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The Potential Use of Pheromone Traps in Managing the Invasive Pest *Spodoptera frugiperda*

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Authors' contributions

This work was carried out in collaboration among all authors. The study was designed by SSL and DBG authors. Author SSL is responsible for the experiments, and data collection. Author MDG helped in writing the manuscript. Author DBG provided oversight and supervised research work. All authors reviewed and approved the manuscript.

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ABSTRACT

The *Spodoptera frugiperda* invasive pest was first reported in Karnataka in the year 2018 and now 2024 it has spread all over India. Commonly known as the fall armyworm, it is a destructive pest that affects a wide range of crops, particularly maize (corn), but also sorghum, rice, cotton, and various vegetable crops. Agricultural insect pest management is heavily reliant on synthetic pesticides, which do not accomplish long-term pest population reductions, particularly in areas with

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warm climates and extended growing seasons whereas continuous long-term pheromone-based control reduces population levels of targeted pest species. The lure for lepidopterans is generally based on the sex pheromone emitted by females Mating disruption, monitoring, and mass trapping are the major techniques of lepidopteran pest management that use female sex pheromones and they can be utilized alone, as in mating disruption or mass trapping, or in conjunction with pesticides, entomopathogens, and sterilants. In the experimental design, different densities of pheromone traps were used against *Spodoptera frugiperda* for monitoring pest populations in the study area.

By using different densities of pheromone traps, it was discovered that at trap densities of 8, 16, 24, 32, and Control, the Spodoptera frugiperda infection in maize crops was 61%, 51%, 30%, 10%, and 91.25%. The 10% infestation result lowest in maize crop with pheromone traps was an effective component of integrated pest management and often used in conjunction with other control methods such as biological control agents, cultural practices, and selective pesticide applications to manage fall armyworm populations sustainably and effectively.

The results showed that the percentage of fall armyworm infestation in maize crops dropped as pheromone trap densities increased. The F-test Two Sample for Variance indicated that there was a significant difference in FAW infestations between the trap densities (F = 13.05, P <0.01446) and F critical one tail 6.3882. This suggests that pheromone traps could be useful for monitoring fall armyworm males in the Maharashtra district of Nashik.

Keywords: Pheromone traps; Invasive pest; Spodoptera frugiperda; pest monitoring; fall armyworm; monitoring; densities; sex pheromone lure.

ABBREVIATIONS

FAW	*: Fall Army Worm*
VE	*: Emergence*
V2 – V4	*: 2-4 Leaves Fully Emerged*
V5 – V7	*: 5-7 Leaves Fully Emerged.*
V8 – V11	*: 8-11 Leaves Fully Emerged*
V12 – V15	*: 12-15 Leaves*
R1 – R2	*: Tasselling/Silking Fully Formed*
R3	*: Maturity (Drying)*
H	*: Harvest*
Ha	*: Hector*
IPM	*: Integrated Pest Management*
Z9-14Ac	*: Z-9-tetradecen- 1-ol Acetate*
Z7-12Ac	*: Z-7-dodecen1-ol Acetate*
Z9-12Ac	*: Z-9-dodecan-1-ol Acetate*
Z11-16Ac	*: Z-11-hexadecen-1-ol Acetate*

1. INTRODUCTION

"Maize (*Zea mays*) is one of the main and popular cereal crops due to its high value as high nutritional value and a persistent need for animal feed and fuel and even for construction purposes [1]. Maize (*Zea mays*) is the third most-produced cereal in India, both in terms of area and production, registering the maximum growth rate among food crops" [2]. Over 140 insect species feed on and cause varying degrees of damage to maize crops right from sowing until harvest and fall armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) is currently the major biotic stress factor in maize crops of Asia and Africa [3].

"Fall armyworm (FAW) is native to tropical and subtropical Americas and is known as a sporadic pest in the United States since 1797. A severe outbreak of FAW on corn and millet was documented in 1912 and early documents on its management are also available" [4]. Outside America, fall armyworm was first noticed in Africa in 2016 and it reached as far as Australia by 2022.

