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Using food lures to monitor and control pest populations: case of fall armyworm on maize

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ABSTRACT

Considering the voracious feeding impact of the fall armyworm (FAW), *Spodoptera frugiperda* in major corn-growing belts of Africa, low-cost food lures were compared with the commercial pheromone for monitoring and control of this pest *via* mass adult captures. The lures: palm wine, honeygar, commercial pheromone, maize chyme, and a water control each replicated four times were tested in randomised complete block experimental designs during the rainy and dry seasons in two agro-ecological zones of Cameroon. Using the Generalized Linear Mixed Model showed that the maize chyme lure attracted significantly higher numbers of the moths compared to the commercial pheromone ($p<0.001$). The maize chyme attracted a total mean of 61.75 FAW adults in the Western Highland savanna which is significantly different from the Humid rainforest with 30.50 moths ($p<0.001$). Next was honeygar with 53.25 and 28.12 adults in the Highland savanna and Humid rainforest zones respectively, which were significantly different from Palm wine ($p<0.001$). The control treatment attracted no moth throughout the experiment, while the commercial pheromone had a mean of 12.75 and 4.30 moths in the Western Highland savanna and Humid rainforest zones respectively. There was a negative correlation ($p = -0.57$) between the number of adult armyworm moths captured in traps and the number of their destructive larvae on maize as well as the maize damage score. The number of larvae on maize and the damage score were negatively correlated with maize yields (($p = -0.66$) and ($p = -0.56$) respectively). This study showed the effectiveness of home-made traps and food lures compared to commercial pheromone trap and lure for monitoring FAW populations and also reducing the larval populations and crop damage to improve maize yields. These home-made traps and food lures can serve as components of indigenous integrated management strategy of fall armyworm for resource-constrained smallholder farmers.

KEYWORDS: fall armyworm, food lures and traps, commercial pheromone, pest monitoring, integrated pest management, agro ecological zones.

1. INTRODUCTION

Maize, *Zea mays* L. (Poaceae), the cereal with highest production worldwide, is 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 [1]. In Africa, more than 300 million people depend on maize as their main food crop [2]. Maize is also valuable as feed for farm animals and for alcohol (biofuel) production.

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 [3, 4] and accounting for 73% of calorific intake [1]. Maize production is constrained by drought, diseases and several pests, including

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lepidopteran stemborers, such as *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), *Eldana saccharina* Walker (Lepidoptera: Pyralidae), *Sesamia calamistis* (Hampson) (Lepidopotera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae).

Climate change, human activities and transportation of goods and persons across territorial boundaries have exacerbated movement of insect pest species between countries/continents and hemispheres. Insects such as the Africanized honey bee, *Apis mellifera scutellata* Lepeletier [5], small hive beetle, *Aethina tumida* Murray [6], longhorn crazy ant, *Paratrechina longicornis* (Latreille) [7], and the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) [8] hitherto endemic to Africa, have become established in North America. Similarly, the fall armyworm (FAW), *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 [9, 10]. *Spodoptera frugiperda* with its devastating feeding habits currently occurs in Africa, Asia, Australia, North and South America [11-14]. The pest can cause maize yield losses of between 21–53% in low-input smallholder farming systems [15]. The impact of *S. frugiperda* on maize has been a major challenge for the continent since it is a serious threat to food and nutrition security for millions of people [16]. In Cameroon, the pest exists in all the major maize producing agro ecological zones of the country, with the highest severity and infestation in the Sahelian and Highland savanna zones [10, 17].

The polyphagous *S. frugiperda* feeds on approximately 353 crop species from 76 plant families mainly Poaceae, Asteraceae, and Fabaceae in its native range [18]. Maize, rice, sugarcane, and sorghum are known to be the major hosts of *S. frugiperda* while vegetables, cotton, and turf are minor hosts [19-22]. The destructive caterpillars of FAW feed on young maize leaf whorls, stems, branches, and reproductive organs, such as tassels and ears inflicting substantial damage to the crop and causing high grain yield loss [23, 13]. The pest in Africa is threatening the livelihood of indigenous smallholder farmers who rely on maize production for income and food security [9, 15]. The sporadic spread of the pest and its potential to travel 1600 km over a 30-h period [24] signifies more danger for grain producers in Africa where the crop is often produced by resource-constrained smallholder farmers [25, 26]. This highlights the importance to adapt pest control measures, and monitoring procedures appropriate to this influential category of crop producers. Genetically modified maize hybrids expressing *Bacillus thuringiensis* insecticidal proteins have been used to control *S. frugiperda* [27-29]. Generally, the indigenous African smallholder grain producers rely on synthetic pesticides to control their maize pests [30-33]. However, the use of synthetic pesticides has exacerbated the effect of poisonous substances in food and non-target areas with devastating consequences on the environment [34, 35]. This underscores the need to develop *S. frugiperda* management strategies appropriate to the local farmers' needs and priorities [36] who are the major grain producers in most African countries. There is therefore an urgent need for a reliable low-cost, early detection technology for the pest and its sustainable management for resource-constrained smallholder farmers.

