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Field Evaluation of Commercial Sex Pheromone Lures and Home-made Traps for Monitoring of Male Fall Armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) in Los Baños, Laguna, the Philippines

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The fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), is an invasive pest of corn and a potential threat to cause yield losses. In this study, the efficacy of commercially available sex pheromone lures and home-made traps for monitoring male FAWs was evaluated in the corn fields of Los Baños, Laguna, the Philippines, during the wet and dry seasons of 2022. Two trials were conducted to compare the capture rates of male FAWs using two home-made trap designs (bucket and delta trap) baited with commercially available pheromone lures. Delta traps baited with BioPhero (Z9, E12) 9,12-tetradecadien-1-ol acetate, acquired significantly more male moths than the other trap combinations during the field trials. There was a correlation in the number of captures of male FAW between trap designs and pheromone lures. Additionally, a statistically significant interaction between trap design and pheromone lures was observed during field trials conducted in both the dry and wet seasons of 2022. The design of home-made traps and the efficacy of lures significantly influence the overall performance of the trap. This study may contribute to the development of efficient combinations of lure and trap for monitoring Philippine FAW populations.

Keywords: fall armyworm, monitoring, pheromone lures, *Spodoptera frugiperda*, traps

INTRODUCTION

The fall armyworm (FAW), scientifically known as *Spodoptera frugiperda*, is a highly destructive lepidopteran pest belonging to the family Noctuidae, which includes armyworms and cutworms. This pest primarily inflicts severe damage on a wide range of crops, particularly corn. The larval stage of FAW is the most destructive stage throughout their life cycle. Its life cycle involves six larval instars, each lasting from 12–20 d depending on temperature and environmental conditions (FAO 2018a). The FAW larvae consume the whorl leaf and create perforation, especially at the late whorl stage of corn (Sisay *et al*. 2019; Sarkowi and Mokhtar 2021).

The adaptability and ecological advances of FAW pose significant threats to yield production. The pest originated from the sub-tropical regions of the Americas (Sparks 1979; Wan *et al*. 2021) and subsequently expanded into Asia in 2018 (Sharanabasappa *et al*. 2018; Canico *et al*. 2021). Confined to its habitat, the strong migration ability has led to its biological characteristics to disperse over long

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distances, resulting in significant economic implications (Meagher and Nagoshi 2004; Wan *et al*. 2021). The first incidence of FAW infestation in the Philippines was first reported in June 2019 in Piat, Cagayan (Navasero *et al*. 2019). Traditional pest management practices, including the application of pesticides, have been employed against the rapid spread of FAW. However, pesticide misuse and overuse consequently contributed to ecological disruption and human health concerns.

Integrated pest management has become the approach to mitigate these risks, offering alternative practices that are sustainable and environmentally resilient. Early detection of FAW, such as the use of light and bucket traps, has been carried out to aggregate as additional control measures (Capinera 2014; Bratovich *et al*. 2019). To complement these strategies, the use of sex pheromones has become the interest of many studies. Pheromone lures have been successfully employed for insect monitoring, mass trapping, and mating disruption.

A pheromone is a specific semiochemical that is naturally emitted by an animal to trigger a behavioral response such as mating, alarm, and defense (Carde and Millar 2009). The sex pheromone of *S. frugiperda* has a primary component of (Z)-9-tetradecenyl acetate (Z9-14:Ac), alongside secondary components such as (Z)-7-dodecenyl acetate (Z7-12:Ac), (Z)-11-hexadecenyl acetate (Z11-16:Ac), and (Z)-9-dodecenyl acetate (Z9-12:Ac). These components are essential in attracting male FAW moths in the field (Tumlinson *et al.* 1986; Bratovich *et al.* 2019; Guo *et al.* 2020).

Various studies have demonstrated the efficacy of sex pheromone lures in monitoring FAW populations. For example, one study reported that water-pan traps baited with pheromone lures captured the highest number of FAW moths (Sisay *et al.* 2024). Contrastingly, delta traps and Scentry *Heliothis* traps captured a higher proportion of male moths, likely due to variations in FAW population densities (Malo *et al.* 2001). Responses of male FAWs are discrete and different between geographically distant populations (Bratovich *et al.* 2019). These differences in the number of FAW captures significantly rely on the choice of pheromone lure and trap type design. It is essential to conduct a thorough evaluation of pheromone lures and traps to identify the most effective ones in different geographical locations.