"The fall armyworm, *Spodoptera frugiperda*, is a lepidopteran pest that feeds in large numbers on the leaves, stems, and reproductive parts of more than 350 plant species, causing major damage to economically important cultivated grasses such as maize, rice, sorghum, sugarcane, and wheat but also other vegetable crops and cotton" [5]. "In 2018, *Spodoptera frugiperda* was first reported from the Indian subcontinent" [6].

"Long an important pest of agriculture in its native New World range, the fall armyworm (FAW) *Spodoptera frugiperda* was first reported and confirmed across central and sub-Saharan Africa between 2017/2018, Middle East India (2018) and surrounding nations such as Thailand followed by Southern China in early January 2019. Across the native and invasive ranges, FAW individuals have been classified into rice- or corn-preferred strains, either based on the partial mtCOI gene or through the TPI partial gene from the z-chromosome" [7].

"Agricultural insect pest management is heavily reliant on synthetic pesticides, which do not accomplish long-term pest population reductions, particularly in areas with warm climates and extended growing seasons [8], whereas continuous long-term pheromone-based control reduces population levels of targeted pest species" [9].

"This is due to their species-specificity and nontoxicity to nontarget organisms (beneficial organisms), as well as pheromone potency at low population densities. Pheromones aid in pest control techniques by altering insect behavior, and mainly by capturing the adult pest stages to reduce pest populations" [10].

"The lure for lepidopterans is generally based on the sex pheromone emitted by females [11]. Mating disruption, monitoring, and mass trapping are the major techniques of lepidopteran pest management that use female sex pheromones, and they can be utilized alone, as in mating disruption or mass trapping, or in conjunction with pesticides, entomopathogens, and sterilants" [12,13].

In this study, we compared the performance of a pheromone trap density against *Spodoptera frugiperda*. In addition, the efficiency of pheromone trap density that showed the highest captures was evaluated to find trap alternatives for catching *Spodoptera* frugiperda males in corn crops. We assumed that the densities of the trap evaluated would perform better in catching *Spodoptera frugiperda* males in maize crops in Nashik District Maharashtra India.

2. METHODOLOGY

2.1 Study Area

The study was conducted at the four different maize crop agricultural fields in the Vinchur Gavali (Latitude 20.037265^{o} and Longitude 73.885942^{o}) and Ozar villages (Latitude 20.067635^{o} and Longitude 73.899935^{o}) of Nashik districts. They were selected to conduct the study in a farmer's croplands. The temperature and humidity in Nashik district were 28.5 ^{0} and 83.3. % and suitable to carry out the experimental study.