Monitoring the FAW is often done using pheromone-baited traps that attract male moths [37]. 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 [38]. The Centre for Agriculture and Bosciences International (CABI) and Food and Agriculture Organization of the United Nations (FAO) [39] 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 Systeme (FAMEWS) mobile application tool requires users to input both field scouting and pheromone trap data [40]. FAO and Pennsylvania State University jointly developed a talking mobile app called *Nuru* (Swahili for 'light') in several African countries [40]. 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. Scarcity of the pheromone lures and traps and their high-cost is also problematic for the indigenous smallholder farmers in Africa.

FAW pheromone trap data can be used to predict the abundance of larvae in pastures [41] though McGrath *et al.* [37] observed no relationship between the numbers of FAW males caught in traps and those 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 of plastic containers as compared to bucket traps [42]. However, there is vital 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 the resultant destructive larvae in the farm as well as use as a monitoring technique. Consequently, the aim of this study was to test home-made low-cost food-based lures in low-cost traps for monitoring and control of the fall armyworm as a component of an indigenous integrated management strategy (IIMS) of this pest.

2. MATERIALS AND METHODS

2.1. Sampling sites

This study was conducted between August 2020 and June 2021 in Buea, a high maize production monomodal humid rainforest ecological zone and Mbouda, a highland savanna agro-ecological zone (AEZ) 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 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 relative humidity of 86%, a mean annual rainfall of 2800 mm and a mean monthly air temperature range of 19-30 °C [43, 44]. The soils are derived from weathered volcanic rocks. Mbouda is in the Western savannah highland region with an average rainfall of 1800-2400 mm, mean temperature of 21 °C and an elevation of 1500-2500 metres above sea level.

2.1.1. Trapping of fall armyworm

A site was selected in each AEZ and maize planted during the first (March) and second (September) cropping seasons. Each field was 1008 m^2 divided into 20 experimental units of 4m x 4m each separated from each other by a 4m alley. In the center of each experimental unit, an improvised low-cost trap was placed; the distance between traps was 8 m to prevent interference between lures. The experiment was set up in a randomised complete block design with 5 treatments based on the following lures/ baits: palm wine, honeygar, commercial pheromone, maize chyme, and a water control each replicated four times. In each experimental unit, three UBNMS001 maize variety seeds were planted per hole at 80 × 50 cm inter and intra row spacing, respectively and then later thinned to two seedlings per stand after ten days. All experimental units were amended at two weeks after germination with granular inorganic fertilizer (NPK 20:10:10) at 5 g 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 by Agrobiological Society of Africa, having a slow-release insecticidal tablet. The commercial pheromone, solid insecticide tablet, and trap were bought from an agrochemical shop in Yaoundé Cameroon. Three of the baits were food-based attractants prepared as follows:

i. Vinegar bait (honeygar): a mixture of 500 ml vinegar and 50 ml honey in 1 L of water.
ii. Brewers' waste: fermented leftover maize chyme obtained from local brewers of a 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.
iii. Palm wine: 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.

Portable water obtained from public taps was used as a control.

