Potential of indigenous low-cost lures for monitoring and as a component of integrated management of fall armyworm *Spodoptera frugiperda*

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Research Article

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Abstract

Background: Considering the increasing voracious feeding impact of the invasive fall armyworm; *Spodoptera frugiperda* (Smith) in major corn-growing belts of Africa, indigenous low-cost lures were compared with the commercial pheromone for monitoring and control of this pest via mass capture of the adults.

Methods: Four sets of trials were conducted during two cropping (rainy and dry) seasons in two agro-ecological zones of Cameroon. The experiments were setup in randomised complete block designs with 5 lure treatments; palm wine, honeygar, commercial pheromone, Maize chyme, and a water control each replicated five times.

Results: The Generalized Linear Mixed Model (GLMM) showed that the maize chyme low-cost lure attracted significantly higher numbers of the moths compared to the commercial pheromone ($p<0.001$). The maize chyme attracted more moths in the Western Highland savanna with a mean of 61.75 significantly different from the Humid rainforest with 30.50 moths ($p<0.001$). This was followed by Honeygar with 53.25 and 28.12 moths in the Highland savanna and Humid rainforest zones respectively. These were both significantly different from Palm wine ($p<0.001$). The highest numbers of adult fall armyworms were recorded in the Dry season, which were significantly different from the rainy season ($p<0.001$).

Conclusion: The indigenous low-cost lures are effective tools in monitoring and control of fall armyworm as components of Integrated Pest Management (IPM) strategy for resource-constrained smallholder farmers.

1. Background

Climate change, human activities and transportation of goods and persons across territorial boundaries have exacerbated movement of insect species between continents and hemispheres. Insects such as the africanized honey bee, *Apis mellifera scutellata* Lepeletier (Eimanifar et al. 2018), small hive beetle, *Aethina tumida* Murray (Neumann et al. 2016), longhorn crazy ant, *Paratrechina longicornis* (Latreille) (Deyrup et al. 2000), and the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (De Meyer 2005) hitherto endemic to Africa, have become established in North America. Similarly, the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) native to the tropical and sub-tropical regions of the Americas has spread to Asia and also first observed in Africa in early 2016 (Goergen et al. 2016; Tindo et al. 2017). *Spodoptera frugiperda* with its devastating feeding habits currently occurs in Africa, Asia, Australia, North and South America (Nagoshi et al. 2017; Cock et al. 2017; FAO. 2018; Uzayisenga et al. 2018). The fall armyworm is endemic to the Neotropics, attacking vegetables, row, and turf crops (Luttrell and Mink, 1999; Braman et al. 2000; Nuessly et al. 2007; Souza et al. 2013). The pest has the potential to cause maize yield losses between 21 –53% in low-input smallholder farming systems (Abrahams et al. 2017).

Maize, *Zea mays* L. (Poaceae), the cereal with highest production worldwide can be grown commercially as an industrial and/or food crop. It is grown across a wide range of agro-ecological zones, from wet to hot semi-arid lands and in different soil types (Shiferaw et al. 2011). In Africa, More than 300 million people depend on maize as their main food crop (IPBO. 2017). The crop is also valuable as feed for farm animals and for alcohol (biofuel) production. In most of Africa, the crop is often produced by resource-constrained smallholder farmers (Odendo et al. 2001; Cairns et al. 2013), exacerbating the importance to adapt pest control measures, and monitoring procedures to this influential category of crop producers.

In sub-Saharan Africa (SSA), maize is the most widely grown staple food crop providing food and livelihood for about 208 million people in the region (Parihar et al. 2011; Macauley. 2015; FAOSTAT. 2019) and accounting for 73% of calorific intake (Shiferaw et al. 2011). However, production is constrained by drought, diseases and several pests, including lepidopteran stemborers, such as *Busseola fusca* (Fuller) (Noctuidae), *Sesamia calamistis* (Hampson) (Noctuidae) and invasive *Chilo partellus* (Swinhoe) (Crambidae). Recently, the impact of fall armyworm *Spodoptera frugiperda* on maize has been a great challenge for the continent since it is a major threat to food and nutrition security for millions of people (Huesing et al. 2018). Maize losses due to *S. frugiperda* damage range from 8.3 to 20.6 million tons, with annual financial losses of US$2,481–6,187 million (Abrahams et al. 2017). In Cameroon, the pest exists in all the major maize producing agro-ecological zones of the country, with the highest severity and infestation recorded in the Sahelian and Highland savanna zones (Tindo et al. 2017; Kuate et al. 2019).

The popyphagous *S. frugiperda* feeds on approximately 353 crop species from 76 plant families mainly Poaceae Asteraceae and Fabaceae in its native range (Montezano et al. 2018). Maize, rice, sugarcane, and sorghum are known to be the major hosts of *S. frugiperda* whereas vegetables and cotton are the minor hosts (Prasanna et al. 2018). The caterpillars of the destructive larval stage of FAW feed on young leaf whorls, stems, branches, and reproductive organs, such as tassels and ears inflicting substantial damage to maize crops and causing high grain yield loss (De Almeida et al. 2002; FAO. 2018). Damage by first instar larvae on maize appear as silvery patches called “windowpanes” because one side of the leaf is eaten, leaving the opposite epidermal layer intact. Damage by the third and fourth instar larvae is more significant with holes appearing on the edges and with characteristic row of perforations visible due to feeding on the whorl of the growing plants. The larvae also migrate from the leaves to the tassels and the developing ears/grains causing grain yield losses and exposing the grains to mycotoxin contamination.

