Original Research Article

The Possible Potential of Pheromone Traps Against Invasive Pest *Spodoptera frugiperda.*

Abstract

The *Spodoptera frugiperda* invasive pest was first reported in Karnataka in the year 2018 and now in ~~year~~ 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 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.

The *Spodoptera frugiperda* infestation in maize crops by using different densities of p~~P~~heromone traps showed the average infestation in 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.

Key Words: Pheromone traps, Invasive pest, *Spodoptera frugiperda*, Pest Monitoring, Fall armyworm.

INTRODUCTION

Maize (*Zea mays*) is one of the main and popular cereal crops due to its high value as stable food as well as its stover demand for animal feed and fuel and even for construction

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Commented [A2]: Unclear. Do you mean that you used the different densities of pheromone traps and that it resulted in a reduction of the pest by these percentages? Rephrase the whole sentence please so that it conveys the message you want it to convey.

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purposes (Abebe and Feyisa, 2017). Maize (*Zea mays* L.) is the third most-produced cereal in India, both in terms of area and production, registering the maximum growth rate among food crops (Rakshit and Chikkappa, 2018). Over 140 insect species feed on and cause varying degrees of damage to maize crops right from sowing until harvest (Reddy and Trivedi, 2008), and fall armyworm (FAW) *Spodoptera frugiperda* (J. E. ~~smith~~Smith) is currently the major biotic stress factor in maize crop of Asia and Africa.

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. Fall armyworm is native to the Americas and has been known as a pest in the United States since 1797 and early documents on its management are also available (Walton and Luginbill, 1916).

Outside America, ~~Fall~~ fall ~~Army~~ army worm 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. Native to the Americas, it has been repeatedly intercepted at quarantine in Europe and was first reported from Africa in 2016 where it caused significant damage to maize crops. In 2018, *Spodoptera frugiperda* was first reported from the Indian subcontinent (Ganiger et al., 2018; Sharanabasappa Kalleshwaraswamy et al., 2018).

Long an important pest of agriculture in its native New World range, the fall armyworm (FAW) *Spodoptera frugiperda* was first reported in West Africa in early 2016, followed by confirmation 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~~.~~ (Wee *et al*. 2022).

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 (Witzgall *et al*., 2010), whereas continuous long-term pheromone-based control reduces population levels of targeted pest species (Weddle *et al*., 2009).

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This is due to their species-specificity and nontoxicity to nontarget organisms (beneficial organisms), as well as pheromone potency at low population densities (Witzgall *et al*., 2010). Pheromones aid in pest control techniques by altering insect behavior, and mainly by capturing the adult pest stages to reduce pest populations (Ahmad and Kamarudin, 2011).

The lure for lepidopterans is generally based on the sex pheromone emitted by females (Cork, 2016). Mating disruption, monitoring, and mass trapping are the major techniques of lepidopteran pest management that use female sex pheromones (Silverstein, 1981), and they can be utilized alone, as in mating disruption or mass trapping, or conjunction with pesticides, entomopathogens, and sterilants (El-Sayed *et al.*, 2006).

In this study, we compared the performance of a ~~Pheromone~~ 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 at least one of the densities of the trap number evaluated would have a better performance and efficiency than the number of pheromone traps in catching *Spodoptera frugiperda* males in maize crops in Nashik District Maharashtra India.

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MATERIALS AND METHODOLOGY

- **1. Study Area: -** The study was conducted at the four different maize crop agricultural fields in the Vinchur Gavali and Ozar villages of Nashik districts. They were selected to conduct the study in a farmer's cropland. The temperature and humidity in Nashik district were 28.5 and 83.3~~.~~ and suitable to carry out the experimental study.

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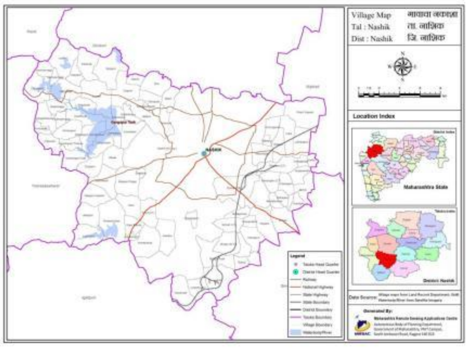

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Figure 1.-a~~.~~ Map of Study area Nashik District.