Most pheromone studies assumed that different trap types and pheromone lures would have a direct significant effect on the catch rate of male FAW. This study was therefore conducted to evaluate the field efficacy of commercially available sex pheromone lures and traps for developing pheromone lures in the future.

MATERIALS AND METHODS

Field Site

The field performances of commercial pheromone lures baited with home-made buckets and delta traps were evaluated in the Central Experiment Station of the University of the Philippines Los Baños (UPLB) (14.166401, 121.253652) in a yellow and white corn field (5,000 m^2). The field trials were performed during the dry and wet seasons of 2022. Overall, two trials were performed throughout the study.

Traps and Lures

The performance of commercial pheromone lures was tested in a field trial set-up using two different trap designs. The home-made bucket trap featured a rectangular entrance on both sides of the bottle, cut approximately 5 in from the base of a 5–6-L water bottle, forming a 4.5 in x 4 in rectangular strip. A twine or aluminum hook was affixed to the bottle cap to attach the lure. The container was filled with soapy water prepared by adding dishwashing liquid to water until a visible lather was formed (approximately 1% dishwashing liquid) to act as a killing agent and hung on a suspended pole approximately 1.5 m above the ground (Figure 1).

A home-made delta trap (28 cm length x 21 cm width x 16 cm height) was constructed from corrugated cardboard and featured triangular entrances at each end. To trap and retain moths, the interior of delta traps was coated with yellow sticky traps (Figure 2). Lures were caged inside both trap designs. Traps without pheromone lures served as the control treatment in the field trial.

Two commercially available lures registered with the Fertilizer and Pesticide Authority (FPA) were validated for efficacy. Two synthetic pheromone lures were used: Fall Army-Lure (Z)-9-tetradecenyl acetate and BioPhero (Z9, E12) 9,12-tetradecadien-1-ol acetate. Traps without pheromone lures served as a control treatment.

Field Tests and Trial Management

The trials conducted during both the dry and wet seasons assessed the effectiveness of Fall Army-Lure and BioPhero commercial lures, as well as the performance of bucket and delta traps. The trial comprised two treatments (trap types and pheromone lures used) and blocks arranged in a 3 x 6 block design, with three replicates. All trap designs were arranged in a 2 x 3 factorial design and placed randomly in a complete block design. Sweet corn varieties (Ramgo) were planted in both the wet and dry season trials. Corn was planted 75 cm between rows, with 25 cm spacing between the plants. The fertilizer was applied during planting, while urea was applied 30

