Bamenda is located in the western highland situated at 5.9631° N, 10.1591° E, and at elevation of 1,258 m a.s.l, with cool temperate-like climate influenced by the mountainous relief featuring several dormant volcanoes. The average rainfall is about 2,400 mm and temperature ranges between 15–32°C (Innocent et al., 2019). The rainy season in Bamenda starts from March to October, and the dry season from November to February characterized by the Harmattan with dry air. Farmlands and grazing fields have replaced the characteristic natural forest vegetation in both agro-ecological zones, with only small patches remaining that are recognized as globally important sites for biodiversity conservation. Average rainfall and temperature conditions for both agro-ecological zones during the experimental period are given in figure 1.

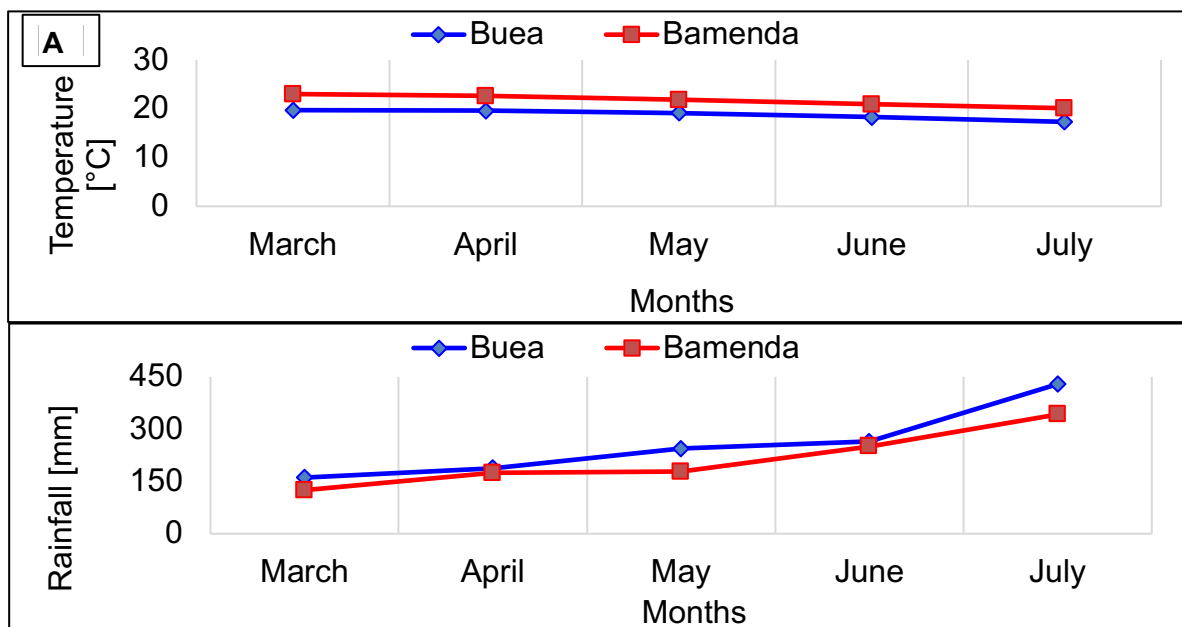


Figure 1. Average monthly temperature (A) and rainfall (B) from March to July 2019 for the two investigated agro-ecological zones of Cameroon (Buea – Coastal Lowland and Bamenda – Western Highland). Source: CLIMATE-DATA.ORG

Experimental design

This study was established as a randomized complete block design with four maize cultivars ($n=4$; PAN-12, PAN-53, CMS-8704 and Landrace) in two agro-ecological zones ($n=2$; Coastal Lowland and Western Highland). Two field experiments were established simultaneously in both agro-ecological zones in a randomized complete block design with three replications each. The field sites were cleared manually using a cutlass and partitioned into 12 experimental plots measuring 4x3.5 m (14 m²) each. All plots were manually tilled at 30 cm soil depth using a hoe, and separated from each other by non-tilled 1 m buffers.