2.1.2. Monitoring of fall armyworm

For each of the food-based lure and the water control, 300 ml was measured and put in a home-made trap prepared from repurposed 1.5 l cylindrical plastic portable water bottle. Two round holes of 2.5 cm diameter each were created on opposite sides half way the height of the plastic bottle using a knife. The normal opening of the bottle was closed with the lid, and a 30 cm string tied to it was used to hang the bottle on a wooden pole. In each experimental unit, a trap each containing 300 ml of a particular lure was hung on the wooden pole about 1.5 m above the ground. Each trap was monitored once after every five days; 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, the trap was also serviced by replacing the bait with the corresponding fresh bait. Ten maize plants in the middle of each experimental unit were sampled for the occurrence of fall armyworm larvae and associated damage indices on the plant. The average number of fall armyworm larvae per plant and damage was recorded on weekly intervals *via* destructive sampling (such that older larvae inside the whorls were recorded) beginning from three weeks after germination (WAG). Damage score was recorded based on a scale ranging from 0-9. Maize yield data were also recorded at crop maturity.

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 done throughout all growth stages of the maize crop from vegetative to cob maturity. The surrounding weeds, grasses, and dry maize stalks were also scouted regularly for egg masses and larvae of fall armyworm.

2.1.3. Identification and sexing of FAW moths caught in traps

Identification and sexing of adult FAW moths was done through examination of genitalia, wing patterns, and size of the abdomen (the abdomen of female FAW moths is fatter, and the wings bigger than those of the male). The forewings were used as a distinctive sexing feature in male and female. The forewings of the male FAW moths are gray and brown, with triangular white spots at the tip and near the center of the wing. Meanwhile, the forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray [45].

2.2. Evaluation of foliar damage

Maize foliar 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 3 WAG. A numerical scale of 0–9 (Table 1) was used to score the foliar feeding damage [46].

2.3. Data analysis

Data were analyzed using R and R studio 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 R studio version

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

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 these, 1144 were caught in the traps baited with maize chyme (241 males, 903 females) and 936 in the traps baited with honeygar (321 males, 615 females) while only 199 were caught in the commercial pheromone baited traps (191 males, 0 females). 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. Also, 59 fruit flies and 401 house flies were recorded in honeygar-baited traps which were significantly different from all other treatment 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 home-made 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 had the 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 which recorded 53.25 in Highlands zone and 28.12 in humid rainforest Zone, and both were 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 ($p = 0.037$) (Figure 1a 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 $p<0.001$ (Figure 2). The maximum number of 36 adult FAW moths per trap was caught in the Highland savanna as compared to 23 in the humid rainforest zone.

3.3. Population dynamics of adult FAW at various days after germination across agro-ecological zones

Result of the Generalized Linear Mixed Model showed significant difference in abundance of FAW adults with season and collection day across the ecological zones. The highland savanna had significantly higher numbers of FAW in the experimental units 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 which then dropped gradually to the lowest between 42 to 52 DAG (Figure 3).

3.4. The cost of lures and traps

The cost of a moth trap and lure have several elements: cash for purchase, labour/time to make the trap and lures, labour/time to replace the lure, and labour/time to count the catch (including sorting out FAW from other species). Table 2 shows detailed cost of commercial and food lures and traps.

3.5. Impact of food lures on damage caused by FAW larvae and maize yields

There was a negative correlation ($p = -0.57$) between number of adult FAW moths captured in traps and the number of larvae causing damage on maize as well as the damage score recorded on maize. The number of larvae recorded on maize and the damage score were negatively correlated with maize yield in tons/ha (($p = -0.66$) and ($p = - 0.56$) respectively).

Trapping adult FAW is therefore a potential control method, and these results therefore confirm the effectiveness of lures/traps for monitoring FAW population abundance, and as a method for reducing larvae populations and crop damage to improve maize yields (Figure 4).