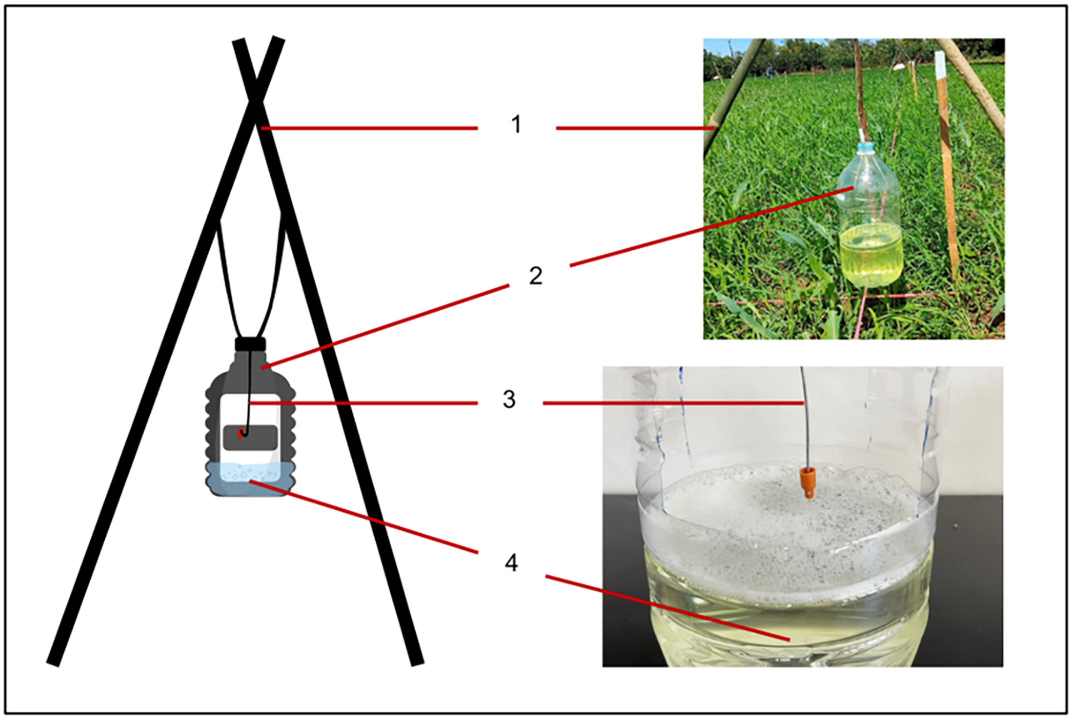

Figure 1. Home-made bucket trap baited with commercial sex pheromone lure: [1] a suspended pole about 1.5 m above the ground; [2] a 5-6 L discarded water bottle, featuring a rectangular entrance on both sides of the bottle (4.5 x 4 inches); [3] twine or aluminum hook for placing the pheromone lure; [4] soapy water, prepared by adding dishwashing liquid to water.

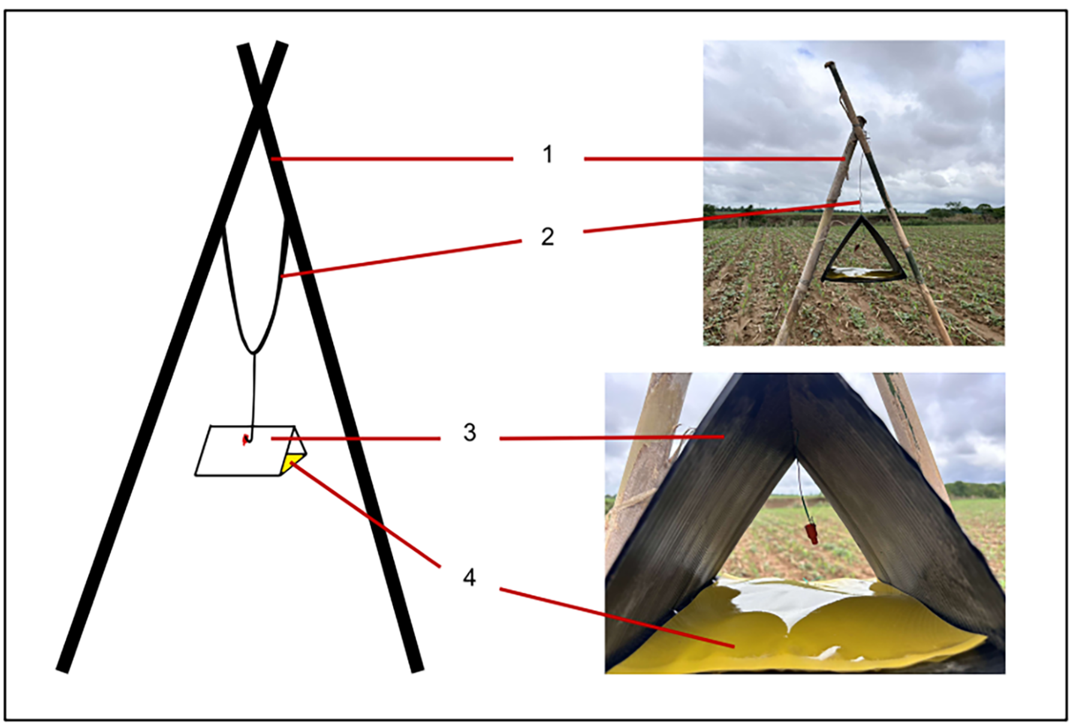

Figure 2. Home-made delta trap baited with commercial sex pheromone lure: [1] a suspended pole about 1.5 m above the ground; [2] twine or aluminum hook for placing the trap and pheromone lure; [3] a corrugated plastic cardboard constructed into a triangular shape (28 cm length x 21 cm width x 16 cm height); [4] yellow sticky trap.

d after planting. Irrigation was done using hollow metal tubes connected to a water supply system. No pesticides were applied and any other agronomic practices such as weeding were done as recommended.

Trap Observations

The efficacy of commercially available sex pheromone lures was assessed during both the dry and wet seasons, with observations and testing conducted until 60 d after planting (DAP) during the dry season and 48 DAP during the wet season. Traps were deployed on 24 and 11 DAP for the dry and wet season trials, respectively. Traps were spaced 18 m x 11.6 m apart. Each plot was situated with a single trap. Traps were inspected every 3 d, and all lures were replaced monthly.