Maize cultivation and management

The PAN-12 and PAN-53 maize cultivars purchased from local agro-shops were produced by Pidelta (www.pidelta.co.za) that produces high quality hybrid PANNAR® seeds (e.g. for improved resistance and yield). The Cameroon “CMS-8704” maize cultivar purchased from local agro-shops were produced by the Institute of Agricultural Research for Development (IRAD, Cameroon). CMS-8704 was released in 1987 by IRAD and it is the most cultivated commercial open pollinated maize cultivar with tolerance to acid soils. The Landrace is local cultivar obtained from own-saved seeds by smallholder farmers after their previous harvests in the respective agro-ecological zone (i.e. Buea or Bamenda). Maize seeds were planted at 80x50 cm inter and intra row spacing, respectively, giving a total of five rows and seven stands per row for each plot. Three seeds were planted per stand, and later thinned to two vigorous seedlings after germination, leading to seventy maize plants per plot. All plots were amended twice at two and six weeks after germination using granular inorganic fertilizer (NPK 20:10:10; Yara, Cameroon) applied at 5 g per plant by ringing at 5 cm from the plant. Plots were monitored regularly for weed emergence and weeded manually using a hoe, while soil moisture relied on the rain fed system according to the local rainfall regime. No pesticide was applied in both agro-ecological zones, since the study was intended to evaluate the susceptibility of maize cultivars to FAW.

Data collection

Fall armyworm infestation severity and damage incidence

Considering that pest ecology, environmental factors, and inherent cultivar-specific defensive traits may exert differential responses on FAW, four maize cultivars were evaluated simultaneously in two major agro-ecological zones. Larval specimens were examined for occurrence of distinctive characteristics on the head capsule and second to the last abdominal segment that are peculiar with FAW. FAW larvae were identified based on visual observation of characteristic marks and dotted spots such as inverted “Y” marking on the head area, four large dorsal spots in a near square arrangement on the second last segment, lighter dorsal area, pale dorsal line, pale latero-dorsal line, and lighter ventral area (Todd and Poole, 1980). Fall armyworm infestation severity was assessed weekly starting from three to seven weeks after planting based on the number of FAW larvae found per plant. On weekly basis, twenty maize plants were randomly sampled per plot for the number of FAW larvae per plant (i.e. assessed the entire plant, especially leaves and leaf whorls). In addition, FAW damage incidence (the proportion of plants with evidence of FAW damage per plot) was assessed on all seventy plants per plot on weekly interval by visual observation for symptoms of FAW larval damage on leaves and leaf whorls (e.g. small holes, scratches or skeleton damage of leaves with partially damaged epidermis giving a windowpane appearance). FAW damage incidence on maize (Mean % $\pm$

standard deviation – SD) was calculated as percentage of infested plants per plot to the total number of plants per plot:

FAW damage incidence (%):

$$= \frac{\text{Number of plants with evidence of FAW damage per plot}}{\text{Total number of plants per plot}} \times 100$$

Maize growth and yield

Growth parameters were recorded from twenty randomly selected and tagged maize plants on each plot. Stem girth was measured at 2/3 of the plant height using a calibrated tape expressed in centimetres (cm). The number of leaves were visually observed and counted, while plant height was measured from ground level to the collar of the upper leaf using a calibrated tape. At physiological maturity, twenty maize plants were randomly harvested manually from each plot, and the cobs were hand-threshed and oven-dried at 60°C for five days. Dry maize grains were weighed on a top loading balance to obtain the yield and presented in t ha⁻¹.

Statistical analysis

All data sets were subjected to statistical analyses using STATISTICA 13.2 for Windows. Dependent variables (FAW infestation severity, damage incidence, and maize yield) were subjected to factorial analysis of variance ($P < 0.05$) to test effects of four maize cultivars ($n=4$) and two agro-ecological zones ($n=2$). Significant data means were compared between the dependent variable (yield) and categorical predictors (FAW infestation severity and damage incidence) using Tukey's HSD ($P < 0.05$) and Spearman Rank Correlation ($P < 0.05$).

