J. Trop. Plant Pests Dis.
Vol. 26, No. 1, March 2026
Pages: 237–246

ISSN: 1411-7525
E-ISSN: 2461-0399
DOI : 10.23960/j.hptt.126237-246

RESEARCH PAPER

Pheromone-based monitoring and population dynamics of *Spodoptera frungiperda*: implications for maize IPM in Lampung Province, Indonesia

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Manuscript received: 24 August 2025. Revision accepted: 2 October 2025. Available online: 14 February 2026.

ABSTRACT

Spodoptera frugiperda is a major pest of maize, capable of causing damage throughout all crop growth stages. This study evaluated the use of sex pheromone traps to monitor adult male populations of *S. frugiperda*, characterize population dynamics during maize growth, and determine optimal trap density under field conditions. A trap density experiment was conducted using four pheromone trap densities (10, 20, 30, and 40 trap/ha^{-1}), each replicated five times. Adult moth captures were recorded at 7-day intervals from trap installation until harvest. In a separate assessment, the intensity of leaf and ear damage was compared between maize plots equipped with pheromone traps and conventional plots without pheromone deployment. Adult capture data revealed clear population fluctuations, with peak abundance occurring during the early vegetative stage of maize, followed by a gradual decline toward harvest. Increasing trap density significantly increased the number of male moths captured, indicating a density-dependent response to pheromone deployment. Maize plots with pheromone traps consistently exhibited lower leaf and ear damage than conventional plots, demonstrating a strong association between reduced adult populations and decreased crop injury. These results indicate that pheromone traps are effective tools for monitoring *S. frugiperda* populations and for identifying critical intervention periods within an integrated pest management (IPM) framework. While primarily serving as monitoring devices, higher trap densities also showed potential to reduce mating success when deployed over sufficiently large areas. The species-specific nature of pheromone traps further supports environmentally sustainable pest management by minimizing non-target effects.

Keywords: Crop damage, IPM, mass trapping, pheromone, *Spodoptera frugiperda*

INTRODUCTION

Maize (*Zea mays* L.) is a strategic food and feed crop essential to national food security systems. In Indonesia, however, maize production has been under persistent pressure from the fall armyworm (*Spodoptera frugiperda* J.E. Smith; Lepidoptera: Noctuidae), an invasive insect pest that rapidly achieved major pest status following its first detection in West Sumatera in 2019 (Lubis et al., 2020). During the early invasion phase, widespread infestations were reported across major maize-producing regions, including Lampung Province and West Java (Trisyono et al., 2019; Lestari et al., 2020; Maharani et al., 2019; Sartiami et al., 2020). The pest's high dispersal ability, long-distance migratory behaviour, rapid reproductive capacity, and broad host range facilitate frequent population outbreaks and highly unpredictable infestation dynamics (Nonci et al., 2019; Montezano et al., 2018; Hruska, 2019; Srikanth et al., 2018; Song et al., 2020). In Lampung Province alone, early infestation levels reached as high as 79.12% (Lestari et al., 2020). Feeding damage during the vegetative stage results in severe leaf injury and disrupted plant growth (Trisyono et al., 2019), leading to substantial yield losses (Navik et al., 2021).

In many affected regions, the predominant and often immediate response to *S. frugiperda* outbreaks remains the use of chemical insecticides (Tambo et al., 2020). However, intensive and repeated insecticide applications increase the risks of resistance development, pest resurgence, disruption of natural

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enemy populations, and escalating production costs (Matova et al., 2020; Day et al., 2017). This heavy reliance on chemical control reflects limitations in pest surveillance and decision-making systems, where management actions are frequently driven by perceived pest presence rather than quantitative assessments of actual population pressure. Within the framework of Integrated Pest Management (IPM), accurate and timely detection of pest population fluctuations is therefore essential to ensure that control interventions are both effective and environmentally sustainable (Deguine et al., 2021).