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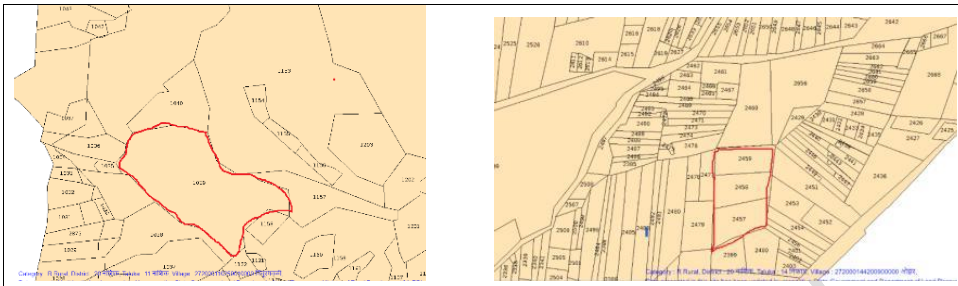

Figure 1.b) Map of study area Vinchur Gavali 1.c) Map of study area Ozar, Village of Nashik district.

2. Sex~~EX~~ Pheromone lure of *Spodoptera frugiperda*.

The sex pheromone was lured in this experiment to target the adult male moths. All traps in seasons were baited with the sex pheromone optimized by ~~(~~Cruz-Esteban et al., (2020) with a red rubber dispenser.

This lure ~~is containing~~ contained ~~a~~ 4 ~~-~~components~~-~~, namely~~such as~~: -

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 (Knight and Croft 1987; Kondo et al. 1993; Williams and Jonusas 2019); as well as environmental factors, such as rainfall, relative humidity, temperature, and wind speed and direction (Pitcairn et al. 1990; Delisle et al. 1998), among others, can affect a trap's efficiency in catching insects, rendering it necessary to carry out rigorous evaluations in the field (Malo et al. 2018; Whitfield et al.2019).

3. **The universal funnel traps.**

Universal funnel traps consist of a cap, cage, funnel, Pheromone Lure Dispenser, and ~~Plastic~~ plastic bag.

~~Source: FAO Guidance Note 3 – Fall armyworm trapping~~ (FAO, 2018).

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.

Commented [A18]: Surely it was the males that were lured by the pheromone? The sex pheromone was used to lure the males?

Commented [A19]: Everything you report on has already happened in the past, thus past tense.

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Maize crop growth stage was sampled at different maize phenological stages as shown ~~on~~in Table 1.

Table 1: Maize phenological stages used for 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

5. Sex 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. The life of the lure is 60 days and after 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.

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<td>Figure 2.a) Infestation of Spodoptera frugiperda in ~~Maiz~~ maize ~~Crop~~ crop</td>
<td>Figure 2. b) Installation of pheromone traps in ~~M~~mazie crop</td>
<td>2. c) Pheromone traps in the ~~Study~~ study area.</td>
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Commented [A22]: I presume control had 0 traps? You should say that.

Commented [A23]: How many days?

6. Statistical ~~analysis~~ analyses

1. The proportion of maize plants that exhibited Fall Army Worm signs of damage as well as the presence /absence of eggs and larvae was determined using equation 1.

$$\text{FAW infestation} = \frac{\text{Number of infected plants}}{\text{Total number of plants observed}} \times 100 \qquad (1)$$

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

2. Statistical ~~analysis~~ analyses using Microsoft Excel-2021 can be performed using various built-

in functions and tools to calculate and plot such as average, percentage, ~~Correlation~~ correlation &

graph F tests two sample ~~Variance~~variance.