RESULTS

Fall armyworm infestation severity and damage incidence

The number of FAW larvae per plant differed significantly ($P < 0.05$) across maize cultivars in the Coastal Lowland at 3, 4 and 5 weeks after planting, and at 5 weeks after planting for the Western Highland (Table 1). The number of FAW larvae ranged from 0.0–2.7 individuals per plant across weeks in the Coastal Lowland and 0.5–2.1 individuals per plant across weeks in the Western Highland. The highest number of FAW larvae occurred in the hybrid maize cultivars and the lowest in Landrace. However, the number of FAW larvae per plant did not differ ($P > 0.05$) significantly between maize cultivars at the latter stages of plant growth (e.g. 6 and 7 weeks after planting).

Table 1. Infestation severity of fall armyworm (Number of larvae per plant, Mean $\pm$ SD) on four maize cultivars in two agro-ecological zones (Coastal Lowland and Western Highland) at seven weeks after planting

Maize cultivars	Coastal Lowland – Weeks after planting					Western Highland – Weeks after planting				
	3	4	5	6	7	3	4	5	6	7
PAN-12	0.0 $\pm$ 0.0b	2.67 $\pm$ 0.58a	1.73 $\pm$ 0.31ab	1.0 $\pm$ 0.0a	1.40 $\pm$ 0.69a	2.07 $\pm$ 1.10a	1.67 $\pm$ 1.15a	2.07 $\pm$ 0.12a	1.0 $\pm$ 0.0a	1.27 $\pm$ 0.46a
PAN-53	2.13 $\pm$ 1.21a	1.87 $\pm$ 0.42a	2.0 $\pm$ 0.0a	1.33 $\pm$ 0.58a	1.80 $\pm$ 0.35a	2.13 $\pm$ 1.21a	1.87 $\pm$ 0.42a	1.73 $\pm$ 0.31ab	1.07 $\pm$ 0.12a	1.33 $\pm$ 0.31a
CMS-8704	0.25 $\pm$ 0.25b	0.27 $\pm$ 0.23b	1.07 $\pm$ 0.31bc	1.0 $\pm$ 0.0a	1.33 $\pm$ 0.58a	0.25 $\pm$ 0.25a	0.27 $\pm$ 0.23a	1.07 $\pm$ 0.31bc	1.0 $\pm$ 0.0a	1.47 $\pm$ 0.50a
Landrace	0.50 $\pm$ 0.50ab	0.28 $\pm$ 0.10b	0.47 $\pm$ 0.46c	0.60 $\pm$ 0.35a	0.73 $\pm$ 0.31a	0.50 $\pm$ 0.50a	0.28 $\pm$ 0.10a	0.47 $\pm$ 0.46c	0.60 $\pm$ 0.35a	0.80 $\pm$ 0.35a

Values within columns for each agro-ecological zone (e.g. Coastal Lowland and Western Highland) with different letters are significantly different ($P < 0.05$).

Damage incidence by FAW differed significantly ($P < 0.001$) across maize cultivars in each agro-ecological zone, but the infestation severity did not differ ($P > 0.05$) significantly between the two agro-ecological zones (Fig. 2). Damage incidence ranged from 67.6–99.0% and differed ($P < 0.001$) significantly across cultivars in the Coastal Lowland, with the highest in hybrid maize PAN-12 and PAN-53 cultivars, followed by CMS-8704 and Landrace. Damage incidence ranged from 74.3–97.1% and differed significantly ($P < 0.05$) across cultivars in the Western Highland, with the highest in the hybrid maize PAN-53 cultivar compared to Landrace with the lowest damage incidence.