The pest in Africa is threatening the livelihood of indigenous smallholder farmers who rely on maize production for income and food security (Goergen et al. 2016; Abrahams et al. 2017). The sporadic spread of the pest and its potential to travel 1600 km over a 30-h period (Prasanna et al. 2018) signifies more danger for grain producers in Africa. Genetically modified maize hybrids expressing *Bacillus thuringiensis* insecticidal proteins has been used to control *S. frugiperda* (Blanco et al. 2010; Okumura et al. 2013; Huang et al. 2014), but the indigenous African smallholder grain producers rely on synthetic pesticides as a control measure for maize pests (Cook et al. 2007; Khan et al. 2010; Midega et al. 2018; Tanyi et al. 2020). However, the use of synthetic pesticides has exacerbated the effect of poisonous substances in non-target areas with devastating consequences on the environment (Perez et al. 2000; Xu et al. 2010). This underscores the need to develop *S. frugiperda* management strategies based on the local farmers' needs and priorities (Kumela et al. 2019) since they are the major grain producers in most African countries. There is therefore an urgent need for a reliable low-cost technology for early detection of the pest and its sustainable management for resource-constrained smallholder farmers.

Knowledge of the seasonal variation of the pest in different locations (De Almeida et al. 2002) as well as early detection, monitoring, surveillance, and scouting are key tools to aid a successful integrated pest management program that includes biological control, resistant varieties, and cultural control strategies (McGrath et al. 2018). Monitoring reveals the presence, population size, spread and movement of a pest. Monitoring the fall armyworm is often done using pheromone-based traps that attract male moths (McGrath et al. 2018). However, there have been conflicting results across geographic regions on the use of varied blends of the synthetic analogues of the natural sex pheromones as lures in different trap types in monitoring FAW (Meagher et al. 2019).

CABI and FAO in 2019 advocated for monitoring FAW using this technique to give advance warning to farmers at the beginning of the maize-cropping season. The FAO Fall Armyworm Monitoring and Early Warning System (FAMEWS) mobile application tool requires users to input both field scouting and pheromone trap data (FAO and CABI. 2017). In addition, FAO and Pennsylvania State University jointly developed an innovative talking mobile app called *Nuru* (Swahili for "light") in several African countries (FAO and CABI. 2017). Although the technologies are good, implementation by farmers is problematic since most of them are often not educated and/or cannot use mobile telephones and hence lack the skills needed for effective use of the technology. The adoption of commercially available pheromones by indigenous smallholder farmers in Africa is also constrained by the scarcity of the pheromone lures and traps and their high-cost.

FAW pheromone trap data can be used to estimate, a week in advance, the subsequent abundance of larvae in pastures (Silvain 1986) though McGrath et al. 2018 observed no relationship between the number of FAW males caught in traps and the number of females laying eggs in the same locality. Thus, catches of male moths in traps should simply be used to estimate the presence of potential egg-laying females in the area. Some researchers have reported similarities in moths captured with locally produced low cost traps made from repurposed materials such as plastic containers as compared to bucket traps (Critchley et al. 1997). Therefore, there is vital and urgent need for local lures that can attract high numbers of male and female moths into traps to directly reduce the egg laying potential and resultant number of the destructive larvae in the farm as well as used as a monitoring technique. Consequently, the aim of this study was to test indigenous low-cost lures in low-cost traps for monitoring and control of the fall armyworm as a component of the Indigenous Integrated Management of this pest.

2. Materials And Methods

2.1. Sampling sites

This study was conducted between August 2020 and June 2021 in Buea situated in the high maize production monomodal humid rainforest and Mbouda in the Western Highlands agro-ecological zones of Cameroon. Each of these ecological zones has a rainy season that runs from mid-March to mid-November and a dry season from mid-November to mid-March. Buea with a mono-modal rainfall regime is situated between latitudes 4º3'N and 4º12'N and longitudes 9º12'E and 9º20'E and 870 m above sea level; it has an average of 86% relative humidity. The soils are derived from weathered volcanic rocks, and it has a mean annual rainfall of 2800mm, and mean monthly air temperature ranging from 19 – 30°C. (Fraser et al. 1998; John et al. 2007). Mbouda is in the Western savannah highland region of Cameroon with an average rainfall of 1800–2400mm, mean temperature of 21^{0C} and an elevation of 1500–2500 m.a.s.i[a].

2.1.1. Trapping of fall armyworm

In each agro-ecological zone, one site was selected each during the first and second cropping seasons to plant maize. Each field was 24 m^2 divided into four 4m x 4m plots each separated from the other by 1m alley. The experiment was set up in a randomised complete block design with 5 treatments based on the following lures or baits; palm wine, honeygar, commercial pheromone, Maize chyme, and a water control each replicated five times. In each plot, three UBNMS001 maize variety seeds were planted per hole at 80 × 50 cm inter and intra row spacing and later thinned to two seedlings per stand after ten days. All plots were amended at two weeks after germination with granular inorganic fertilizer (NPK 20:10:10) at 5g per plant. Manual weeding was done regularly using a hoe.

One of the baits used in the experiment, Captorplus® was a commercial *Spodoptera frugiperda* pheromone, PH-869-1PR produced and distributed by Agrobiological Society of Africa, having a slow-release insecticidal tablet. The commercial pheromone, insecticide solid formulated-tablet and trap were bought from an agro shop in Yaoundé Cameroon. Three of the baits were food attractants prepared as follows:

1. Vinegar bait (honeygar); a mixture of 500 ml vinegar and 50 ml honey in 1 L of water.
2. Brewers’ waste; fermented leftover maize chyme obtained from local brewers of traditional beer. Five hundred grams of this brewers’ waste was mixed in 1.5 L of water, allowed to settle for 10 min, then the liquid supernatant decanted and used as the bait.
3. Palm wine; a local traditional liquor tapped from the flower of the oil palm. Waste palm wine was obtained from local drinking joints and used as the lure.

The last lure used as a control was portable water obtained from public taps.