Statistical Analysis

Data obtained for the number of male FAW caught in traps baited with pheromone lures were analyzed separately as a group using the e-statistical software SAS software 3.81 (Enterprise Edition) (SAS Institute Inc. 2012) to perform an analysis of variance to validate the assumption. The least significant difference (LSD) test was utilized to compare the trap at each level of the pheromone lure used and *vice versa*. Maximum likelihood estimation was conducted in Statistical Tool for Agricultural Research or STAR version 2.0.1 to estimate the probability distribution of male FAW catches. A significant p-value rejects the null hypothesis, indicating that there is a statistically significant difference between pheromone lures and trap types and confirming a significant relationship between these variables and the number of male FAW catches.

RESULTS

2022 Dry Season Trial

The total number of FAW males caught for all traps in the 2022 dry season trial was 154 males with a mean of 0.66 male FAW moths per trap per observation date (Figure 3). The number of captures showed a declining trend during 33 and 36 DAP, where the latter appeared to have the highest count in the trial. Following the peak, there was a steep decline in FAW catches, reaching its lowest point at 42 DAP (Figure 4). The overall trend of catches in the dry season exhibited a rapid increase in around 30 DAP. On the other hand, minor peaks were observed at around 45–54 DAP, which indicates a possible pest resurgence. During the peak DAP in the dry season, delta traps baited with BioPhero caught significantly more male FAW moths than those baited with Fall Army-Lure, with a catch of 52 moths (Figure 5). Overall, delta traps baited with BioPhero lures showed the highest capture rate of 2.54 moths per observation date (Table 1). Delta traps captured the greatest number of males compared to bucket traps or the control.

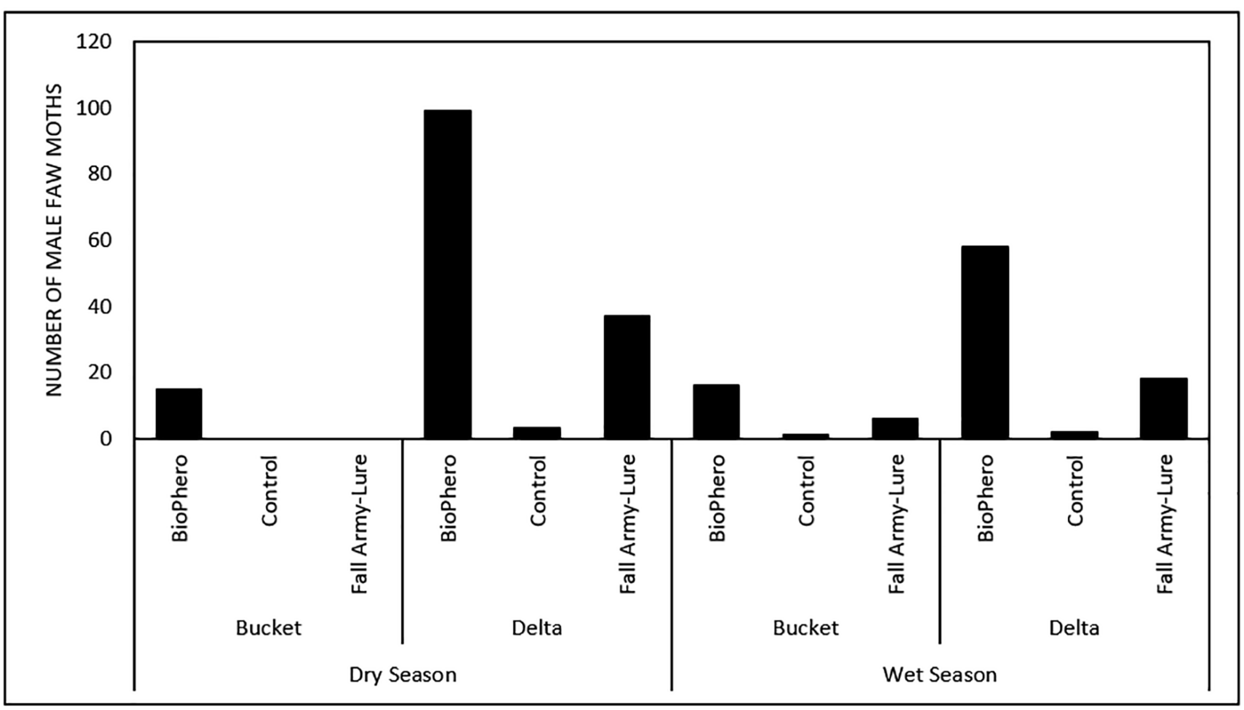

Figure 3. Number of male FAW moths captured by pheromone-baited traps during 2022 dry and wet season trials in Central Experiment Station, UPLB.