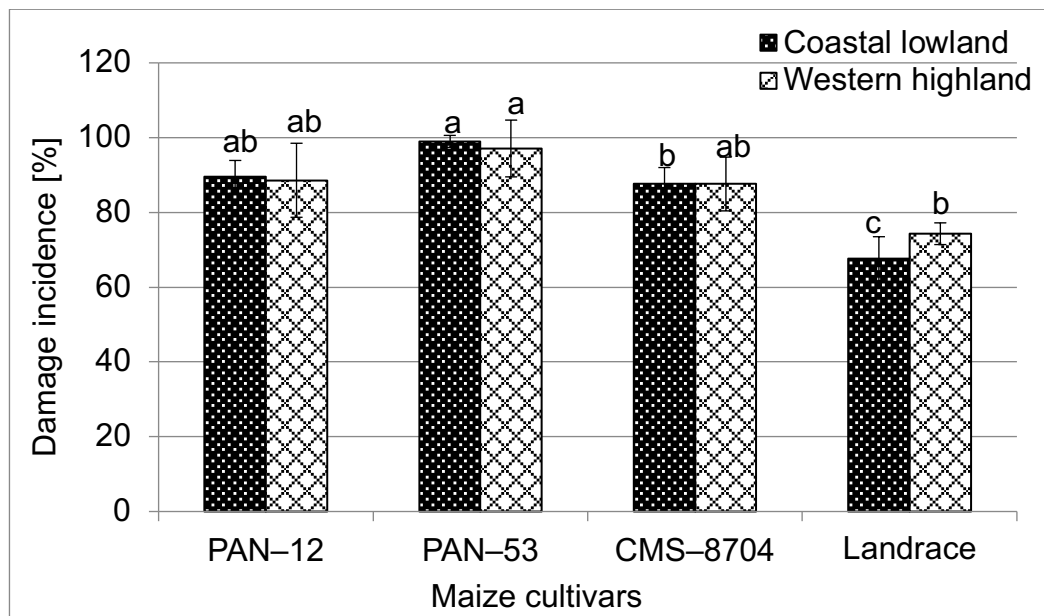


Figure 2. Percentage (Mean % $\pm$ SD) damage incidence of four maize cultivars across each agro-ecological zone (Coastal Lowland and Western Highland)

Maize growth and yield

Plant height differed significantly ($P<0.001$) across maize cultivars, agro-ecological zones and their interactions, and ranged from 141.8–174.7 cm per plant in the Coastal Lowland and 90.0–110.4 cm per plant in the Western Highland (Table 2). The CMS-8704 and Landrace cultivars were taller than PAN-12 and PAN-53 in both agro-ecological zones, while PAN-53 and PAN-12 were the shortest in the Coastal Lowland and western highland, respectively. All maize cultivars in the Coastal Lowland were taller than their counterparts in the Western Highland. The number of leaves differed significantly ($P<0.001$) across agro-ecological zones, and ranged from 14.0–15.0 leaves per plant in the Coastal Lowland and 12.7–13.3 leaves per plant in the Western Highland (Table 2). PAN-12 and CMS-8704 cultivars had more leaves in the Coastal Lowland than Western Highland. Stem girth differed significantly ($P<0.001$) across cultivars and agro-ecological zones, and ranged from 5.6–7.0 cm per plant in the Coastal Lowland and 4.9–6.5 cm per plant in the Western Highland (Table 2).

Table 2. Growth performance (Mean $\pm$ SD) of four maize cultivars in two agro-ecological zones (Coastal Lowland and Western Highland)

Maize cultivars	Plant height (cm per plant)				Number of leaves per plant				Stem girth (cm per plant)			
	Coastal Lowland		Western Highland		Coastal Lowland		Western Highland		Coastal Lowland		Western Highland	
	158.3	$\pm$	90.0	$\pm$	14.7	$\pm$	12.7	$\pm$	7.0	$\pm$	6.5	$\pm$
PAN-12	3.1bA		1.5bB		0.6aA		0.6aB		0.1aA		0.1aB	
	141.8	$\pm$	110.4	$\pm$	14.0	$\pm$	13.3	$\pm$	6.6	$\pm$	6.1	$\pm$
PAN-53	2.3cA		5.9aB		0.0aA		0.6aA		0.1aA		0.3aB	
	174.7	$\pm$	105.9	$\pm$	14.3	$\pm$	13.3	$\pm$	5.8	$\pm$	5.2	$\pm$
CMS-8704	1.5aA		5.3aB		0.6aA		0.6aA		0.4bA		0.3Ba	
	170.7	$\pm$	109.7	$\pm$	15.0	$\pm$	13.3	$\pm$	5.6	$\pm$	4.9	$\pm$
Landrace	2.5aA		5.4aB		0.0aA		0.6aB		0.2bA		0.1Bb	

Values within columns with different lowercase letters are significantly different, while values within rows for each growth parameter with different uppercase letters are significantly different ($P<0.05$).