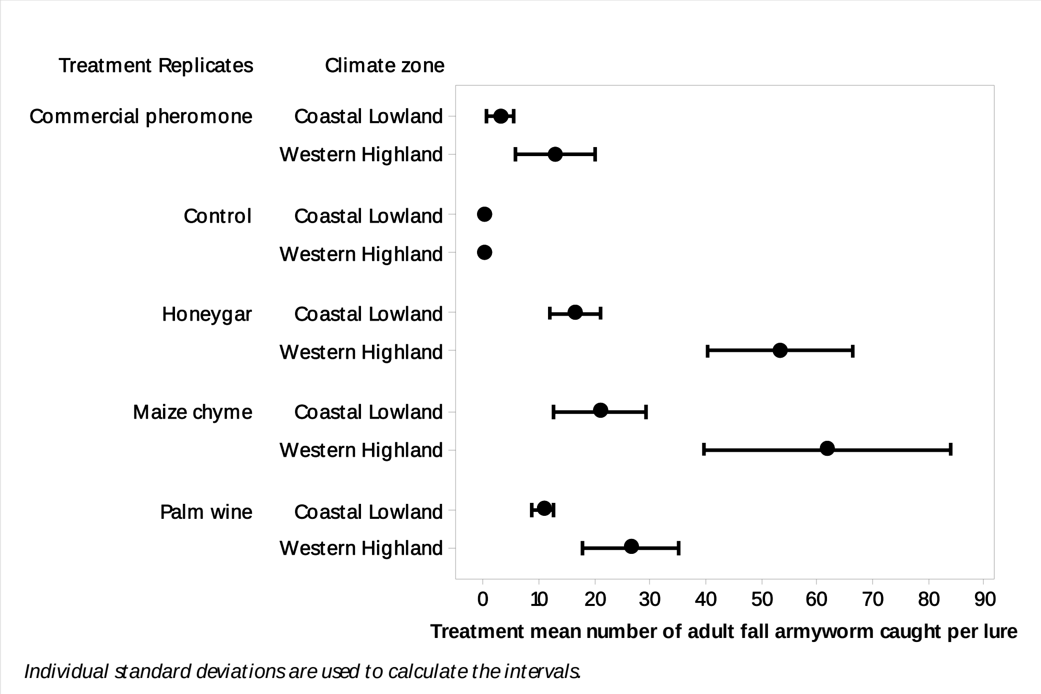

Figure 1a. Model output for effect of lures on fall armyworm trapped in the humid rainforest (Coastal Lowland) and Western Highland savanna.

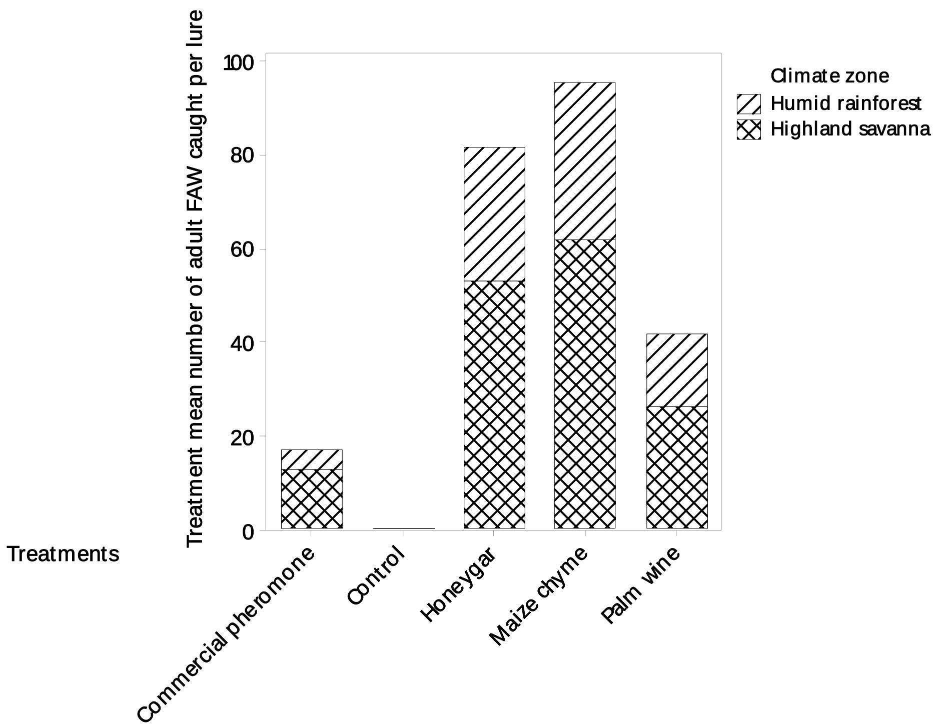

Figure 1b. Mean numbers of fall armyworm adult caught in traps with different lures in the humid rainforest and Highland savanna zones in 2020-2021.