Fig. 1.a). Map of study area Nashik district

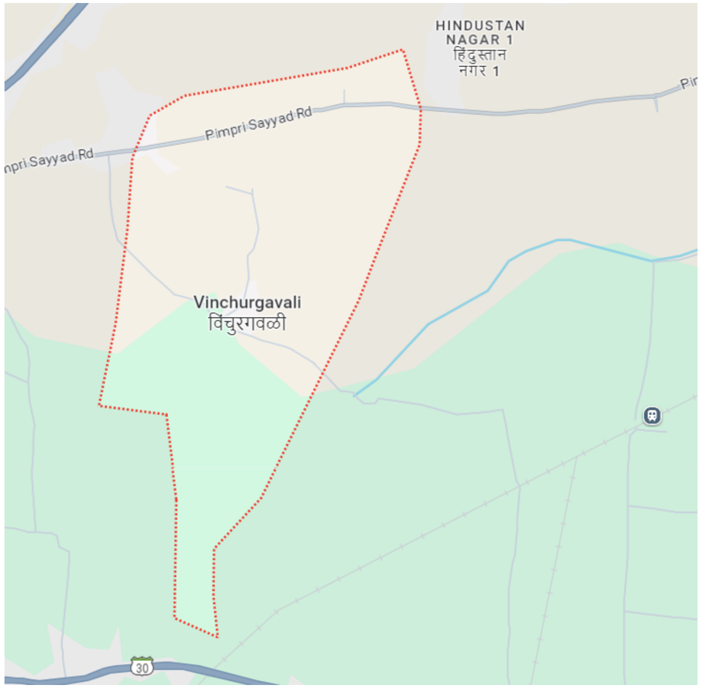

Fig. 1.b) Map of study area Vinchurgavali,

Fig. 1.c) Map of study area Ozar, village of Nashik district

2.2 Pheromone lure of *Spodoptera frugiperda*

The pheromone lure was used in this experiment to target the adult male moths. All traps in seasons were baited with the pheromone lure optimized by (Cruz-Esteban *et al.,*2020) with a red rubber dispenser [14].

This lure contained 4-components namely: -

1. (Z)-9-tetradecen- 1-ol acetate, (Z9-14Ac)
2. (Z)-7-dodecen1-ol acetate, (Z7-12Ac)
3. (Z)-9-dodecan-1-ol acetate, (Z9-12Ac) and
4. (Z)-11-hexadecen-1-ol acetate, (Z11-16Ac).

However, several biological factors, including insect size, flight ability, female population density, and host plant habitat [15,16 & 17]. As well as environmental factors, such as rainfall, relative humidity, temperature, and wind speed and direction among others, can affect a trap's efficiency in catching insects, rendering it necessary to carry out rigorous evaluations in the field [18,19].

2.3 The Universal Funnel Traps

Universal funnel traps include a cap, cage, funnel, pheromone lure dispenser and plastic bag [20].

2.4 Identifying Maize Growth Stages

The stages of maize growth were divided into vegetative (V), reproductive stages (R), and harvest stage (H). The stages were then simplified to; a) VE – V7 stages (early whorl) b) V8 – V15 stages (late whorl), c) R1 - R3 stages (reproductive), and d) H - harvest stage. Notably, rather than counting the total number of leaves, the V stages (vegetative stage) of the maize were determined by the proportion of leaves with a leaf collar. The maize crop growth stage was sampled at different maize phenological stages as shown in Table 1.

Table 1. Maize phenological stages used for the installation of pheromone traps

Growth Stage	Description
VE	Emergence
V2 – V4	2-4 leaves fully emerged
V5 – V7	5-7 leaves fully emerged.
V8 – V11	8-11 leaves fully emerged
V12 – V15	12-15 leaves
R1 – R2	Tasseling/silking fully formed.
R3	Maturity (drying)
H	Harvest

2.5 Pheromone Trap Setup for *Spodoptera frugiperda*

Eighty universal funnel traps were used for this study. The four treatments of the experimental field involved the application of the sex pheromone traps randomly placed at 4 different densities of 8, 16, 24, and 32 traps/ha and in control 0 traps/ ha. The life of the lure is 60 days and after 30 days lure is changed. Study sites from 1-4 were visited once in week to check and count the captured male adults of fall armyworm.

Fig. 2.a). Infestation of *Spodoptera frugiperda* in maize crop

Fig. 2.b). Installation of pheromone traps in maize crop

Fig. 2.c). Pheromone traps in the study area

2.6 Statistical Analyses

The proportion of maize plants that exhibited FAW signs of damage as well as the presence or absence of eggs and larvae was determined using the equation.

$$FAW\ infestation = \frac{Number\ of\ infected\ plants}{The\ total\ number\ of\ plants\ observed}\ X\ 100$$

The number of FAW male moths captured per trap density was converted to percentages of the total number captured within each trap density based on the simplified maize growth stage.

Statistical analyses using Microsoft Excel-2021 can be performed using various built-in functions and tools to calculate and plot such as average, percentage, correlation & graph F tests two sample variances.