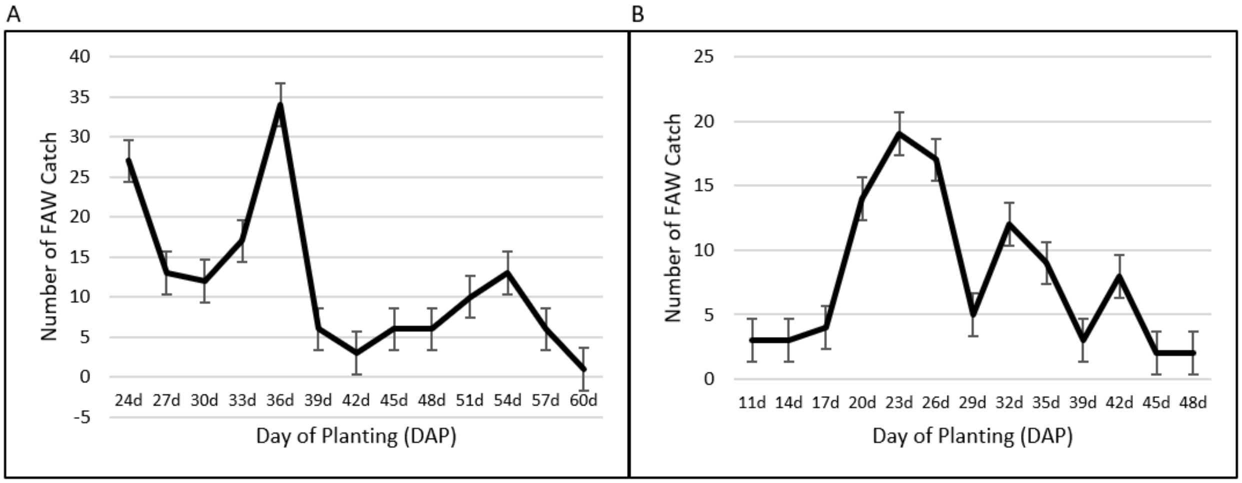

Figure 4. Seasonal variation in the total number (+SE) of male FAW caught on observation dates in Central Experiment Station, UPLB: [A] dry season; [B] wet season.

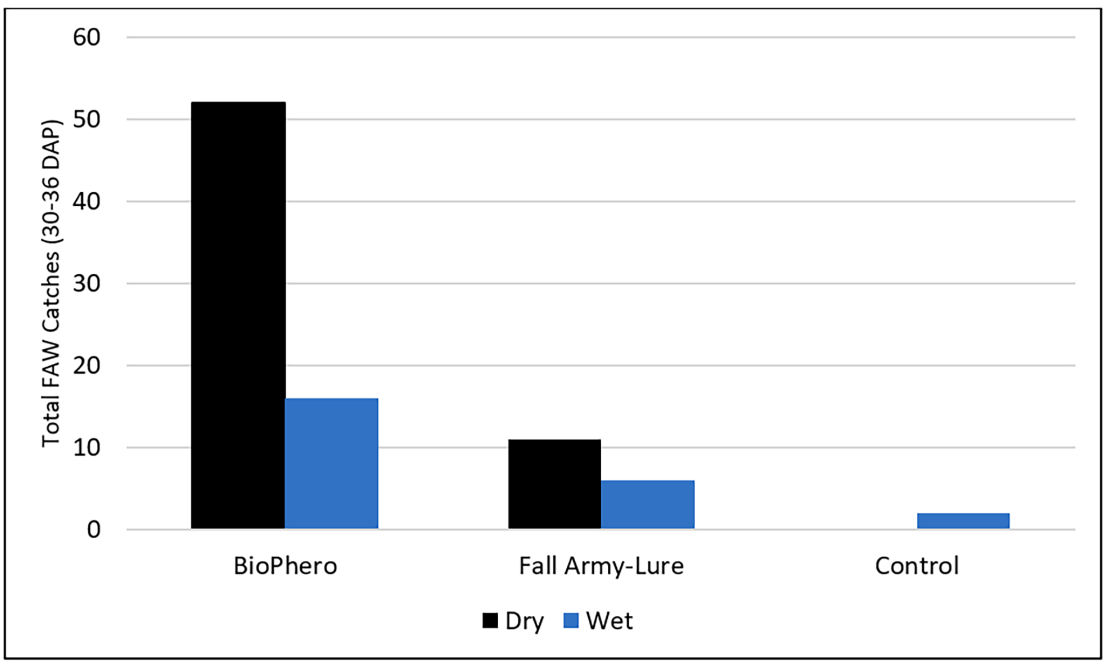

Figure 5. Comparison of FAW catches in the dry and wet seasons across different commercial pheromone lures at peak DAP.