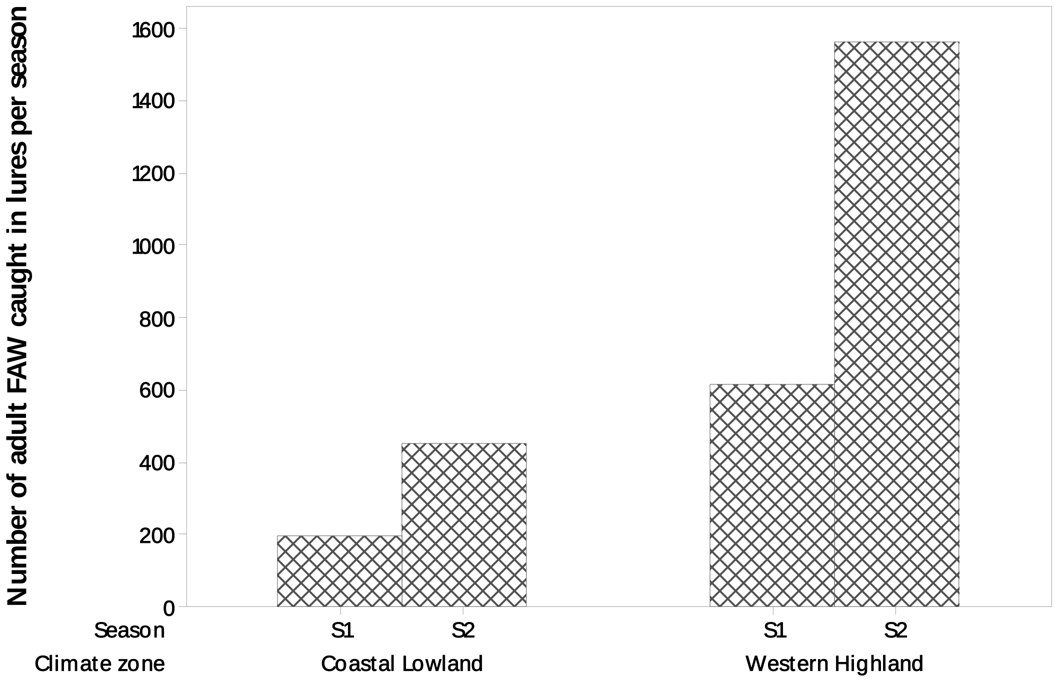

Figure 2. Seasonal (S1 rainy and S2 dry) variation of adult fall armyworm caught in the humid rainforest (Coastal Lowland) and highland savanna (Western Highland) agro-ecological zones.