Pheromone-based trapping has emerged as a promising approach for monitoring and managing *S. frugiperda* populations. The successful incorporation of pheromone traps into IPM programs has been reported in several regions, including parts of Africa and India (Sisay et al., 2024; Londhe et al., 2024). Synthetic sex pheromones that mimic female-emitted chemical signals attract male moths with high specificity, making trap captures a reliable indicator of reproductive activity and real-time population dynamics in the field (Liu et al., 2025; Sisay et al., 2024). Analysis of temporal patterns in adult captures enables the identification of population peaks, improved prediction of subsequent larval infestations, and more accurate estimation of crop damage risk (Ahissou et al., 2022). When deployed at sufficient spatial scales, pheromone traps may also contribute to population suppression through mass trapping, thereby complementing chemical and biological control strategies within an IPM framework.

Despite substantial evidence supporting their effectiveness, the use of pheromone traps in Indonesian maize agroecosystems remains limited, fragmented, and insufficiently standardized. Empirical studies that explicitly link pheromone-based monitoring data with field-level population dynamics and crop damage across maize growth stages are still scarce. As a result, pheromone trap data have not been fully exploited to establish economic thresholds or to optimize the timing of insecticide applications. Strengthening the scientific basis for pheromone-based management requires determining effective trap densities and clarifying how capture patterns correspond to adult population peaks and subsequent crop injury. Integrating trap-derived population indicators with plant damage assessments can provide a more refined understanding of critical infestation periods, thereby enabling more selective, timely, and resource-efficient control measures. Given these advantages, pheromone traps have considerable potential as a core component of sustainable IPM strategies for *S. frugiperda*, particularly in major maize-producing regions such as Lampung Province. Therefore, this study aimed to evaluate the effectiveness of pheromone traps in monitoring *S. frugiperda* population dynamics and their relationship with crop damage across maize growth stages, as well as to assess their potential contribution to population suppression under field conditions in support of evidence-based integrated pest management.

MATERIALS AND METHODS

Research Site. Field experiments were conducted over two maize growing seasons, namely April–June 2024 and February–May 2025, in farmers' maize fields located in East Lampung Regency (5.08383715° S; 105.41730178° E) and South Lampung Regency (5°22′48″ S; 105°23′55″ E), Lampung Province, Indonesia. Each study site consisted of a 5-ha maize field. These locations were selected because they represent major maize-producing areas and are known to be endemic to *S. frugiperda* infestations.

Materials. The pheromone used in this study was a commercial sex pheromone lure for *S. frugiperda* (FAW BB LURE), produced by PT Agritek Mitra Tani Indonesia and commercially available through online marketplaces. The lure is specifically formulated to attract adult male *S. frugiperda* moths. Bucket traps were used for pheromone deployment. These traps consisted of cylindrical yellow plastic containers with lids, approximately 20 cm in diameter and 25 cm in height. Each trap was composed of an upper chamber for pheromone placement and a lower chamber containing 500 mL of water mixed with 1–5 mL of cooking oil to retain captured moths.

Treatments and Experimental Design. This study comprised two interrelated experiments conducted within an IPM framework. The first experiment aimed to determine the optimum pheromone trap density required for effective monitoring of *S. frugiperda* populations in maize fields. The second experiment evaluated adult population dynamics and maize damage in fields equipped with pheromone traps compared with fields without traps (control), in order to assess the potential of pheromone-based trapping as an environmentally friendly IPM component for reducing infestation levels and crop damage.

Trap Density Determination. The trap density experiment was conducted in East Lampung Regency from April to June 2024 using a Randomized Complete

Block Design (RCBD). Four pheromone trap density treatments were evaluated, each replicated five times T1= 10 traps/ha, T2 = 20 traps/ha, T3 = 30 traps/ha, T4 = 40 traps/ha. Each experimental unit covered approximately 0.2 ha, with traps installed at an inter-trap distance of approximately 17 m. Trap density was defined as the number of pheromone traps installed per hectare. The selected density range represented low to high deployment levels commonly considered in IPM programs, enabling evaluation of both biological effectiveness and practical cost efficiency.