Results showed that different trap designs exhibited significant effects on the number of FAW captures (F = 39.15, $p < 0.0001$). As for the effect of pheromone lures, the results also indicated a significant difference in the number of FAW using pheromone lures from Fall Army-Lure and BioPhero (F = 12.19, $p < 0.0001$). BioPhero lures lead to significantly different mean catches of male FAW than Fall Army-Lure.

The interaction between trap types and lure showed a significant effect (F = 9.60, $p = 0.0001$). In this trial, delta traps have a synergistic interaction when paired with BioPhero lures. The LSD result indicated that this lure significantly affected the mean catches of male FAW, with an average of 1.46 and a variability of ± 2.55.

2022 Wet Season Trial

A similar pattern of captures to that in the dry season trial was observed in the 2022 wet season trial, although the total number of male FAW captured was comparatively lower (101 males; mean catch rate of 0.43 male moths/trap/observation date) than in the previous trial (Figure 3). The peak FAW activity in the wet season occurred later in 23 DAP (Figure 4). The trend showed a similar

Table 1. Mean number of male moths captured per observation date with different combinations of trap design and pheromone lure.

2022 dry season trial		
Trap design	**Pheromone lure**	**Mean ± SE**
Bucket trap	Control	0.00 ± 0.00
	BioPhero	0.38 ± 1.21
	Fall Army-Lure	0.00 ± 0.00
Delta trap	Control	0.08 ± 0.35
	BioPhero	2.54 ± 3.01
	Fall Army-Lure	0.95 ± 1.69
2022 wet season trial		
Trap design	**Pheromone lure**	**Mean ± SE**
Bucket trap	Control	0.03 ± 0.03
	BioPhero	0.41 ± 0.10
	Fall Army-Lure	0.15 ± 0.06
Delta trap	Control	0.05 ± 0.04
	BioPhero	1.49 ± 0.20
	Fall Army-Lure	0.46 ± 0.11

secondary rise in male FAW catches after the initial decline. However, the overall catch in the wet season was relatively low due to environmental factors, which also contributed to the observed fluctuations. The results indicated that the FAW catch rate peaked at approximately 30 to 36 DAP of corn during both the dry and wet seasons (Figure 5). Even at the peak catch rate on the day of planting, the catch with the BioPhero lure was low, which is approximately three times higher in the dry season (Figure 5). Overall, significantly more males were captured in delta traps baited with BioPhero lures. On average, 1.49 male moths were caught in each delta trap baited with BioPhero lures during each observation date (Table 1). This suggests that this trap-lure combination was particularly effective in attracting and capturing male moths, even in the wet season.

In this trial, 75.51% of the total male FAW captured was trapped using the BioPhero lures. Results showed that trap types ($F = 16.78$, $p < 0.0001$) and lure ($F = 22.92$, $p < 0.0001$) used in the field trial significantly influenced FAW capture rates, indicating variability in the total number of captures. The observed variability across different trap types suggests that delta traps may be more effective at capturing FAW. The lure effectiveness is particularly pronounced during the wet season ($F = 22.92$) than in the dry season ($F = 12.19$).

Furthermore, the interaction between trap types and lure also had a notable effect on FAW capture counts during the wet season ($F = 7.10$, $p = 0.0010$). Although the interaction is slightly lower in the wet season as compared to the dry season, it remains statistically significant. A substantial difference was observed in the mean number of male FAW catches depending on trap design. The results showed that the delta trap had a mean catch of 1.18 male FAW (SD = 2.26), whereas the bucket trap had a mean catch of 0.12 male FAW (SD = 0.73). In comparison to the previous trial, traps baited with BioPhero lures captured 1.5 times more in the 2022 dry season trial. Bucket traps had captured the lowest number of males regardless of what lure was used.

DISCUSSION

Trap-Lure Combination

Results showed that delta traps baited with BioPhero lures captured the most male FAW moths in the dry and wet seasons of 2022. There was a noticeable difference in the number of FAWs attracted to each type of pheromone lure when comparing their efficacy. However, the effectiveness of the trap design did not vary significantly depending on the type of pheromone lure used. Among all trap-lure combinations, the delta trap baited with BioPhero significantly exhibited the highest catch rate.