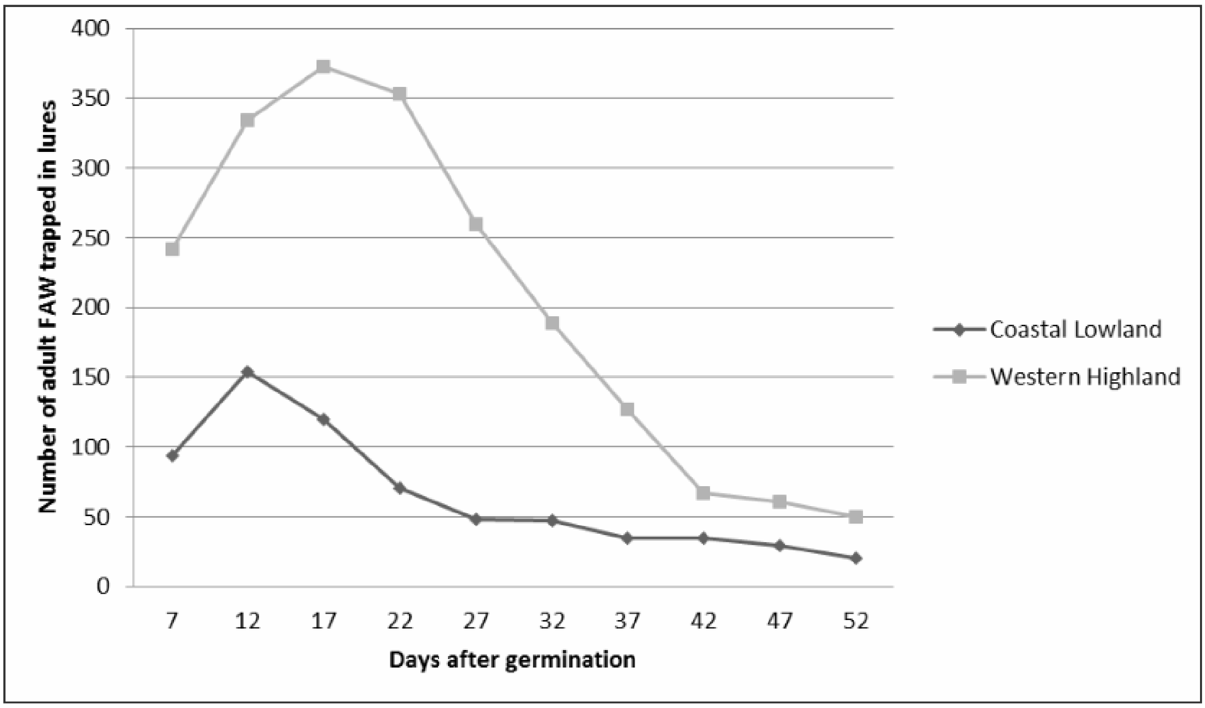

Figure 3. Population dynamics of adult FAW at different days after germination in the humid rainforest and highland savanna agro-ecological zones.

Table 2. Cost of commercial and food lures.

Lures	Requirements	Unit cost (FCFA)	Quantity	Total (FCFA)	Explanatory notes
Maize chyme	1.5L Plastic Bottles	160	5	800	Cost of picking a plastic from the environment and adapting it to a trap
	Brewers waste	50	12L	600	300 ml of brewers waste per trap x 5 traps x 8 weeks of servicing = 12 liters
	Filter mesh	100	1	100	For servicing traps
	Wooden peg	50	5	250	Wooden peg of Height 1.5m
	Servicing cost	100	40	4000	100 FCFA per trap x 5 traps per week for 8 weeks
Total		**460**		**5,750**	**11,500 FCFA for two seasons**
Palm wine	1.5L Plastic bottles	160	5	800	Cost of picking a plastic bottle from the environment and adapting it to a trap
	Fresh palm wine	200	12L	2400	300 ml of fresh palm wine per trap x 5 traps x 8 weeks of servicing = 12 liters
	Filter mesh	100	1	100	Purchase cost of filter mesh
	Wooden peg	50	5	250	Wooden peg of Height 1.5m
	Servicing cost	100	40	4000	100 FCFA per trap x 5 traps per week for 8 weeks
Total		**6,10**		**7,550**	**15,100 FCFA for two seasons**
Honeygar	1.5L Plastic bottles	160	5	800	Cost of picking a plastic bottle from the environment and adapting it to a trap
	Vinegar	500	6L	3,000	500 ml per liter of honeygar x 8 weeks of servicing = 6 liters
	Honey	2500	0.4L	1,000	50 ml of honey per liter of honeygar x8 weeks of servicing = 400 ml (0.4 liter).
	Water	0	5.6L	0	Free Water from the surrounding
	Wooden peg	50	5	250	Wooden peg of Height 1.5 m
	Servicing cost	100	40	4000	100 FCFA per trap x 5 traps per week for 8 weeks
Total		**3,310**		**9,050**	**18,100 FCFA for two seasons**
Commercial pheromone	Pheromone trap	15,000	5	75,000	Purchasing cost of commercial pheromone traps
	Insecticidal tablet	1,000	10	10,000	1 tablet per trap x 5 traps serviced after ever 4 weeks
	Pheromone lure (Captorplus®)	5,000	10	50,000	5000 FCFA per x 5 traps serviced after every 4 weeks
	Wooden peg	50	5	250	Wooden peg of Height 1.5 m
Total		**21,050**		**135,250**	**270,500 FCFA for two seasons**
Control (water)	1.5L Plastic bottles	160	5	800	Cost of picking a plastic bottle from the environment and adapting it to a trap
	Wooden peg	50	5	250	Wooden peg of Height 1.5m
	Total	**170**		**1,050**	**2,100fcfa for two seasons**