Maize yield differed significantly ($P<0.001$) across the different cultivars and agro-ecological zones, and ranged from 4.2–5.5 t ha⁻¹ in the Coastal Lowland and 3.2–4.6 t ha⁻¹ in the Western Highland (Fig. 3). Maize yield differed significantly between cultivars in the Coastal Lowland ($P<0.01$) and Western Highland ($P<0.001$), with the highest in PAN-12 and PAN-53 cultivars as compared to CMS-8704 and Landrace for both agro-ecological zones. All the maize cultivars produced higher yields in Coastal Lowland as compared to the Western Highland. Overall, no significant ($P>0.05$) correlation occurred between maize yield and FAW infestation severity or damage incidence.

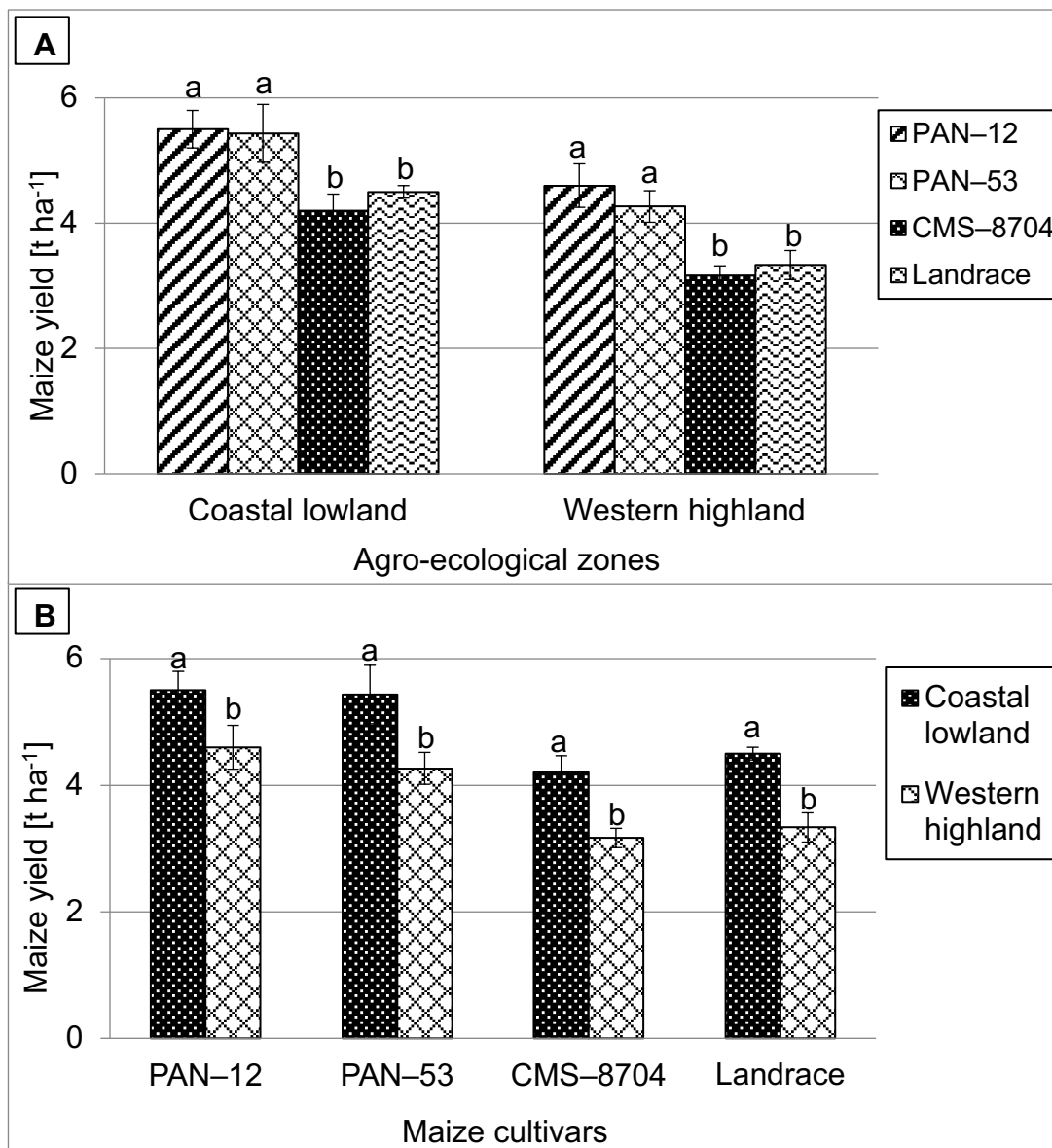


Figure 3. Maize yield ($t\ ha^{-1} \pm SD$) of four cultivars in two agro-ecological zones (Coastal Lowland and Western Highland); A – values for maize cultivars within each agro-ecological zone with different letters are significantly different ($P < 0.05$); B – values for agro-ecological zones within each maize cultivar with different letters are significantly different ($P < 0.05$)

DISCUSSION

Fall armyworm infestation severity and damage incidence

High damage incidence for hybrid maize cultivars (PAN-12, PAN-53 and CMS-8704) compared to the Landrace is likely due to cultivar-specific resistant traits (Santiago et al., 2011; Chiriboga et al., 2021). This does not support the hypothesis that hybrid maize cultivars would be more resistant, which is probably because they were not developed for resistance to FAW, and morphological defences might have favoured the Landrace through introgression of foreign genes via open pollination (Williams et al., 2000). The FAW infestation severity of up to 2.7 larvae per plant in this study did not reduce the yield significantly. This might also be because of high infestation severity at the early and midwhorl stages, which might have been