Monitoring of fall armyworm

For each of the food based attractant and the water control, 300 ml were measured and put in an indigenous trap prepared from repurposed 1.5L plastic containers that are often littered in unwanted places. Two round holes of 2.5 cm diameter each were created on opposite sides half way the height of the plastic container using a knife. The normal opening of the plastic container was closed with the lid, and a 30 cm string tied to it was used to hang the container on a wooden pole. A trap each containing 300 ml of a particular lure was hung on the wooden pole about 1.5 m above the ground in each plot. There were four replicate traps of each bait per agro-ecological zone and season. Each trap was monitored once every week; on each occasion, all fall armyworm adults in each trap were collected and put in an appropriately labelled jar for further confirmation of the identity in the laboratory. On each monitoring date, each trap was also serviced by replacing the bait with the corresponding fresh bait. In addition, the number of non-target pests per trap was also recorded. Ten maize plants per plot were sampled for the occurrence of fall armyworm. The average number of fall armyworm larvae per plant and damage was recorded on weekly intervals beginning from 3 WAG. Damage score was recorded based on a scale ranging from 0–9, and maize yield recorded at maturity stage.

Physical monitoring was also done through visual observation to locate the egg masses of fall armyworm (on the under surfaces of maize leaves) and the larvae in the leaf whorls. This monitoring was extended through all growth stages of the maize crop including vegetative, fruiting, and cob maturity. Accordingly, the surrounding weeds, grasses, and dry maize stalks were also scouted regularly for egg masses and larvae of fall armyworm.

2.2. Evaluation of foliar damage

Foliar maize damage under natural infestation by fall armyworm was evaluated at weekly intervals by sampling 10 plants randomly in the selected central rows of each experimental unit from three weeks after germination (3 WAG). The Davis numerical scale (1–9) was used to score the foliar feeding damage (Davis et al. 1989, 1992 as shown in Table 1.

Table 1
Visual rating scales for leaf damage assessment).

Scale	Description
0	No visible leaf damage
1	Only pinhole damage on leaves
2	Pinhole and shot hole damage on leaf
3	Small elongated lesions (5–10 mm) on 1–3 leaves
4	Midsized lesions (10–30 mm) on 4–7 leaves
5	Large elongated lesions (>30 mm) or small portions eaten on 3–5 leaves
6	Elongated lesions (>30 mm) and large portions eaten on 3–5 leaves
7	Elongated lesions (>30 cm) and 50% of leaf eaten
8	Elongated lesions (30 cm) and large portions eaten on 70% of leaves
9	Most leaves with long lesions and complete defoliation observed

2.5. Data analysis

Data was analyzed using R and rstudio version 1.3.1073.0 for Windows.

A generalized linear model (GLM) was used to assess the effect of lures on FAW abundance. The formula for this model was;

Cumulative adult FAW ~ Treatment Replicates

The data of FAW dynamics were subjected to statistical analyses using R and rstudio version 1.3.1073.0 for Windows. The dynamics of FAW across seasons and ecological zones was analysed using the Generalized Linear Mixed Model (GLMM). The formula used was:

Adult_FAW_Abundance ~ Season + Day + (1 | Ecological_zone)

3. Results

A total of 2833 adult FAW were caught in the various baits during the two cropping seasons in the two agro-ecological zones. Out of the total, 1144 were caught in the traps baited with maize chyme followed by 936 in the traps baited with honeygar and only 199 were caught in the commercial pheromone baited traps. Irrespective of the agro-ecological zone and the season, traps with food-based lures caught significantly higher numbers of FAW than the commercial pheromone-based lure in the order maize chyme > honeygar > palm wine > commercial pheromone (Table 2).

Table 2
Percent mean number (± SD) of adult fall armyworm caught per lure across agro-ecological zones

	Seasons	Number of caught	
Treatments (Lures)		**Humid rainforest**	**Highlands Total**
Maize chime	**S1**	**83 ± 2.01B**	**247 ± 5.17B 330**
	S2	**185 ± 3.74A**	**629 ± 9.12A 814 1144**
Honeygar	**S1**	**65 ± 1.31B**	**213 ± 4.25B 278**
	S2	**160 ± 2.88A**	**498 ± 8.86A 658 936**
Palm wine	**S1**	**42 ± 0.90B**	**105 ± 2.21B 147**
	S2	**83 ± 1.76A**	**324 ± 4.89A 407 554**
Commercial pheromone	**S1**	**11 ± 0.45B**	**51 ± 1.26B 62**
	S2	**24 ± 0.77A**	**113 ± 2.34A 137 199**
	S1	0 ± 0.00A	0 ± 0.00A 0
Control	S2	0 ± 0.00A	0 ± 0.00A 0 2833

Uppercase letters signifies comparisons within each treatment. Means with same lower case letters or same uppercase letters are not significantly different at $p < 0.05$.

3.1. Comparison between traps and lures

Results from the Generalized Linear Mixed Model (GLMM) analysis showed that the food-based low cost indigenous lures had significantly higher trapping effect compared to the commercial pheromone ($p < 0.001$). Although there was no significant difference between maize chyme and honeygar in both ecological zones, maize chyme demonstrated highest degree of attractiveness in the Highland savanna Zone (61.75) which was significantly different from Humid Rainfall Forest Zone (30.50) at ($p < 0.001$). In both ecological zones, the degree of attractiveness of maize chyme was highest, followed by Honeygar (53.25 and 28.12 in Highlands Zone and humid rainforest Zone respectively) both significantly higher than palm wine ($p < 0.001$). However, the commercial pheromone lure was significantly more attractive than the control (water) in the Highland savanna Zone ($p = 0.037$) (Fig. 2a and b).

3.2. Ecological and seasonal variation in abundance of adult FAW

Result of GLM showed significant differences in adult FAW abundance across treatments, seasons, and agro ecological zones ($p = 0.000$). The highest numbers of adult FAW were recorded in the second season (Dry season), which was significantly different from the first season (rainy season) at ($p < 0.001$) (Fig. 3).

The maximum number of 36 adult FAW moths per trap was caught in the Highland savanna as compared to 23 adult FAW in the humid rainforest Zone.