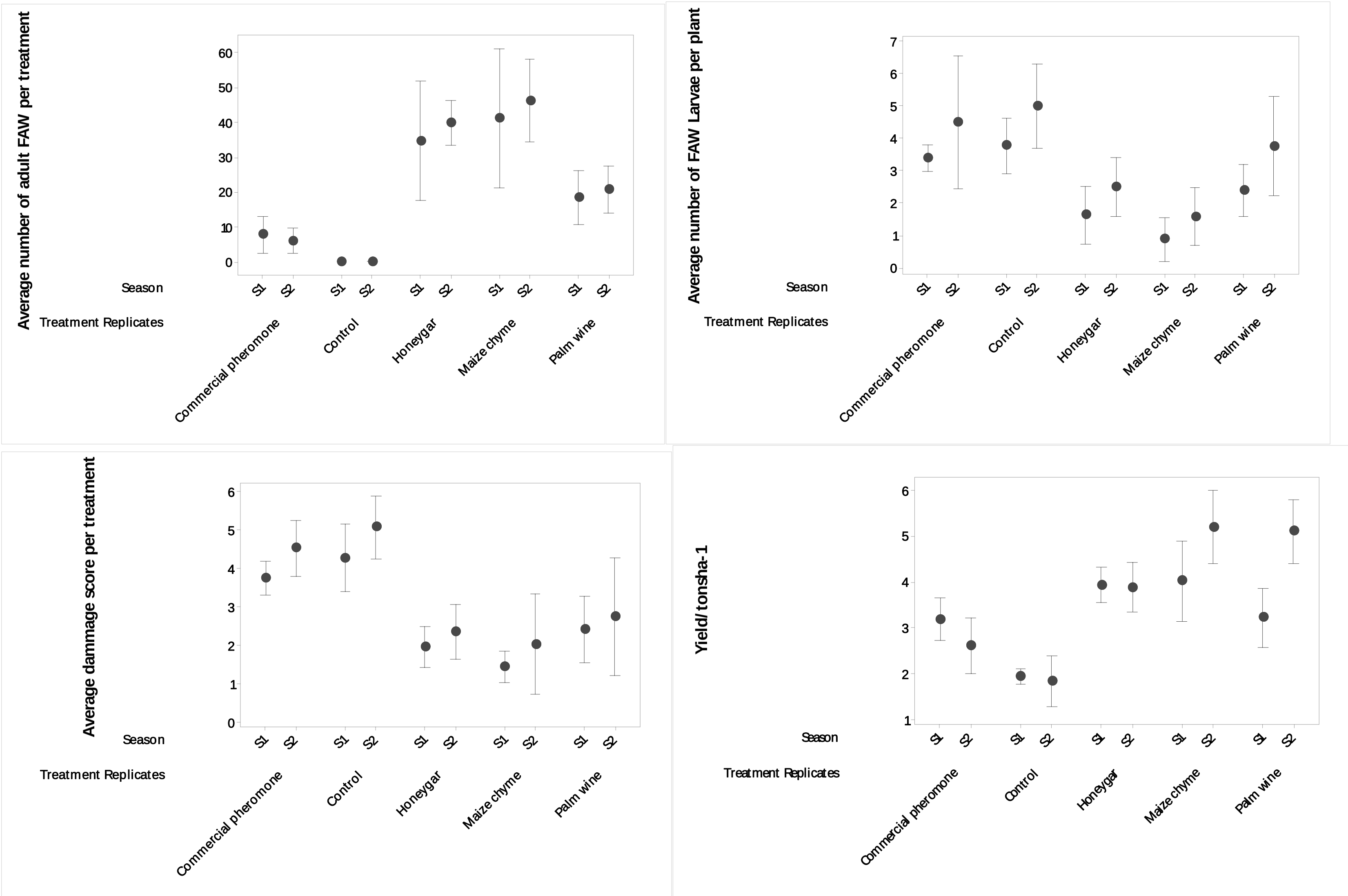

Figure 4. Interval plot of number of adult FAW; average number of FAW larvae per plant; average damage score per treatment; yield/tonsha^{-1}. Individual standard deviations are used to calculate the intervals. 95% CI for the Mean.

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 food lures and the commercial pheromone lure were exposed to the same conditions in identical repurposed plastic bottle traps.

However, each of the food-based lures of maize chyme, honeygar and palm wine attracted higher numbers of FAW (males and females) compared to the commercial pheromone lure. 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 food lures are not destined for mating disruption, but rather lure both the male and female moths to a possible source of food. Sugar, sugar-rich materials, 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* [47]. 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 [48]. The high number of female moths captured in home-made trap and lures was possibly also partly due to the occurrence of more females than males as it is a common phenomenon in other living organisms in nature.