Population Monitoring and Damage Assessment. Population monitoring and damage assessment were conducted from February to May 2025 in both East Lampung and South Lampung Regencies. At each location, five plots measuring 25 m × 25 m were established and equipped with pheromone traps at a density of 30 traps/ha, based on the results of the trap density experiment. In addition, control plots without pheromone traps were established solely for comparison of plant damage intensity and ear damage, and were not used for moth population monitoring.

Trap Installation and Maintenance. Pheromone traps were installed on the same day as maize sowing. Bamboo poles approximately 3 m in height were used to suspend the bucket traps, with each pole inserted about 50 cm into the soil to ensure stability. Traps were positioned at the height of the maize canopy and adjusted periodically to accommodate plant growth (Figure 1). The pheromone lure was attached to a hook on the inner side of the bucket lid. Lures were initially installed at the beginning of the experiment. Under high-temperature field conditions, lure replacement was conducted when a noticeable decline in moth captures was observed. When replacement was necessary, it was performed simultaneously across all experimental units to ensure consistency.

Observation of *S. frugiperda* Moth Population. The first observation was conducted at 7 days after sowing (DAS), followed by weekly observations until the crop approached harvest. The number of *S. frugiperda* moths captured in each trap was recorded for each plot. Control plots without pheromone traps were excluded from moth population analysis, as they did not provide trap catch data.

Assessment of Leaf Damage Intensity. Leaf damage assessments were carried out to evaluate the effect of pheromone trap deployment on *S. frugiperda* infestation. Observations were conducted on 20 randomly selected plants per plot at 25 and 45 DAS, corresponding to vegetative growth stages when foliar injury was most apparent. Damage severity was scored using the modified scale of Davis et al. (1992) (Table 1; Figure 2). Damage Intensity (DI) was calculated using the following formula:

$$DI\,(\%) = \frac{(\sum n_i \times v_i)}{N \times Z} \times 100\%$$

DI = Disease intensity (%);
ni = Number of plants at score v;
vi = Damage severity score value;
N = Total number of observed plants;
Z = The highest damage score.

Assessment of Ear Damage. Ear damage assessment was conducted at 70 DAS on 20 sample plants per plot. The percentage of damaged ears was calculated as follows:

$$IR\,(\%) = \frac{n}{N} \times 100\%$$

IR = Infestation rate (%);
n = Number of damaged maize ears;
N = Total number of observed plants.

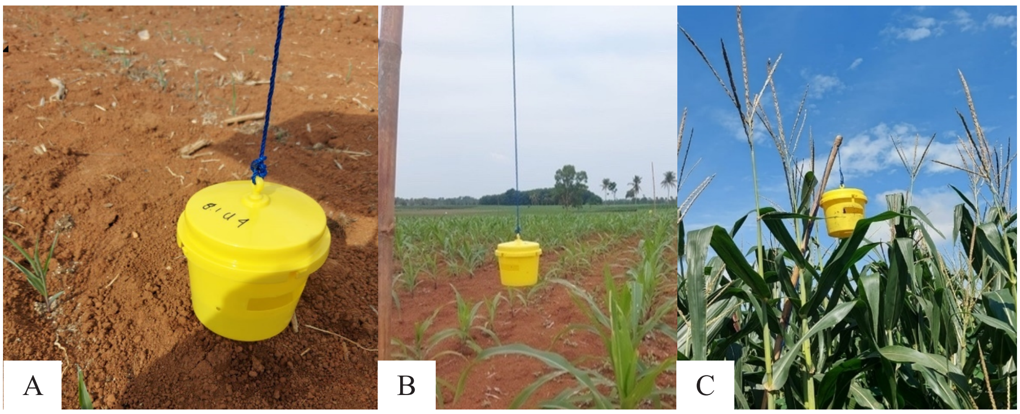

Figure 1. Installation of bucket traps at different maize growth stages. A. Maize at 7 days after sowing (DAS); B. Maize at 25 DAS; C. Maize at 70 DAS.