3. RESULTS

After the pheromone traps were setup in the maize crop field four treatments of trap densities such as 0 trap as control, 8, 16, 24, and 32 traps were used against the adults of *Spodoptera frugiperda*. In this experiment, it was observed that the maximum number of males was trapped in mass trapping of males of *Spodoptera frugiperda*. In Fig. 3.a) a male adult of *Spodoptera frugiperda* was trapped after the setup of a pheromone trap in a maize crop 3 hours after of installation of traps.

3.1 Fall Armyworm Adult Captured Compares with the Phenological Growth Stage of Maize and Pheromone Trap Densities

The fall armyworm adult captures were highest at maize phenological stages 12-15 leave and low capture of adults at the emergence and harvest maize phenological stages to trap densities, 12, 16, 24, and 32 traps it has highest capture as 28, 34, 72, and 87 respective to their trap densities.

In all the experimental plots, the 32 traps/ha had the highest rates of capture in all the phenological stages except the emergence & harvest stage, since no traps in the control plots, we will discuss other treatments.

Fig. 3.a). Male trapped in pheromone trap.

Fig. 3.b). Mass capture of *Spodoptera frugiperda* adults

Table 2. Maize Phenological stages trap density and *Spodoptera frugiperda* adult male capture

Stage of Maize crop	*Spodoptera frugiperda* adult males capture				
	8 traps/ha	**16 traps/ha**	**24 traps/ha**	**32 traps/ha**	**0 traps/ha Control**
Emergence	5 - 6	6-7	8-10	12-16	**0**
2-4 leaves	8 -9	10-12	11-16	14-20	**0**
5-7 leaves	10-13	14-17	16-20	22-27	**0**
8-11 leaves	18-20	20-22	22-25	30-40	**0**
12-15 leaves	26-30	32-40	60-85	80-95	**0**
Tasseling	16-18	22-30	40-65	60-75	**0**
Maturity	12-16	16-24	20-30	25-45	**0**
Harvest	1-2	3-4	4-5	6-10	**0**
Total	**80- 114**	**123 -156**	**181-256**	**249-328**	**0**

Table 3. Average of adult males captured with pheromone traps densities with maize crop growth stages

Stage of maize crop	Spodoptera frugiperda adult male capture				
	Control 0 trap/ha	8 traps/ha	16 traps/ha	24 traps/ha	32 traps/ha
Emergence	0	5.5	6.5	9	14
2-4 leaves	0	8.5	11.5	15.5	18
5-7 leaves	0	11.5	15.5	18	24.5
8-11 leaves	0	19	21	23.5	23
12-15 leaves	0	28	36	72.5	87.5
Tasselling	0	17	26	52.5	67.5
Maturity	0	14	20	25	35
Harvest	0	1.5	3.5	4.5	8
Total	**0**	**97**	**139.5**	**218.5**	**288.5**

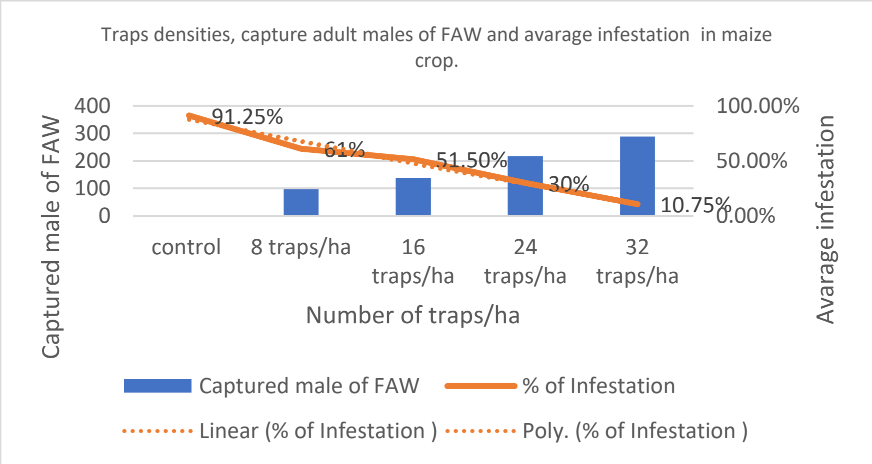

Fig. 4. Adult males captured with pheromone trap densities and average infestation