3.3. Population dynamics of adult FAW from the 7th to 52 days after germination in the humid rainforest and highland savanna agro-ecological zones

Result of the Generalized Linear Mixed Model (Formula: Adult_FAW_Abundance ~ Season + Day + (1 | Ecological_zone)) showed significant difference in abundance of Adult FAW with season and collection day across the ecological zones. The highland savanna had significantly higher numbers of FAW in the maize plots irrespective of the days after germination (DAG}. The peak populations of FAW occurred at 12 DAG in the humid rainforest and 22 DAG in the highland savanna then dropped gradually to the lowest between 42 to 52 DAG (Fig. 4).

3.4. Numbers of FAW larvae in plots with and without traps

The highest numbers of FAW larvae per plant were recorded in the plots without traps containing lures though there were not significant differences between these plots. There was a significant difference in the average numbers of FAW larvae per plant in plots with traps across ecological zones with higher numbers recorded in the humid rainforest zone compared to the Highland savanna zone (Fig. 5).

3.5. Yield of maize in plots with and without traps

There was a significant difference in grain yield across the two ecological zones and treatments; the highest yield was recorded in plots that had traps with maize chyme lure in the humid rainforest zone though the differences were not significantly different. However, in the Highland savanna zone, there was a significant difference ($p < 0.001$) in maize yield from plots that had traps with the maize chyme lure compared to the plots with commercial pheromone and the control plots (Table 3).

Table 3
Impact of treatments on Yield (Mean % ± SD) across agro ecological zones.

Treatments	Yield (tha^{-1})	
	Ecological zones	
	Humid rainforest	Highland savanna
Maize chyme	4.7 ± 0.4aA	4.1 ± 0.5aA
Honeygar	4.5 ± 0.8aA	3.9 ± 0.5aA
Control (water)	4.0 ± 0.9aA	2.2 ± 0.2aB
Commercial pheromone	4.1 ± 0.7aA	2.8 ± 0.3aAB

Uppercase letters are for comparisons across ecological zones and lowercase letters across treatments. Means with same lower case or same uppercase letters are not significantly different at $p < 0.05$.

The maize yields for the second season (September planting) were generally higher than those of the first season (March planting). The yields in plots that had traps containing maize chyme, honeygar lures and the commercial pheromone were significantly higher than those in the control plots during the first cropping season while there were no significant differences during the second season (Table 4).

Table 4
The impact of treatments on maize Yield (Mean % ± SD) across seasons

Treatments	**Yield (tha^{-1})**	
	Seasons	
	First	**Second**
Maize chyme	4.3 ± 0.4aA	5.0 ± 0.3aA
Honeygar	3.9 ± 0.4abB	5.1 ± 0.3aA
Control (water)	2.7 ± 0.6bAB	4.8 ± 0.2aA
Commercial pheromone	3.2 ± 0.5abB	4.8 ± 0.3aA

Uppercase letters are for comparisons across seasons and lowercase letters for comparisons across treatments. Means with same lower case or same uppercase letters are not significantly different at $p < 0.05$.

Damage score versus maize yield

There was a strong negative correlation between damage score and grain yield ($r < -0.07$); the maize yields decreased with increased damage score in both agro ecological zones in the study area.

4. Discussion

Appropriate and timely monitoring of pests in fields is essential for all integrated pest management programs. The fall armyworm is relatively a new invasive pest in maize fields in Africa and therefore it is vital to develop effective and sustainable methods of monitoring its population in the fields using traps and lures. Throughout the studies, all the tested lures and the commercial pheromone lure were exposed to the same conditions in identical locally adapted plastic traps.

However, each of the food-based lures of maize chyme, honeygar and palm wine attracted higher numbers of FAW more than the commercial pheromone. This is possibly because the food-based lures were non-selective and attracted both the male and female FAW unlike the commercial pheromone which is formulated to attract only adult male FAW moths. Unlike the commercial pheromone lure, the local lures are not adapted for matting disruption, but are rather food-based baits for mass capture of both sexes of the moths. Sugar and sugar rich materials as well as fruits and alcohol beverages are often used by collectors of Lepidoptera to attract moths and butterflies to sites where they can be captured. For example, traps baited with solution of molasses or unrefined palm sugar (jaggery) captured significant numbers of the moth *Mocis latipes* (Landolt 1995). The attraction and feeding of moths on artificial sugar baits is because in nature, they often feed on natural sources of sugar such as rotting fruit, plant exudates, insect honeydew, and flower nectars (Jose et al. 2017).

The local lures used in the current study were liquids formulated from freshly collected readily available ingredients in the study area; the liquid nature of these baits might have aided their attractiveness via easy volatilization of the odorous constituents. Maize chyme attracted the highest probably because it contained sugars and their fermented derivatives; sugars such as sucrose, refine cane, beet sugar and beer have been indicated to attract various moth species (Ogunwolu and Habeck 1975).

Maize chyme is a fermentation product and these have been reported to be economical and helpful for the attraction of different Lepidoteran families (Iqbal and Feng et al. 2020). Maize chyme being a fermentation product has safe biochemical constituents with no toxic effects to the environment (Iqbal and Feng et al. 2020). It is therefore environmentally friendly and a vital component of organic crop production. These result are consistent with similar research using fermented lures which attracted more insects into treated traps compared to the control traps (Iqbal and Feng et al. 2020).

Traps baited with maize chyme caught more FAW moths in the Highlands Zone (61.75) which was significantly different from humid Rainfall Forest Zone (30.50) in both cropping seasons. This might be due to a higher population of FAW in the savanna vegetation of the Highland Zone which may have more alternate hosts of FAW compared to the humid rainforest zone.. Other external factors like temperature, wind-speed, relative humidity and higher numbers of maize fileds may also affect lure effectiveness. The savanna Highland zones are the highest maize producing areas in Cameroon, followed by North, Center and the Adamawa region (INS. Agriculture 2015). The significantly higher numbers of FAW larvae per maize plant in the humid rainforest in plots without traps compared to those with traps shows the suitability of local lures to be used to sustainably control and monitor FAW in organic maize production. The significant decrease in the numbers of FAW larvae per plant in plots with traps is possibly as a result of continuous reduction of gravid FAW adults in the fields via the low-cost lures and traps. This could have then resulted to fewer eggs laid and resultant fewer numbers of larvae per plant compared to plots without traps.