Table 1. Leaf damage scores caused by *S. frugiperda* feeding, based on Davis et al. (1992)

Definition of damage	Score
No visible leaf damage.	0
Only pin-hole damage.	1
Pin-hole and small circular hole damage to leaves.	2
Pinholes, small circular lesions and a few smaal elongated (rectangular shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves.	3
Several small to mid-sized 1.3 to 2.5 cm in length elongated lesions present on a few whorl and furl leaves.	4
Several large elongated lesions greater than 2.5 cm in length present on a few whorl and furl leaves and/or a few small to mid-sized uniform to irregular shaped hole (basement membrane consumed) eaten from whorl and/or leaves.	5
Several large elongated lesions present on several whorl and furl leaves and/or several large uniform to irregular shaped hole eaten from whorl and/or leaves.	6
Many elongated lesion of all sizes present on several whorl and furl leaves plus several large uniform to irregular shaped hole eaten from the whorl and furl leaves.	7
Many elongated lesion of all sizes present on most whorl and furl leaves plus many mid-sized to large uniform to irregular shaped hole eaten from the whorl and furl leaves.	8
Whorl and furl leaves almost totally destroyed.	9

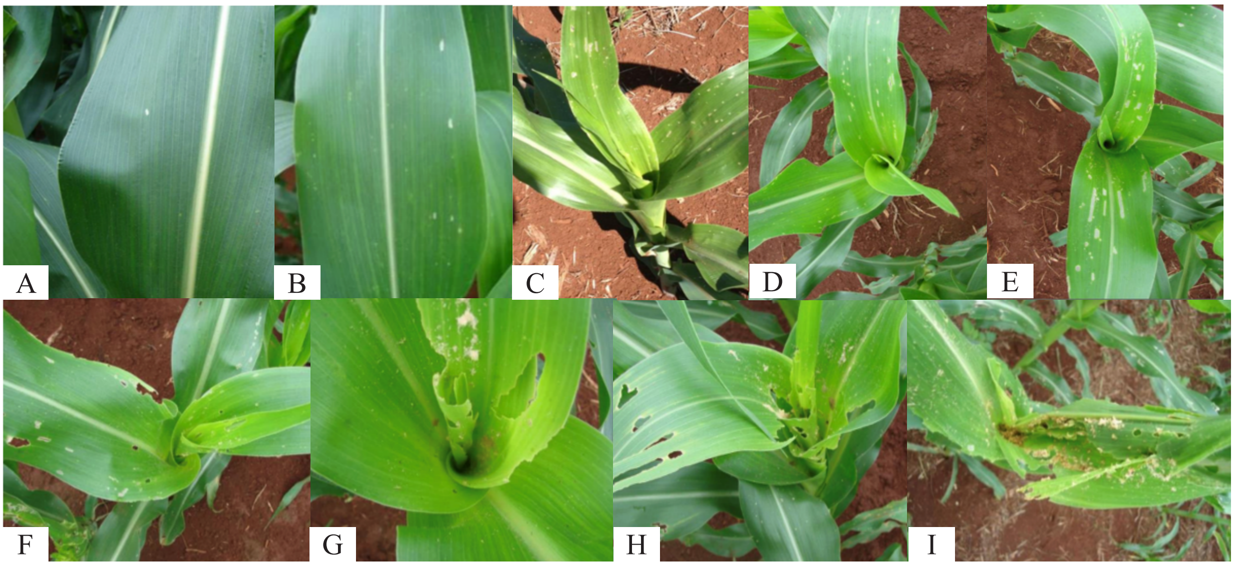

Figure 2. Visualization of leaf damage scores based on the Davis et al. (1992) scale. A. Score 1; B. Score 2; C. Score 3; D. Score 4; E. Score 5; F. Score 6; G. Score 7; H. Score 8; I. Score 9.

Data Analysis. Moth catch data were tested for normality and homogeneity of variance prior to statistical analysis. Data were then analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level. Leaf damage intensity and ear damage data were analyzed by comparing pheromone-treated plots and control plots using an independent *t*-test. Control plots were included only in damage analyses and were excluded from moth population analyses.