An effective trap and pheromone lure combinations are vital in detecting and monitoring insect pest populations. It is important to consider that while several commercial pheromone lures exist, their efficacy can vary depending on different geographical locations (Batista-Pereira *et al.* 2006; Meagher *et al.* 2019). The efficacy of a particular pheromone lure might be effective in a specific location yet ineffective in others. Studies have shown that the efficacy of the pheromone lures varies on the specific habitat of FAW (Sisay *et al.* 2024). In practical application, the combinations of traps and lures can differ depending on location. Hence, it is crucial to conduct field tests of trap-lure combinations in unmonitored areas to evaluate their specificity (Meagher *et al.* 2019).

The damage observed in the field is a direct indication of increasing FAW populations. With FAW populations and reports of field damage continuing to increase, the optimization of different trap-lure combinations is maximized once the trap installation is properly executed, along with other factors such as maintenance and trap placement. The primary purpose of pheromone traps is to directly monitor FAW populations in the field and assess their infestation level, thus it is crucial to install traps as early as the planting stage of corn because FAW moths tend to attack corn seedlings, which are highly vulnerable to FAW damage (Cruz *et al.* 2012). The Food and Agriculture Organization of the United Nations also recommends placing the pheromone traps immediately after planting and monitoring should be done as soon as the seedlings emerge to detect the first arrival of FAW (FAO 2018b). This recommendation is a requisite in monitoring strategies because *S. frugiperda* adults typically lay eggs during the vegetative stage between 7–45 DAP (Lestari *et al.* 2024).

In our study, however, the installation of pheromone traps occurred later – specifically at 24 and 11 DAP during the dry and wet seasons, respectively. This may have limited the detection of FAW infestations during the early stages of corn development. Nevertheless, our findings suggest that a decreasing trend in FAW catch rate is likely due to their lower oviposition preferences for matured corn plants (Sisay *et al.* 2024). For an effective trap-lure combination, it must be set up at the start of planting when seedlings are prone to pest damage.

The distinct trends of FAW catch during the dry and wet seasons differ in the intensity of peak catches. The present study revealed that the catch rate of FAW in the dry season was more pronounced in the wet season. Despite this difference, the FAW catch rate during the peak range of 30–36 DAP showed a consistent pattern across both the dry and wet seasons. The consistency in the timing of peak catches suggests that FAW activity is strongly associated with the phenological stages of corn within this DAP range. This period of corn corresponds to the V5–V6 stage (vegetative). The incidence of FAW during this stage is likely due to the preference of FAW larvae for the early vegetative stage of corn (FAO 2018a). The alignment of FAW activity with these stages suggests the need for synchronized pheromone trap deployment to effectively monitor FAW populations.

Aside from the timing of trap placement, it is also important to determine the appropriate number of pheromone traps for a specific area. The general recommendation from the FAO suggests using one trap for every 0.5–2 ha. For similar noctuid species like *Spodoptera exigua*, Lestari *et al*. (2020) recommended three traps per 2,000 m^2. Meanwhile, Firake *et al*. (2019) suggested installing five traps per acre for regular monitoring of *S. frugiperda*. A more recent study by Bhimani *et al*. (2023) concluded that a trap density of 50 pheromone traps/ha was optimal for managing FAW.

The latter study aligns closely with the recommendations for commercially available pheromone lures in the Philippines, which suggest installing 45 traps/ha at 20–25-me intervals. However, the standardization of trap density must be explored. Further studies are needed to determine the ideal trap density at a specific area, in consideration of the variability in trap designs, composition of pheromone lures, and pest pressure.

Trap Performance

Delta traps in the field trials consistently caught more moths compared to bucket traps. A study has hypothesized that sticky traps – a delta trap in this regard – have an adequate retention efficiency compared to water traps because "insects must fall through the funnel in order to be caught, whereas in a sticky trap, the insect only has to contact the large sticky surface directly below the lure" (Athanassiou *et al.* 2007; Whitfield *et al.* 2019). Another consideration as to why delta traps successfully captured more male moths in this study is the influence of population density. At low population densities, delta traps may perform better due to their retention efficiency, but with such higher population densities, bucket traps can capture more because of their higher maximum capacity (Whitfield *et al.* 2019).

Comparing its efficiency, results suggested that the delta trap is an efficient and effective trap suited for pest monitoring and surveillance against the Philippine population of FAW. A study regarding trap efficiency was conducted by Lewis and Macaulay (1976), asserting that delta traps aligned crosswind captured 40% more male pea moths. They also compared a delta and an "omni-directional" water trap for efficiency and found that delta traps significantly captured more moths than water traps (Carde *et al*. 2017).