OBSERVATION

After the pheromone traps were set up into maize crop field, four treatments of trap densities such as 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 Figure 3.a) ~~A~~ a male adult of *Spodoptera frugiperda* was trapped after setup of a pheromone trap in maize crop 3 ~~hrs.~~hours after ~~of~~ installation of traps. Fall armyworm infestation rate by phenology maize growth and trap density.

Commented [A24]: Since you explained the FAW, you are able to use the abbreviation instead of typing it out every time.

Commented [A25]: Was this following section copied and pasted?? As an image?!!

Commented [A26]: The last sentence in the observation section has no verb, so it makes no sense.

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Figure. 3.a) Male trapped in Pheromone pheromone trapped	Figure. 3.b) Mass capture of *S. frugiperda* adults.	Figure. 3.c) Mass capture of *S. frugiperda* in field maize crop.

Table 2. Maize Phenology phenological maize growth stages, and trap density and ***Spodoptera frugiperda*** *Adult adult male Capturecapture*.

Stage of Maize crop	***Spodoptera frugiperda* Adult adult male Capturecapture**				
	8 traps/ha	**16 traps/ha**	**24 traps/ha**	**32 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

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Total	**80- 114**	**123 -156**	**181-256**	**249-328**	0

Results

1. **Fall armyworm ~~Adult~~ adults captured ~~compares~~ comparedwith the phenological growth stage of maize and ~~Pheromone~~ pheromone trap densities.**
The fall army worm adult captures were highest at 12-15 leaves and low at the emergence and harvest stages to trap densities, 12, 16, 24, and 32 such as 28, 34, 72, and 87. The lowest was 1.5-5.5, 3.5-6.5, 4.5 -9.8-14 captured adult male moth of *Spodoptera frugiperda*.

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

	Spodoptera frugiperda ~~Adult~~ adult male ~~Capture~~capture				
Stage of ~~Maize~~ maize crop	**Control 0 traps/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**

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Commented [A29]: What do you mean? Lowest can surely only be one?

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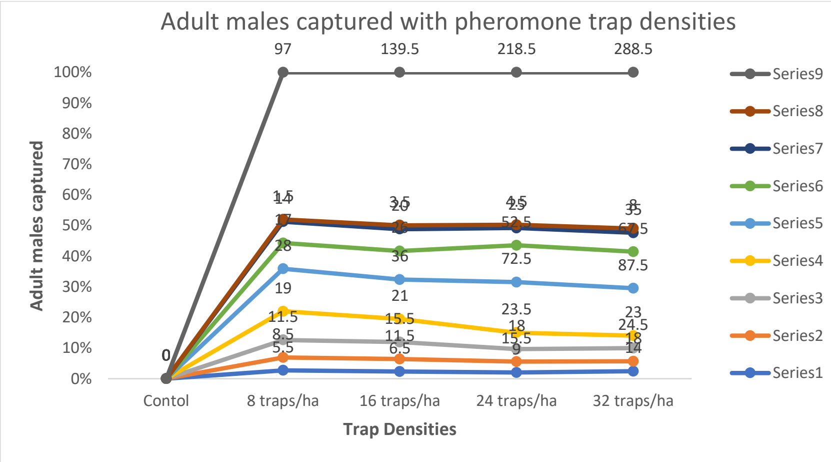

~~Graph~~ Figure ~~1~~4. Adult males captured with pheromone trap densities.

In all the experimental plots, the 32 traps/ha had the highest capture~~d~~ rates in all the phenological stages except the emergence & harvest stage, while the control plot recorded the lowest (zero) capture rates ~~d~~ in all the phenological stages.

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Commented [A32]: Remember; it is not captured rates (the rates cannot be captured) but rates OF capture.

Commented [A33]: Since there were no traps, it could not have trapped anything, surely? Maybe rephrase and say something like: Since there were no traps in the control plots, we will only discuss the other treatments

2. Fall armyworm infestation levels by trap density and simplified maize growth stages

Fall armyworm infestation levels were highest in the 8 traps/ha plots (61%), while the control plot had the lowest levels of FAW infestations (91.25%). The 16 traps/ha plots had the second-highest levels of FAW symptoms on maize plants (51.5%). The proportion of maize plants with FAW infestation symptoms in the 8 traps/ha plots was 61 %, while 10.75% of the maize plants in the 32 traps/ha were infested by FAW.