The significantly lower maize yields in the control treatment across ecological zones and the lack of significant difference in all the treatments with lures demonstrated the effectiveness of the attractive potential of lures in reducing maize damage by FAW and effects on yield.

The percentage relative abundance of FAW was equal (50: 50) in both ecological zones at 7 days after germination (7DAG) and fluctuated with approximately equal proportions within 3 weeks after germination. This could possibly be attributed to the high egg laying ability of the FAW in young maize which is its preferred host (Anandhi et al. 2020). The higher percentage relative abundance of FAW in the costal humid rainforest from days 32 to 42 is consistent with other studies carried out in Ghana where FAW infestations and damage were highest at coastal lowlands compared to mid-altitude and high-altitude lands (Mutyambai et al. 2022). This might be as a result of particular favorable climatic variations across these coastal areas during these early stages of maize growth. However, the overall abundance, infestation and damage throughout the trials were higher in the highland savanna zone contrary to research carried out by Mutyambai et al. 2022. This is possibly due to disparities in overall maize production in the two zones where the trials were conducted with the Highland zone being the highest maize producing zone compared to the coastal humid rainforest with a lower production (INS. Agriculture 2015).

The highest abundance of adult FAW was recorded during the second season (dry season) compared to the rainy season. This might possibly be due to low amount of rainfall and drier spelt during the second cropping season as compared to the first cropping season. These results agree with those of Mitchell et al. (1991) who reported that in the tropics, *S. frugiperda* populations have a tendency to decrease with increase in rainfall.

In the tropics, adult FAW like other insect populations fluctuate with season and collection day across the ecological zones (Tanyi et al. 2020; Anandhi et al. 2020; Mutyambai et al. 2022). Increased temperature during dry season might have favoured the higher photosynthetic rate of maize which in turn favoured the continuous and abundant food supply to *S. frugiperda*. Higher rainfall during the first season has a great negative influence on the *S. frugiperda* population. These results agree with those of Mitchell et al. (1991), and Mutyambai et al. (2022) who reported that in the tropics, *S. frugiperda* populations have a tendency to vary with seasonal changes in rainfall.

Damage scores based on the Davis scale (Sisay et al. 2019) ranged from 0 to 6 which are consistent with previous studies which reported maize leaf damage score by FAW in Kenya to range from 3.2 to 5.3 on the Davis damage scale. There was a strong negative correlation between damage score and grain yield ($r < -0.07$); the maize yields decreased with increased damage score in both agro ecological zones in the study area which is in line with results of Sisay et al. 2019.

The highest number of fruit fly was recorded in honeygar (59). This is an additional advantage to vegetable and fruit growers in the environs where the local lures were used. The highest number of houseflies was captured in Honeygar (401) in Monomodal Rainfall Forest Zone, followed by palm wine (186). This is also an advantage into the environment considering the potential of houseflies as vectors of pathogens.

Traps baited with the low-cost lures especially the maize chyme used in this study caught significantly higher numbers of the fall armyworm adults compared to the traps baited with the commercial pheromone produce for this purpose. Since these low-cost lures are also food-based, they caught both the males and females. This is of additional advantage since a significant number of the females that lay eggs which subsequently hatch into the voracious feeding larvae are also removed thereby indirectly limiting future damage of the maize plants. Both the low-cost lures and the repurposed plastic bottle traps are made of readily available material thereby rendering FAW monitoring and control using these low-cost materials easily adoptable by the resource-poor small-holder maize producer in Africa.

Abbreviations

FAW: fall armyworm; SSA: sub-Saharan Africa; FAO: Food and Agriculture Organization; CABI: Center for Agriculture and Bioscience International; SD: standard deviation; ANOVA: analysis of variance.

Declarations

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 in literature search and manuscript preparation, NNN contributed in 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.

Competing interests

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

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Consent for publication

Informed consent was obtained from all individual participants included in the study.