RESULTS AND DISCUSSION

Optimum Trap Density for Monitoring and Potential Suppression of *S. frugiperda*. Analysis of variance revealed a significant effect of pheromone trap density on the number of *S. frugiperda* moths captured. Adult moth catches increased with increasing trap density per plot, indicating a positive behavioral response of male moths to greater availability of pheromone sources. Higher trap densities therefore resulted in greater removal of adult males from the population. However, no statistically significant difference was observed between densities of 30 and 40 traps/ha (Table 2), suggesting that increases in trap density beyond a certain threshold provide diminishing returns in capture efficiency.

A similar trend was observed for plant damage intensity. Increasing trap density was consistently associated with lower damage intensity values across observation periods, reflecting reduced feeding pressure. Although the lowest damage intensity was recorded at 40 traps/ha, it did not differ significantly from that observed at 30 traps/ha (Table 3). In this study, damage intensity was used as a proxy for infestation level, as the number of infested plants was not directly quantified. Given that fall armyworm larvae typically infest individual maize plants, damage intensity provides a reasonable estimate of larval feeding pressure, although it may not fully capture variation in the number of infested plants. Taken together, these results indicate that a deployment rate of 30 traps/ha represents an optimal balance between biological effectiveness and practical feasibility.

The effectiveness of pheromone-based control is influenced not only by trap density but also by lure composition, trap height, and trap design (Kong et al., 2014; Sisay et al., 2024). Recent advances, including the incorporation of nano-additives into pheromone formulations, have been shown to improve lure stability and substantially enhance capture efficiency (Liu et al., 2025). Increased male capture is a key indicator of potential population suppression, as reduced male availability limits mating success and subsequent larval recruitment. Comparable findings have been reported in other studies, where sufficiently high trap densities led to significant reductions in adult abundance and, consequently, lower larval infestation and crop damage in subsequent generation (Madhu et al., 2019; Colacci et al., 2022).

From a practical perspective, these results highlight two key implications: first, increasing trap density improves both monitoring sensitivity and the effectiveness of mass trapping; and second, exceeding an optimal deployment threshold yields limited additional biological benefits, emphasizing the importance of cost–benefit considerations when designing pheromone-based management strategies.

Seasonal Population Dynamics of *S. frugiperda* in Maize Fields. Pheromone trap captures revealed a clear temporal pattern of *S. frugiperda* moth activity at both East Lampung and South Lampung sites (Figure 3). Adult captures increased rapidly during the early vegetative stage of maize, peaked between 14 and 35 DAS, and then declined gradually toward harvest. This trend reflects synchronized adult flight activity during early crop growth, followed by reduced activity as maize plants reached later developmental stages.

Table 2. Number of *S. frugiperda* moths captured per pheromone trap at different trap at different trap densities in maize fields in East Lampung, Indonesia

Trap densities/ha	Mean of trapped moth
10	6.80 a
20	15.98 b
30	20.09 bc
40	22.26 c

Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

Table 3. Effect of trap density on mean damage intensity (%) at maize at 25 dan 45 DAS

Trap density (Traps/ha)	Mean of damage intensity (%)	
	25 DAS	45 DAS
10 traps/ha	30.60 b	31.60 c
20 traps/ha	25.60 ab	25.20 b
30 traps/ha	24.60 ab	24.00 ab
40 traps/ha	22.60 a	21.00 a
No trap (Control)	46.80 c	36.40 d

Value followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. DAS = Day after sowing.

This results indicate that *S. frugiperda* populations are most active during the vegetative growth stage of maize, particularly when young leaves are abundant. At this stage, maize plants provide favorable oviposition sites and optimal feeding conditions for early instar larvae (Nonci et al., 2019; Navik et al., 2021). Similar temporal dynamics have been reported by Sisay et al. (2024), who observed peak pheromone trap captures during the vegetative phase of maize development.