Commented [A34]: Surely 91.25% is higher than 61%?

Commented [A35]: Rewrite. The control plots had the highest number of FAW, but that is not what you say here.

For the 8,~~16,~~ 16, 24, and 32 traps/ha plots, the late whorl stage recorded lower infestation levels compared to the control simplified stages, however for the 8 traps/ha plot and control plot, it was the early whorl stage. The harvest stage of all the experimental plots showed the highest levels of infection.

Commented [A36]: What do you mean by "control simplified stages"?

Commented [A37]: That is not true according to Table 4. For instance: 16 traps had 48% at emergence, 56% at late whorl and 50% at harvest. So why do you say that harvest stage always showed the highest level of infection? That was not even true for the control!

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Table 4. Trap densities (traps/ha) ~~Fall~~ fall armyworm infestation (%) concerning ~~Maize~~ maize crop growth stages.

Maize growth stages	Description	Trap densities (traps/ha) ~~Fall~~ fall armyworm infestation (%)				
		8 traps/ha	16 traps/ha	24 traps/ha	32 traps/ha	Control
Early whorl (VE – V7)	Emergence, 2-4, & 5-7 leaves	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%**

Table 5. Pheromone trap~~s~~ densities and ~~captures~~ captured males of FAW and ~~Average~~ average infestation of ~~M~~maizie 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 %

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 werehighest in 0 and 8 trap/ha density plots, and lowest in the control plot. The 24 and 32 traps/hadensity plots had distinct FAW infestation levels.

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	

3. FAW infestation levels and FAW adult male moths captured per trap densities

The graphical presentation of ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm infestation and the numbers of ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm adult male moths captured by the 8, 16, 24, and 32 trap/ha density plots is illustrated in ~~Graph~~ Figure ~~.2~~5. Overall, the ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm infestation rate decreased as the number of ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm adult male moths captured per trap densities. No point of intersectionwas observed between the number of f~~F~~all ~~Army~~ army ~~Worm~~ worm adult male moths captured and the number of plants with ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm damage symptoms in the four trap densities. From this graphical and statical observation, we concluded that ~~their~~ there was a positive co -co-correlation between trap density and captured male of ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm and a negative co-relation between captured ~~mole~~ males of ~~Fall~~ fall ~~Army~~

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Commented [A39]: You just said it was highest in 0 traps/ha. Surely that was your control?

Commented [A40]: In science writing something is significant or not significant. Distinct says nothing.

Commented [A41]: Why not use FAW?

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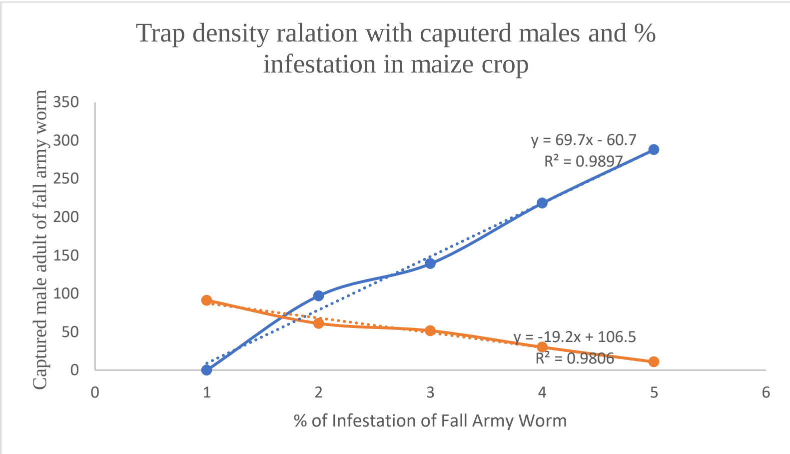
army ~~Worm~~ worm and ~~Infestation~~ infestation of ~~Maize~~ maize crop.