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Figures

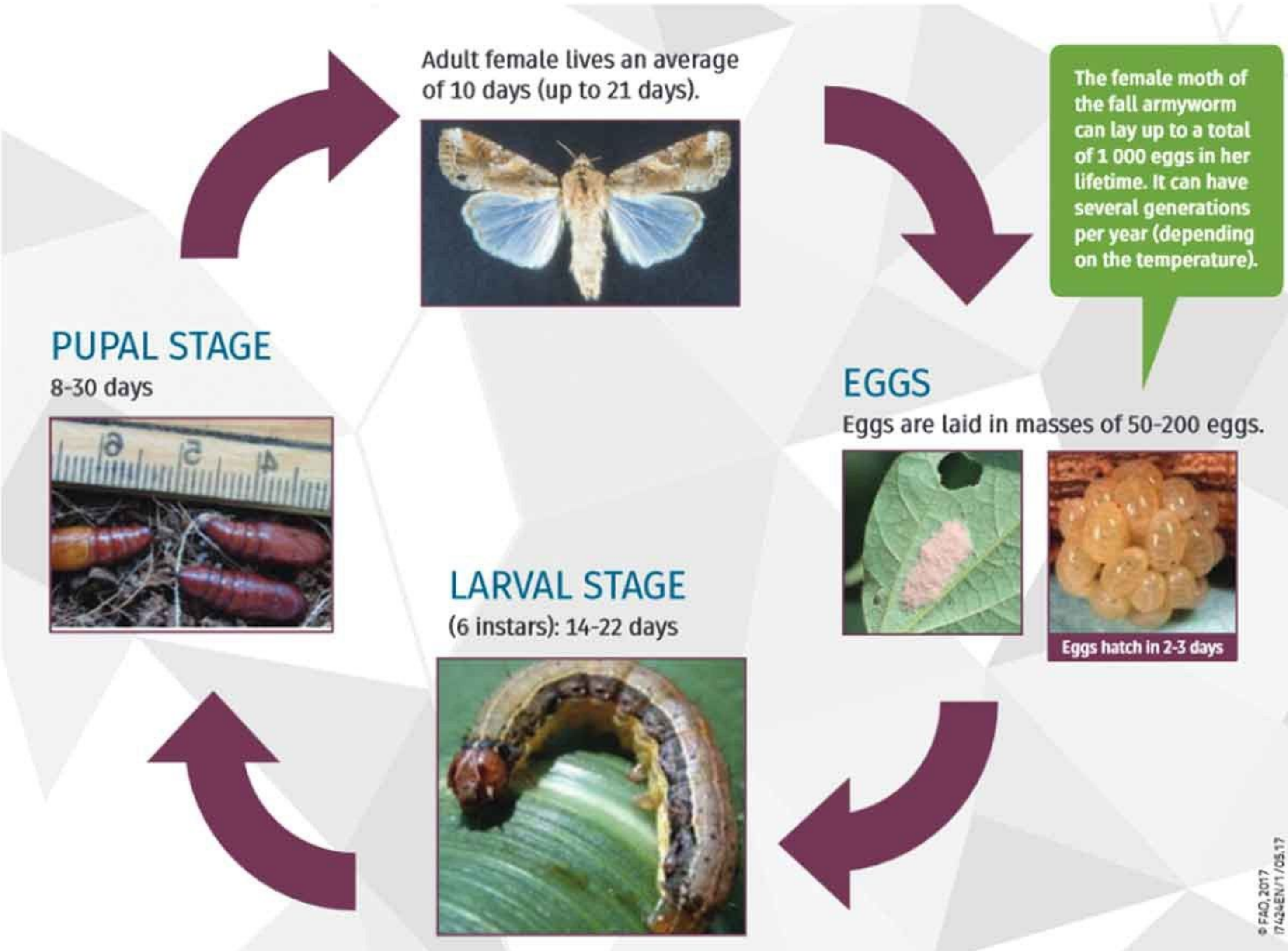
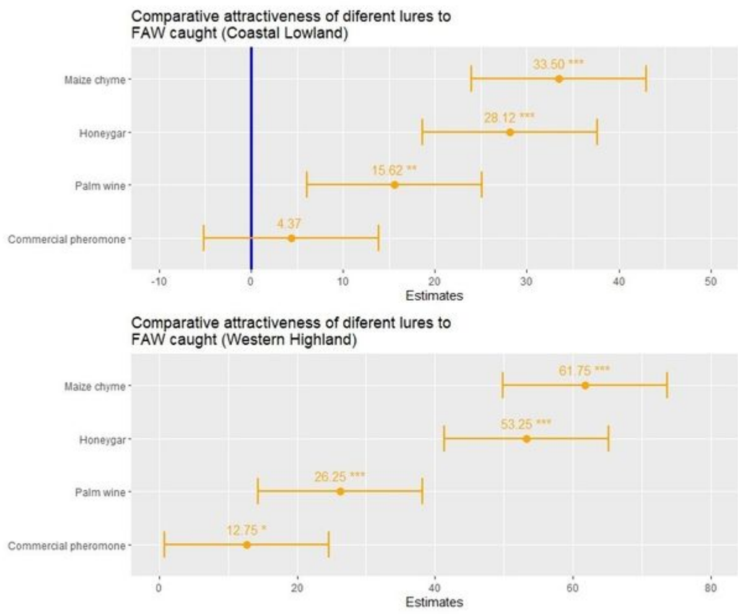


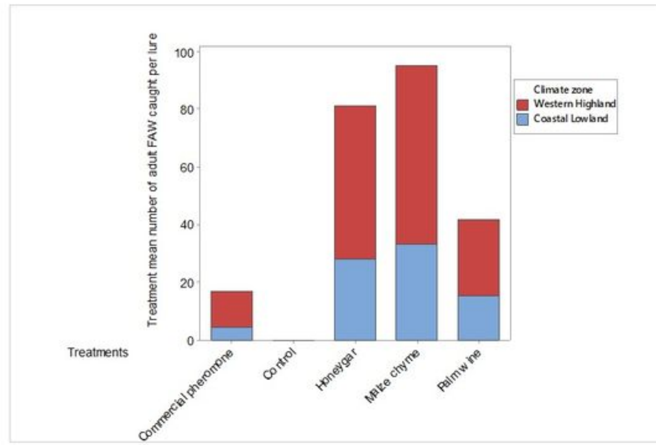
Figure 1

Lifecycle of fall armyworm *Spodoptera frugiperda*

Source: photo by (FAO. 2017) (African Department of Agriculture, Forestry, and Fisheries).



2a



2b

Figure 2

2a. Model output for Effect of lures on FAW trapped in the Coastal and Western Highland

2b. Mean numbers of adult FAW caught in traps with different lures in the humid rainforest and Highland savanna Zones in 2020-2021.