Table 4. Trap densities (traps/ha) FAW infestation (%) concerning maize crop growth stages

Maize growth stages	Description	Trap densities (traps/ha) fall armyworm infestation (%)				
		8 traps/ha	16 traps/ha	24 traps/ha	32 traps/ha	Control
Early whorl (VE – V7)	Emergence, 2-4, & 5-7leaves	58 %	48%	27%	14 %	89 %
Late whorl (V8 – V15)	8-11 & 12-15 leaves	62 %	56 %	33 %	8 %	90 %
Reproductive (R1 - R3)	Tasseling & maturity	64 %	52 %	35 %	9 %	96 %
Harvest	Harvest	60 %	50 %	25 %	12 %	90 %
Average infestation		**61** %	**51.5** %	**30** %	**10.75** %	**91.2**%

3.2 Fall Armyworm Infestation Levels by Trap Density and Simplified Maize Growth Stages

Experimental plots with 0 traps/ha indicated that the peak infestation level occurred during the reproductive stage, reaching 96%, while the minimum was observed at the early whorl stage, recorded at 89%. In plots with 8 traps/ha the highest infestation level was noted at the reproductive stage, at 64%, whereas the lowest was at the early whorls stage, at 58%. For the experimental plots with 16 traps/ha the infestation level peaked at the late whorl stage, at 56%, and was lowest at the early whorl stage, at 48%. In the plots with 24 traps/ha the highest infection level was recorded during the reproductive stage, at 35%, while the lowest was noted at the harvest stage, at 25%. Lastly, in the experimental plots with 32 traps/ha the maximum infection level was found at the early whorl stage, at 14%, and the minimum was at the late whorl stage, at 8%.

A comparison of the impact of five trap densities on FAW infestation (mean & variance) is shown in Table 4. The F-test Two Sample for Variance indicated that there was a significant difference in FAW infestations between the trap densities (*F* = 13.05, P <0.01446) and F critical one tail 6.3882. FAW infestation levels were highest in 0 and 8 trap/ha density plots, and highest in the control plot. The 32 and 24 traps/ha densities plots had respectively lowest FAW infestation levels.

3.3 FAW Infestation Levels and FAW Adult Male Moths Captured Per Trap Densities

The graphical presentation of FAW infestation and the numbers of FAW adult male moths captured by the 8, 16, 24, and 32 trap/ha density plots is illustrated in Fig. 4. Overall, the FAW infestation rate decreased as the number of FAW adult male moths captured per trap densities. No point of intersection was observed between the number of FAW adult male moths captured and the number of plants with FAW damage symptoms in the four trap densities. From this graphical and statical observation, we concluded there was a positive correlation between trap density and captured males of FAW and a negative correlation between captured males of FAW and infestation of maize crops.

Table 5. Pheromone trap densities and captured males of FAW and average infestation of maize crop

Pheromone Trap density	Control	8 traps/ha	16 traps/ha	24 traps/ha	32 traps/ha
Captured males of FAW	0	97	139	218	288
% of Infestation	91.25 %	61 %	51.5 %	30 %	10.75 %