~~Graph 2~~Figure 5. Pheromone Trap density with captured ~~Males~~ males and % infestation in maize crop.

DISCUSSION

The results of this study demonstrated that mass trapping using synthetic sex pheromone was ineffective in suppressing ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm 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~~ pheromone traps showed the average infestation in such as 61%, 51%,,30%, 10%, and control 91.25. % concerning trap densities 8, 16, 24, 32, and ~~Control~~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 ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm variant in Sub-Sahara Africa (SSA) mainly originated in the USA (Goergen et al., 2016). Nagoshi et al. (2018) reported a fall armyworm variant of the R-biotype that is unique to Africa, having been found in Togo, Kenya, and the Democratic Republic of the Congo (Nagoshi et al., 2018). There is a possibility of genetic variation leading to the Scentry - L105A synthetic lure that was effective in capturing ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm adult male moths in the USA (Meagher et al., 2013) was not effective for this population. Genetic explanations for ~~Fall~~ fall ~~Army~~ army ~~Worm~~ worm trap capture inconsistencies include population isolation caused by the high migratory ability of the FAW leading to differences (lack of homogeneity) with the native population (Andrade et al., 2000), gene drifting that occurs during the expansion of the distribution

Commented [A44]: What do you mean? A genetic variation cannot lead to a synthetic lure. It can however lead to the manufacturing of said lure.

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Commented [A46]: I fail to see what this paragraph has to do with your study? You tested densities of traps not types of lures?

References:

1. Abebe, Z. and Feyisa, H. (2017) Effects of Nitrogen Rates and Time of Application on Yield of Maize: Rainfall Variability Influenced Time of N Application. International Journal of Agronomy, 2017, Article ID: 1545280.https://www.hindawi.com/journals/ija/2017/1545280/
2. Ahmad, S. N. & Kamarudin, N. 2011. Pheromone Trapping in Controlling Key Insect Pests: Progress and Prospects. *Oil Palm Bulletin*. 62, 12 – 24 https://www.researchgate.net/publication/311068895_Pheromone_Trapping_in_Controlling_Key_Insect_Pests_Progress_and_Prospects
3. Andrade, R., Rodríguez, C. & Oehlschlager, A. C. 2000. Optimization of a pheromone lure for *Spodoptera frugiperda* (Smith) in Central America. *Journal of the Brazilian Chemical Society*, 11**,** 609-613. https://www.scielo.br/j/jbchs/a/Ztr8NV8VYwn8V5tTzLJ8WNk/
4. CABI. 2020. Invasive Species Compendium: *Spodoptera frugiperda* (fall armyworm). https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.29810
5. Cork, A. 2016. 23. Pheromones as Management Tools: Mass Trapping and Lure-and-Kill. *In:* Jeremy, D. A. & Ring, T. C. (eds.) Pheromone Communication in Moths: Evolution, Behavior, and Application*. University of California Press,* 23, 349-363. https://www.ucpress.edu/book/9780520278561/pheromone-communication-in-moths
6. Cruz-Esteban S, Rojas JC, Malo EA (2020) A pheromone lure for catching fall armyworm males (Lepidoptera: Noctuidae) in Mexico. Acta Zoologica Mexicana 36, 1–11 https://doi.org/10.21829/azm.2020.3612271
7. EL-Sayed, A. M. & Trimble, R. M. 2012. Pheromone content of azinphosmethyl-susceptible and -resistant obliquebanded leafrollers (Lepidoptera: Tortricidae) as a function of time of day and female age. *The Canadian Entomologist,* 134**,** 331-341. https://www.cambridge.org/core/journals/canadian-entomologist/article/abs/pheromone-content-of-azinphosmethylsusceptible-and-resistant-obliquebanded-leafrollers-lepidoptera-tortricidae-as-a-function-of-time-of-day-and-female-age/0C7249405B8E4F8CD6E0F1D2E3F11496
8. EL-Sayed, A. M., Suckling, D. M., Wearing, C. H. & Byers, J. A. 2006. Potential of mass trappingfor long-term pest management and eradication of invasive species. *Journal of EconomicEntomology,* 99**,** 1550-64. https://academic.oup.com/jee/articleabstract/99/5/1550/2218584
9. FAO and CABI. 2019. Community-Based Fall Armyworm (*Spodoptera frugiperda*) Monitoring, Early warning and Management, Training of Trainers Manual, First Edition, 112 [accessed on January 2024]. https://www.cabi.org/wp-content/uploads/ToT-manual.pdf
10. FAO Guidance Note 3 - Fall armyworm trapping (FAO, 2018) https://www.fao.org/3/I8322EN/i8322en.pdf
11. FAO. 2018. Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa, Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i8741en/I8741EN.pdf, [accessed on January 2024].
12. Ganiger, P. C., Yeshwanth, H. M., Muralimohan, K., Vinay, N., Kumar, A. R. V., & Chandrashekara, K. J. C. S. (2018). Occurrence of the new invasive pest, fall armyworm, Spodoptera frugiperda (JE Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India. *Current Science*, *115*(4), 621-623.