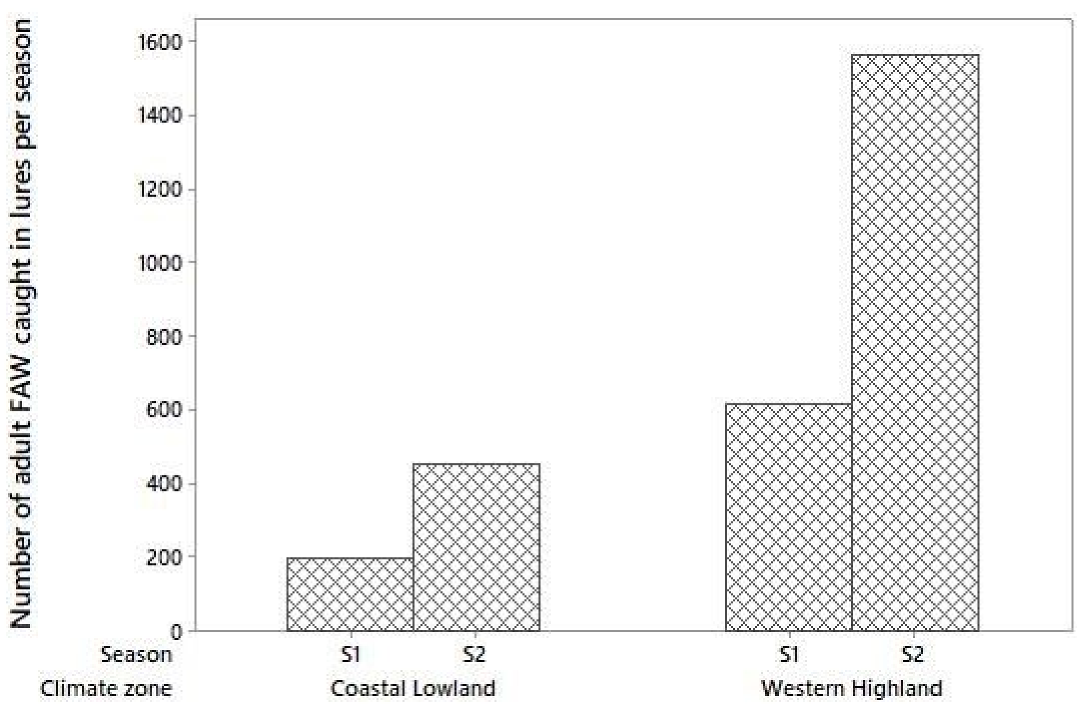


Figure 3

Seasonal variation of adult fall armyworm caught across humid rainforest and highland savanna agro-ecological zones

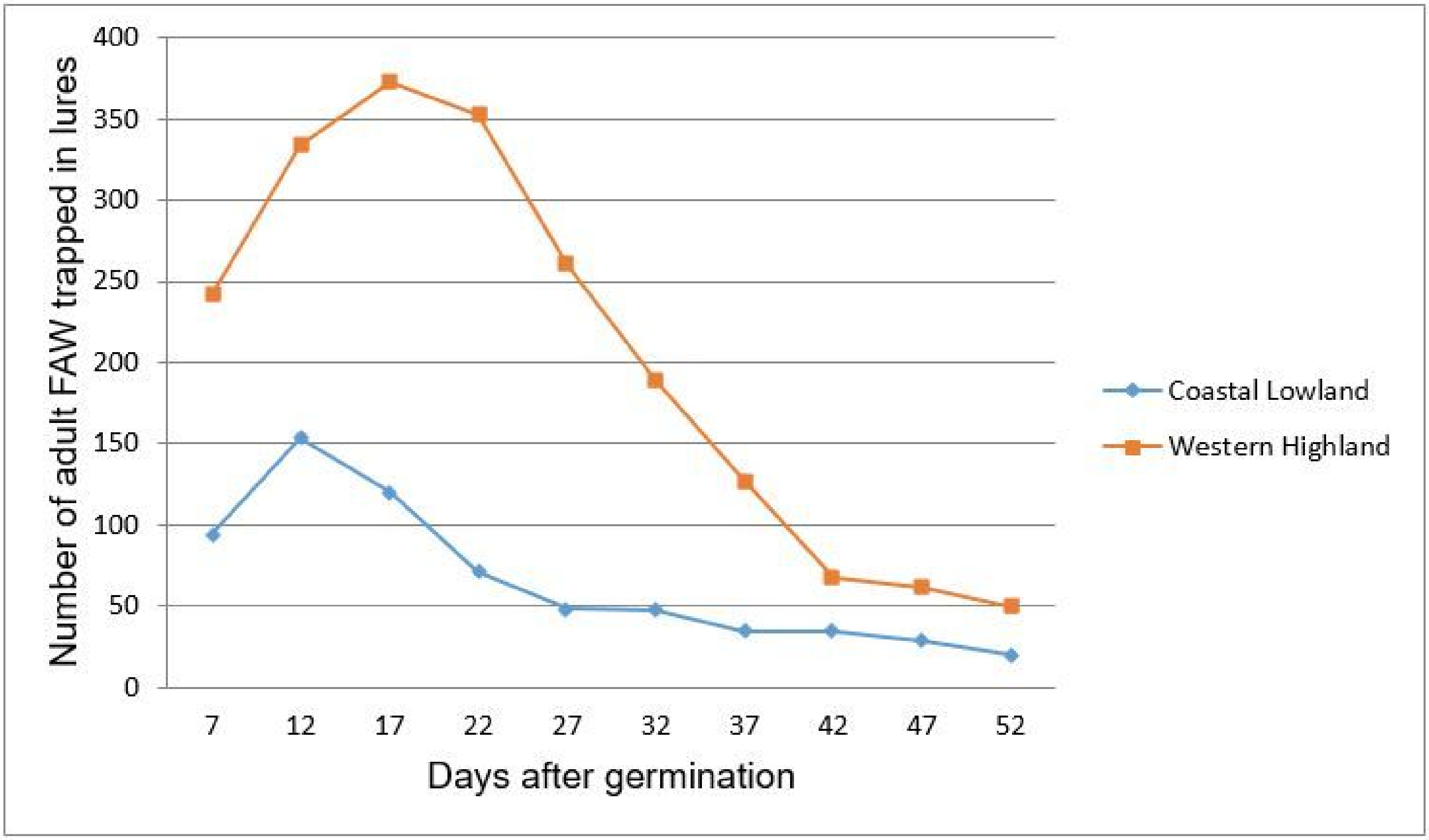


Figure 4

Population dynamics of adult FAW from the 7th to 52 days after germination in the humid rainforest and highland savanna agro-ecological zones