compensated through proper agronomic practices and crop nutrition (Tanyi et al., 2020). Similar study in Brazil to determine the response of fall armyworm damage during maize vegetative growth stages reported insignificant reduction of maize yield due to damages caused in the early and midwhorl stages (V1–V9) of the crop (Marenco et al., 1992; Nagoshi et al., 2007) which strongly support this result. Also, maize have many functional leaves, which can potentially photosynthesize for optimum crop yield despite a certain tolerable percentage of foliar damage especially when infestation occurs at an early stage of the crop under proper agronomic practices. In addition, dietary shift by FAW larvae from leaf tissues on young plants to tassel, silk and ears on more mature plants might have influenced FAW damage incidence depending on cultivar-specific characteristics (Pannuti et al., 2015). Some mechanisms and pathways for maize resistance to FAW larvae have been reported, which may explain the observed differences in FAW damage on different maize cultivars in this study (George et al., 2011; Chiriboga et al., 2021). Moreover, insect damage incidence of some maize genotypes resulted in reduction of chlorogenic acid that is a natural metabolite with demonstrated deterrent against FAW and antioxidant and protective effects against DNA damage (Brooks et al., 2007). Overall, the high damage incidence in hybrid varieties compared to Landrace for the Coastal Lowland and Western Highland without significant differences in yield for all varieties within agro-climatic zones might be a strong indication that yield could not be predicted from FAW folia damage. Therefore, selecting resistant crop varieties, genetically modified seeds, and early maturing varieties that are less susceptible may play vital roles in controlling fall armyworm (Burtet et al., 2017; Harrison et al., 2019).