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https://www.researchgate.net/publication/334320097_Occurrence_of_the_New_Invasive_Pest_Fall_Armyworm_Spodoptera_frugiperda_JE_Smith_Lepidoptera_Noctuidae_in_the_Maize_Fields_of_Karnataka_India

13. George, T., Ladha, J. K., Garrity, D. P. & Torres, R. O. 1995. Nitrogen Dynamics of Grain Legume– Weedy Fallow–Flooded Rice Sequences in the Tropics. *Agronomy Journal,* 87**,**1-6. https://ui.adsabs.harvard.edu/abs/1995AgrJ...87....1G/abstract
14. Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A. & TAMÒ, M. 2016. First Report of Outbreaks of the Fall Armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. *PLoS One,* 11**,** e0165632.https://www.cabi.org/ISC/datasheet/29810.
15. Knight AL, Croft BA (1987) Temporal patterns of competition between a pheromone trap and caged female moths for males of *Argyrotaenia citrana* (Lepidoptera: Tortricidae) in a semi-enclosed courtyard. Environ Entomol 16:1185–1192. https://doi.org/10.1093/ee/16.5.1185
16. Kondo A, Tanaka F, Sugie H, Hokyou N (1993) Analysis of some biological factors affecting differential pheromone trap efficiency between generations in the rice stem borer moth, *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae). Appl Entomol Zool 28:503–511.https://doi.org/10.1303/aez.28.503
17. Litsinger, J. 1994. Cultural, mechanical, and physical control of rice insects. In E.A. Heinrichs (ed.)Biology and Management of Rice Insects. *Wiley Eastern Ltd*., New Delhi, 6. 549-584. https://www.researchgate.net/publication/306959908_Cultural_mechanical_and_physical_control_of_rice_insects
18. Luginbill, P. 1928. The fall armyworm. *USDA Technical Bulletin.,* 34. https://www.jstor.org/stable/3495378
19. Malo EA, Cruz-Esteban S, Gonzalez FJ, Rojas JC (2018) A homemade trap baited with sex pheromone for monitoring *Spodoptera frugiperda* males (Lepidoptera: Noctuidae) in corn crops in Mexico. J Econ Entomol 111:1674–1681. https://doi.org/10.1093/jee/toy128
20. Malo EA, Cruz-Lopez L, Valle-Mora J, Virgen A, Sanchez JA, Rojas JC (2001) Evaluation of commercial pheromone lures and traps for monitoring male fall armyworm (Lepidoptera: Noctuidae) in the coastal region of Chiapas Mexico Fla Entomol 659–664. https://doi.org/10.2307/3496398
21. Meagher, R. L., Nagoshi, R. N., Armstrong, J. S., Niogret, J., Epsky, N. D. & Flanders, K. Captures and Host Strains of Fall Armyworm (Lepidoptera: Noctuidae) Males in Traps Baited with Different Commercial Pheromone Blends. *Florida Entomologist,* 96**,** 729- 740. https://www.researchgate.net/publication/273961813_Captures_and_Host_Strains_of_Fall_Armyworm_Lepidoptera_Noctuidae_Males_in_Traps_Baited_with_Different_Commercial_Pheromone_Blends
22. Nagoshi, R. N., Dhanani, I., Asokan, R., Mahadevaswamy, H. M., Kalleshwaraswamy, C. M., Sharanabasappa & Meagher, R. L. 2019. Genetic characterization of fall armyworm infesting South Africa and India indicate recent introduction from a common source population. *PLoS One*,14**,**e0217755. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0217755
23. Nagoshi, R. N., Goergen, G., Tounou, K. A., Agboka, K., Koffi, D. & Meagher, R. L. 2018 Analysis of strain distribution, migratory potential, and invasion history of fall armyworm populations in northern Sub-Saharan Africa. *Scientific Reports,* 8**,** 3710. https://www.nature.com/articles/s41598-018-21954-1
24. Pitcairn MJ, Zalom FG, Bentley WJ (1990) Weather factors influencing capture of *Cydia pomonell* (Lepidoptera: Tortricidae) in pheromone traps during overwintering flight in California. Environ Entomol 19:1253–1258. https://doi.org/10.1093/ee/19.5.1253
25. Reddy Y V R, Trivedi S. 2008. Maize production technology. Academic Press, London. 192