Climatic conditions further influence *S. frugiperda* population dynamics. Lestari et al. (2024a) reported that populations in Lampung Province tend to increase at the onset of the rainy season, a pattern closely associated with the predominantly rainfed maize cropping system in the region. Under such conditions, pheromone-based monitoring becomes an essential component of IPM. Trap-derived data facilitate the identification of critical intervention windows, particularly between 14 and 35 DAS, when adult populations are actively reproducing. This information supports threshold-based and preventive management approaches, reducing reliance on calendar-based insecticide applications (Liu et al., 2025).

In the present study, traps were installed at canopy height, corresponding to the typical flight height of adult *S. frugiperda*. The frequent observation of egg masses on young leaves supports the assumption that mating and oviposition occur primarily within the crop canopy. Consequently, early-season peaks in adult captures indicate periods of high mating activity and elevated risk of subsequent larval infestation. Disruption of mating during this critical period through pheromone deployment can effectively suppress larval populations in the following generation, a mechanism commonly described as mating disruption (Akter et al., 2025).

Effects of Pheromone Trap Deployment on Leaf Damage Intensity. Leaf damage assessments conducted at 25 and 45 DAS showed significantly lower damage intensity in plots equipped with pheromone traps compared with untreated plots at both study locations (Table 4). At 25 DAS, damage intensity in pheromone-treated plots ranged from 12.67% to 17.78%, whereas untreated plots exhibited damage levels exceeding 44%. This pattern persisted at 45 DAS, with treated plots maintaining substantially lower damage intensity than control plots.

The reduced damage intensity observed in pheromone-treated plots can be attributed primarily to decreased mating success, which leads to lower egg deposition and, consequently, reduced larval

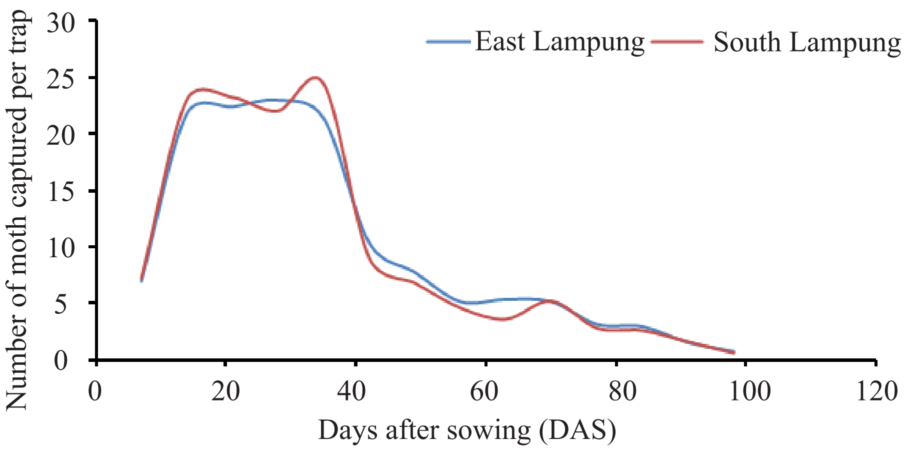

Figure 3. Temporal pattern of *S. frugiperda* moth flight activity based on pheromone trap captures.

Table 4. Leaf damage intensity (%) of maize caused by *S. frugiperda* in plots with pheromone traps and without traps (control) at two observation times and locations

Observation time	Location	Mean ± SD		*t* value	*p* value
		Pheromone trap	Control		
25 DAS	East Lampung	12.67 ± 3.67	44.67 ± 10.08	6.67	0.0006
	South Lampung	17.78 ± 4.60	44.78 ± 8.17	6.44	0.0003
45 DAS	East Lampung	19.80 ± 4.32	53.1 ± 5.71	10.36	0.0000
	South Lampung	18.40 ± 4.68	51.3 ± 6.76	8.93	0.0000

DAS = day after sowing.

infestation. The increasing divergence in damage intensity between treated and untreated plots at 45 DAS suggests that early-season suppression of adult populations has cumulative effects on larval pressure over time. Lower larval densities during early vegetative stages therefore translate into progressively reduced plant damage during later growth phases.