Response of maize yield to fall armyworm

The observed high maize yield for hybrid cultivars at higher damage incidence is likely due to many functional leaves, high photosynthetic carbon fixation, and other yield-producing traits that dominated the effects FWA damage. Hence, high maize yield at high damage incidence could be due to a combination of environmental adaptation, genetic diversity and physiological processes (Mafouasson et al., 2018) which has resulted to tolerance in the hybrid cultivars. Considering that FAW infestation severity and damage incidence did not differ between agro-ecological zones, higher yield recorded in Coastal Lowland than Western Highland is likely due to the interaction of favourable soil conditions in the Coastal Lowland than in Western Highland and the interactions between genotypes and environments (Kandus et al., 2010; Adu et al., 2013; Ngosong et al., 2019). Although there were no significant differences in yield for all varieties tested within each agro-ecological zone, PAN-12 and PAN-53 recorded the highest yields, and were more tolerant to FAW in addition to their nutritional richness. Hence, screening maize cultivars for tolerance to soil acidity is considered an efficient strategy to increase yield (Winkel- et al., 2002). This is consistent with the holistic management approach for FAW damage incidence in order to minimise potential deleterious effects on the environment and humans (Bateman et al., 2018; Bista et al., 2020). The higher yield recorded for hybrid PAN-12 and PAN-21 is in line with their high yielding characteristic and consistent with other reports (Adu et al., 2013). Meanwhile, the lower yield recorded for the Landrace than hybrid cultivars may be due to random low-yielding traits acquired during introgression of foreign genes into the Landrace. Nonetheless, the Landrace used in this study produced higher yield than the reported low yield of 1.8 t/ha for local cultivars in Cameroon (Ngoko et al., 2002), which could be due to gene introgression with the associated maize hybrids. In addition, Landraces are often well adapted to withstand pest and diseases than hybrid cultivars because of co-evolutionary relationship with lepidopteran pest (as observed in this case) than

hybrid cultivars. Cultivars have a tradeoff for more yield and may sacrifice other things to become tolerant. Moreover, substantial yield decrease for CMS-8704 in the Coastal Lowland compared to a recent report is highly indicative of potential effects of FAW in the present study (Ngosong et al., 2019). Overall, the observed increase in maize yields for hybrid PAN-12 and PAN-53 at high FAW damage incidence for both agro-ecological zones, suggests the dominance of yield-producing traits over FAW damage. This may also be due to the high photosynthetic capacity of maize and therefore its ability to tolerate high levels of leaf damage. Kumar et al. (2017) also reported that the high yielding varieties outperformed the FAW resistant varieties despite higher damage. Hence, it is imperative to breed maize cultivars that incorporate pest and environmental constraints, while improving relevant agronomic traits (Sibiya et al., 2013). Overall, the observed yield variation between maize cultivars is consistent with the fact that yield is results from complex interactive effects of genotypic characters, environmental variables, and farm management (Kumar et al., 2017).

CONCLUSIONS AND RECOMMENDATIONS

Africa is already facing significant food security challenges resulting from numerous abiotic and biotic constraints to crop production coupled with current trends in climate variability, which could be exacerbated by the invasive fall armyworm. This study effectively confirms FAW damage on maize in the two major agro-ecological zones of Cameroon, which may further jeopardise productivity. No significant difference occurred in FAW damage between the two agro-ecological zones, but variations occurred between different maize cultivars within each agro-ecological zone. Higher maize yields were recorded for all maize cultivars in the Coastal Lowland than the western highland. Although there were no significant differences in yield for all varieties tested within each agro-ecological zone, PAN-12 and PAN-53 recorded the highest yields, and were more tolerant to FAW. An important finding of this study is that yield could not be predicted from FAW damage since the maize hybrids PAN-12 and PAN-53 recorded the highest damage and the highest yield. This may imply that the impact on photosynthetic capacity maize plants is limited even at high levels of FAW damage, which is an important information from the perspective of developing Integrated Pest Management programmes. The lack of correlation between maize yield and FAW damage implies high cultivar-specific defensive and yield-producing traits, which highlights the need for maize breeding schemes to confer resistance against FAW. Overall, farmers in the Coastal Lowland and Western Highland could be advised to cultivate the hybrid varieties PAN-12 and PAN-53. These results further highlight the need for a holistic approach to grapple with the challenges of FAW invasion across the different agro-ecological zones of Africa. Hence, more insitu based studies are necessary to determine effective integrated pest management strategies that are adapted to the specific needs of local farmers.

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