Contrastingly, several studies have suggested that bucket traps, a trap captured only a few FAW male moths in our study, are effective traps for most invasive moth pests. Mainly, bucket traps are cost-efficient and easy to handle. It also offers high trap density and can withstand inclement weather conditions (Spears *et al.* 2016). Guerrero and co-authors (2014) also argued that sticky traps only capture a limited number of moths, thus not maximizing the capture potential of the trap. In the previous study by Meagher and colleagues (2019), they reported that bucket traps capture more moths than delta traps.

The use of home-made traps in this study addresses resource-constrained pest monitoring strategies. Unlike commercial traps, which are often less accessible and expensive, home-made traps provide a cost-effective and practical alternative that can easily be assembled and scaled for use in different locations. This also offers flexibility in design and materials, which can be tailored to the target pest. For instance, in this study, delta traps were made from corrugated plastic cardboard, which often does not require constant maintenance and can effectively monitor low populations of FAW. The reason for trap design contradictions is still unclear, but such differences might contribute from several factors including their behavior, ecology, and environmental conditions.

The difference in FAW catches between dry and wet seasons is attributed to variations in the population dynamics of FAW influenced by seasonal changes. In our study, more male moths were captured during the dry season compared to the wet season, which supports the hypothesis that warmer temperatures contribute to the development of *S. frugiperda* populations (Nagoshi and Meagher 2004; Baloch *et al.* 2020). Several studies have suggested that the increase in rainfall can reduce FAW populations by filling the whorls with water, thus forcing the larvae to abandon the whorls (Garcia *et al.* 2017; Early *et al.* 2018; Canico *et al.* 2020). The excessive rain can reduce its abundance by washing the egg masses and larvae, consequently affecting the pest population. So, under the Philippine climatic conditions, FAW can infest corn plants throughout the year, but infestations may tend to be more apparent during the dry season.

Our findings align with the notion that climatic conditions influence pest density within a given region. However, the effects of temperature on trap catches were not conclusive in this study, as the peak abundance of FAW populations varies in geographical locations, corn growth stages, and other abiotic factors. In this case, only one location was tested.

Attractiveness of the Lure Formulation

The pheromone lures used in the study contained active components derived from the pheromone gland of female FAW. The Fall Army-Lure contained (Z)-9-tetradecenyl acetate, the main component extracted from the pheromone gland. On the other hand, BioPhero consisted of (Z9, E12)-9,12-tetradecadien-1-ol acetate.

The findings from previous studies suggest that (Z)-9-tetradecenyl acetate was an effective sexual stimulant, yet it did not function as a long-range attractant for FAW males (Mitchell and Doolittle 1976; Hirai and Mitchell 1982). The (Z9, E12)-9,12-tetradecadien-1-ol acetate is commonly present in pheromone compounds of several moth species, including beet armyworm moths and pyralid moths (Ma *et al.* 2014). The report of Ma and team (2014) suggests that (Z9, E12)-9,12-tetradecadien-1-ol acetate is a powerful lure when applied to a rubber septum at 200-µg dosage and can serve as a practical lure for monitoring and trapping.

The effectiveness of the lure formulation can be influenced by species-specific responses of insect pests. An avenue for optimizing commercial pheromone lures involves strategic lure usage. It remains unknown whether (Z9, E12)-9,12-tetradecadien-1-ol acetate is a component of pheromone compounds emitted by the female FAW or only serves as a precursor compound. The FAW pheromone composition shows some resemblance to both commercial lures, but delta traps baited with BioPhero exhibited the highest result.

CONCLUSION

Trap design and the effectiveness of lures have a significant effect on the overall performance of the trap – whether by estimating the likelihood catch rate or by simply monitoring pest population densities. It is important to note that not all commercially available pheromone lures are the same. A direct comparison cannot be made regarding which lure is better because they differ in composition and percentages, and have been tested in one specific location. It is essential to assess these lures in different locations with high FAW populations.

In conclusion, this study provides a practical understanding of suitable home-made trap designs and pheromone lures for monitoring FAW. We recommend using delta and bucket traps for monitoring low and high FAW population densities, respectively. It is acceptable to employ both traps, especially for initial monitoring purposes. Further chemical analysis with pheromone gland extracts is needed to determine the pheromone components of the Philippine population of FAW. This could be used for substantial assessment of trap selectivity for surveillance and monitoring of FAW. Thus, pheromone trap performance should be evaluated periodically to validate lure attractancy.

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