The food-based 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 its fermented derivatives; sugars such as sucrose, refined cane, beet sugar and beer have been reported to attract various moth species [49]. Maize chyme is a fermentation product and these have been reported to be economical and helpful for the attraction of different Lepidoteran families [50]. Since maize chyme is a fermentation product, it has safe biochemical constituents with no toxic effects to the environment [50]. It is therefore environmentally friendly and a vital component of organic crop production. These results are consistent with similar studies that used fermented lures which attracted more insects into treated traps compared to the control traps [50].

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 populated predominantly with various types of trees. Other external factors like temperature, wind-speed, relative humidity and higher numbers of maize fields 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 [51]. The significantly higher numbers of FAW larvae per maize plant in the humid rainforest in plots without traps shows the suitability of local lures for the sustainable control and monitoring of 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 which then resulted in fewer eggs being laid and consequently fewer numbers of larvae per plant compared to plots without traps.

The significantly lower maize yields in the control treatment across ecological zones compared to the treatments with lures shows the effectiveness 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 (7 DAG) and fluctuated with approximately equal proportions at 21 DAG. This could be attributed to the high egg laying ability of the FAW in its preferred young maize host [52].

The higher percentage relative abundance of FAW in the humid rainforest from 32 to 42 DAG 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 [53]. This might be as a result of particular favorable climatic variations across coastal areas during the early maize growth stages. However, the overall abundance, infestation and damage throughout the trials were higher in the highland savanna zone contrary to the results of Mutyambai *et al*. [53]. This is possibly due to disparities in overall maize production in the two zones of the trials; the Highland zone is the higher maize producing zone compared to the coastal humid rainforest [51].

The highest abundance of adult FAW was during the second season (dry season) possibly due to low rainfall and drier spells during this cropping season compared to the first season. These results agree with those of Mitchell *et al*. [54] who reported that in the tropics, *S. frugiperda* populations have a tendency to decrease with increase in rainfall. Generally, adult FAW like other insect populations fluctuate with season and collection day across ecological zones [33, 52, 53].

Damage scores based on the Davis scale [54] ranged from 0 to 6 which are consistent with other studies which reported that FAW maize leaf damage score in Kenya ranged from 3.2 to 5.3 on the 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 AEZs in the study area consistent with results of [54].

In this study, traps baited with the food lures especially the maize chyme caught significantly higher numbers of the FAW adults compared to the traps baited with the commercial pheromone produced for this purpose. The food-based lures caught both the males and females which is advantageous since a significant number of the females that lay eggs which will subsequently hatch into the voracious feeding larvae are also removed. This indirectly limits future damage of the maize plants. Both the food lures and the repurposed plastic bottle traps are made of readily available material which makes the monitoring and control of FAW using these low-cost materials easily affordable and adoptable by the resource-poor small-holder maize producers in Africa.

Evidence on the value of pheromone traps to estimate abundance of FAW is mixed; 'McGrath and others observed no relationship between the numbers of FAW males caught in traps and the number of females laying eggs in the same locality [37]. Thus, catches of male moths in commercial pheromone trap and lures should simply be used to estimate the presence of potential egg-laying females in the area." In contrast, the food lures used in this study attract both males and females, and hence provide a more useful indicator of current pest pressure which can easily be extrapolated to subsequent larval density, damage score and yield.

While the up-front cash for commercial pheromone and trap is clearly higher than that of the home-made trap and food lures, these home-made traps and lures also require less effort and skills to make, install, monitor and serviced weekly at a cheaper cost. This confirms the home-made traps and food lures as 'low-cost' for possible vulgarization as alternatives/supplement to the commercial traps and pheromone lures for the monitoring of fall armyworms.

CONCLUSION

This study introduces and demonstrates the effectiveness of innovative low-cost traps made using repurposed plastic bottles and food lures technique as a potential tool that can be used to monitor FAW and also reduce its damage on maize and increase yields at all production levels to improve livelihood in most developing countries.

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AUTHORS' CONTRIBUTIONS

This work was done in collaboration between all authors. CBT designed, established and managed the experiment, collected data and analyzed it, did literature searches and wrote the first 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.

AVAILABILITY OF DATA AND MATERIALS

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

CONFLICT OF INTEREST STATEMENT

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

ABBREVIATIONS

FAW: fall armyworm; SSA: sub-Saharan Africa; FAO: Food and Agriculture Organization; CABI: Center for Agriculture and Bioscience International; IIMS: Indigenous Integrated Management Strategy; DAG: days after germination; DAP: days after planting; SD: standard deviation; ANOVA: analysis of variance.

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