These findings are consistent with previous studies demonstrating that pheromone-based strategies can significantly reduce foliar damage by disrupting mating and limiting population growth (Meagher & Nagoshi, 2013; Sisay et al., 2024; Londhe et al., 2024). The results further confirm the effectiveness of pheromone traps as a non-chemical component of IPM programs for *S. frugiperda* management.

Effect of Pheromone Traps on Ear Damage Incidence. A similar protective effect was observed for ear damage, with pheromone-treated plots exhibiting significantly lower percentages of damaged ears compared with untreated plots at both locations (Table 5). Because *S. frugiperda* can infest maize at multiple developmental stages, reductions in early vegetative damage are likely to contribute to lower levels of ear infestation later in the season (Sisay et al., 2019; Dessie et al., 2024).

The relationship between adult moth captures and subsequent plant damage underscores the value of pheromone traps not only as a control tool but also as a decision-support system. Temporal variation in adult captures provides early warning of population peaks, enabling more precise timing of supplementary control measures, including targeted insecticide applications, in accordance with IPM principles.

An additional advantage of pheromone-based technologies is their high specificity to the target pest, which minimizes adverse effects on non-target organisms and natural enemy populations. This selectivity allows biological control agents to remain active alongside pheromone-based interventions. In Indonesia, several parasitoids and other natural enemies of *S. frugiperda* have been reported (Lestari et al., 2024b), highlighting the strong potential for integrating pheromone trapping with biological control strategies.

Implications for Integrated Pest Management. Beyond direct reductions in crop damage, pheromone traps offer several advantages within IPM systems. Their high target specificity minimizes disruption to non-target organisms, enabling natural enemies to persist and contribute to long-term pest regulation. In Indonesia, parasitoids such as members of the families Ichneumonidae and Tachinidae have been identified as important natural enemies of *S. frugiperda* (Lestari et al., 2024b). TThe compatibility of pheromone trapping with biological control further underscores its value in sustainable pest management programs.

Overall, the results indicate that deploying pheromone traps at an optimum density of approximately 30 traps/ha provides reliable monitoring of adult *S. frugiperda* populations and is associated with significant reductions in both leaf and ear damage. These findings reinforce the role of pheromone-based monitoring as a decision-support tool rather than a standalone control method, in line with contemporary IPM principles that emphasize early detection, targeted intervention, and environmental safety.

CONCLUSION

Pheromone traps proved to be an effective monitoring tool for *S. frugiperda* within an IPM framework in maize fields. Adult male activity peaked during the early vegetative stage of maize (14–35 DAS), identifying this period as a critical window for population monitoring and for supporting timely, threshold-based management decisions. Increasing trap density resulted in higher total moth captures; however, capture efficiency reached a plateau at densities exceeding 30 traps/ha. Accordingly, a deployment rate of approximately 30 trap/ha can be considered optimal for population monitoring, providing an effective balance between biological performance and practical feasibility. Although larval populations were not directly quantified, the consistently lower levels

Table 5. Percentage of maize ear damage caused by *S. frugiperda* in plots with pheromone traps and without traps (control) at 70 DAS in two locations

Location	Mean ± SD		*t* value	*p* value
	Pheromone trap	Control		
East Lampung	9.00 ± 4.18	25 ± 14.14	2.42	0.0298
South Lampung	12.00 ± 7.58	28 ± 5.70	3.77	0.0034

DAS = Day after sowing.

of foliar and ear damage observed in pheromone-treated plots indicate that pheromone traps contribute to improved crop protection when integrated into IPM strategies. The species-specific nature of pheromone lures allows precise intervention timing while remaining compatible with natural enemy conservation, reinforcing their value as a sustainable component of *S. frugiperda* management in maize agroecosystems.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Institute for Research and Community Service, University of Lampung, for funding this study through the 2024 BLU Research Grant.

FUNDING

This research was funded by the Institute for Research and Community Service, University of Lampung, under the 2024 BLU Research Grant scheme.

AUTHORS' CONTRIBUTIONS

All authors contributed to the conception, implementation, data collection, analysis, and preparation of the manuscript.

COMPETING INTEREST

The authors declare that they have no competing interests.

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