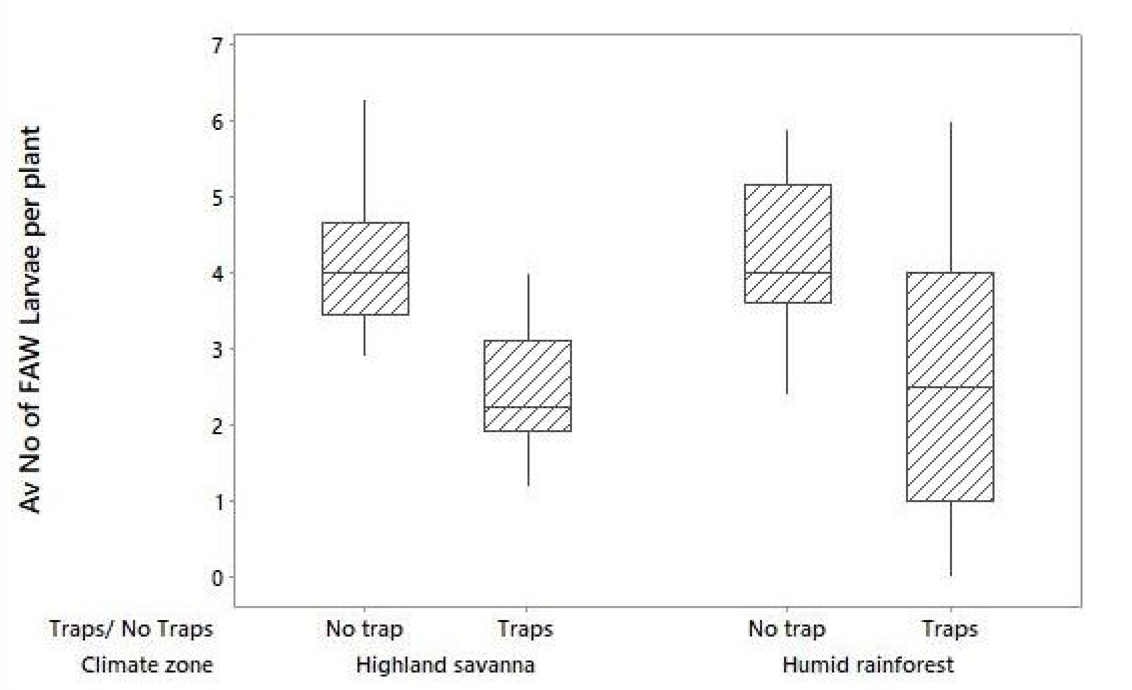


Figure 5

Average number of FAW larvae per plant in plots with and without traps across the Humid rainforest and Highland savanna agro ecological zones

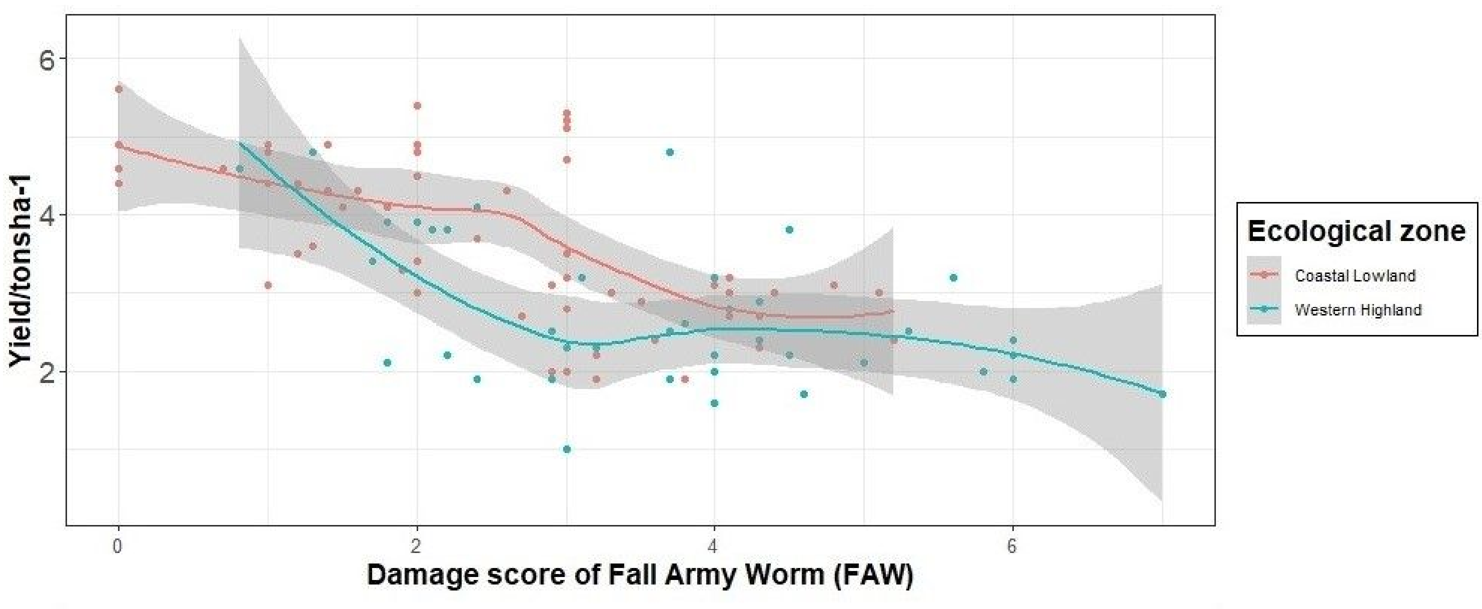


Figure 6

Correlation between fall armyworm damage score and maize yields in the humid rainforest and highland savanna Zones.