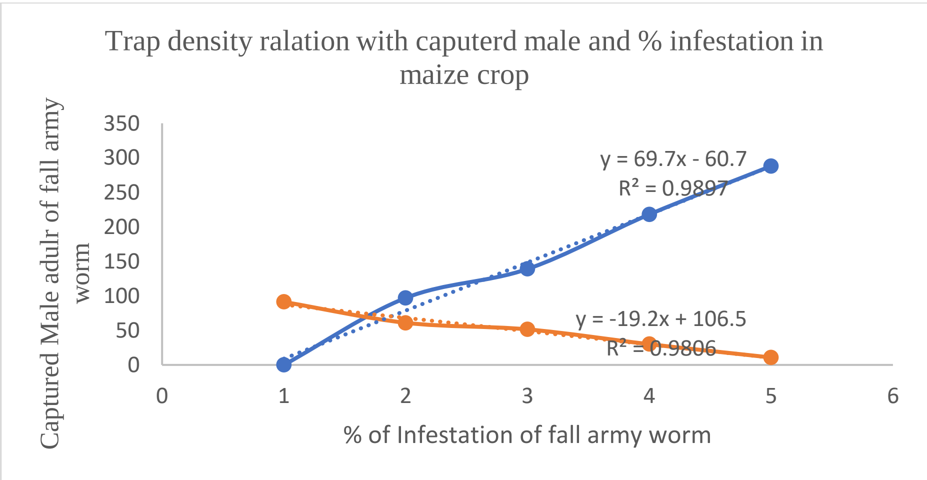

Fig. 5. Pheromone trap density with captured males and % infestation in maize crop

Table 6. F-Test two-sample for variances

Statistical parameters	Capture male of FAW	% of Infestation
Mean	**148.4**	**48.9**
Variance	12271.3	939.83125
Observations	5	5
df	4	4
F	13.05691846	
P(F<=f) one-tail	0.014462375	
F Critical one-tail	6.388232909	

4. DISCUSSION

The results of this study demonstrated that mass trapping using synthetic pheromone lures was ineffective in suppressing fall armyworm populations or reducing maize plant infestation symptoms. These results lend support to the assertion that mass trapping should be used as a monitoring and detection tool, together with scouting the fields to assist in determining when pesticides should be used in a manner that is both environmentally and commercially sustainable. Developing mass trapping as an integrated pest management (IPM) package may offer an economic incentive for farmers to adopt this technology.

The *Spodoptera frugiperda* infestation in maize crops by using different densities of pheromone traps showed the average infestation such as 61%, 51%,30%, 10%, and control 91.25. % concerning trap densities 8, 16, 24, 32, and control. The 10% infestation results highest in maize crop with pheromone traps was an effective component of integrated pest management and often used in conjunction with other control methods such as biological control agents, cultural practices, and selective pesticide applications to manage fall armyworm populations sustainably and effectively.

The present result follows the finding of Bhimani *et al.*, who reported that a trap density of 50 pheromone traps per hectare was optimal for managing fall armyworm infestation in maize [21]. Firake et al*.* [22], Recommended the deployment of five pheromone traps per acre for the consistent monitoring of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) [23]. It was noted that deploying four traps per 100 m² at the height of the crops effectively captured an optimal quantity of male *L. orbonalis* moths in brinjal cultivation. The installation of pheromone traps at a density of 75 units per hectare provided significant protection against *L. orbonalis*, resulting in a reduction of shoot damage by 58.35%, fruit damage by 33.73%, and an increase in yield by 28.67% in brinjal crops [24]. Out of a total of five distinct treatments—30, 40, 50, and 60 traps/ha, it was found that the 60 traps/ha had the most reported captures (250), followed by the 50 and 40 traps/ha. This finding had an impact on the damage to green bolls and flowers in Bt cotton [25]. The study concluded that a trap density of 32 pheromone traps per hectare was optimal for managing fall armyworm infestation in maize in the district of Nashik Maharashtra India.

5. CONCLUSION

The results showed that the percentage of fall armyworm infestation in maize crops dropped as pheromone trap densities increased. The comprehensive findings of pheromone traps targeting *Spodoptera frugiperda* indicated that the traps deployed at densities of 32 and 24 traps per hectare exhibited the lowest infestation rates, recorded at 10.75% and 30%, respectively. Additionally, the total captures of adult males were 288 and 218 in the various phenological growth stages of maize. The study concluded that a trap density of 32 pheromone traps per hectare was optimal for managing fall armyworm infestation in maize. This suggests that pheromone traps could be useful for monitoring fall armyworm males in the Maharashtra district of Nashik

AVAILABILITY OF DATA AND MATERIALS

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

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during the writing or editing of manuscripts.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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