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pp. https://indianentomology.org/index.php/ije/article/view/96

26. Roelofs, W. L., Liu, W., Hao, G., Jiao, H., Rooney, A. P. & Linn, C. E., JR. 2002. Evolution of moth sex pheromones via ancestral genes. *Proceedings of the National Academy of Sciences*. 99(21):13621-6 https://pubmed.ncbi.nlm.nih.gov/12237399/
27. Sharanabasappa, Kalleshwaraswamy C M, Asokan R, Swamy H M, Maruthi M S, Pavithra H B, Hegde K, Navi S, Prabhu S T, Goergen G. 2018. First report of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. Pest Management in Horticultural Ecosystem 24(1): 23-29. https://www.researchgate.net/publication/328289852_Biology_of_invasive_fall_army_worm_Spodoptera_frugiperda_JE_Smith_Lepidoptera_Noctuidae_on_maize
28. Silverstein, R. M. 1981. Pheromones: Background and Potential for Use in Insect Pest Control. *Science,* 213**,** 1326-1332. https://www.jstor.org/stable/1686453
29. Tay, W. T., Rane, R. V., Padovan, A., Walsh, T. K., El fekih, S., Downes, S., ... & Gordon, K. H. (2022). Global population genomic signature of Spodoptera frugiperda (fall armyworm) supports complex introduction events across the Old World. *Communications Biology*, *5*(1), 297. https://pubmed.ncbi.nlm.nih.gov/35393491
30. Wakamura, S., Arakaki, N. & Yoshimatsu, S.-I. 2021. Sex pheromone of the fall armyworm '*Spodoptera frugiperda* (Lepidoptera: Noctuidae) of a "Far East" population from Okinawa, Japan. *Applied Entomology and Zoology,* 56**,** 19-25. https://link.springer.com/article/10.1007/s13355-020-00703-9
31. Walton, W.R. and P. Luginbill. 1916. The fall armyworm or grass worm and its control. Farmers' Bull. 752. USDA. Washington, DC. https://books.google.co.in/books?hl=en&lr=&id=3TOMuTYdop8C&oi=fnd&pg=PA10&dq=31.%09Walton,+W.R.+and+P.+Luginbill.+1916.+The+fall+armyworm+or+grass+worm+and+its+control.+Farmers%E2%80%99+++Bull.+752.+USDA.+Washington,+DC.&ots=0beyHHoexL&sig=WYsQ3xzRFHR2f9ShiAVKxIEXvd4&redir_esc=y#v=onepage&q&f=false
32. Webb, R. E., Tatman, K. M., Leonhardt, B. A., Plimmer, J. R., Boyd, K. V., Bystrak, P. G., Schwalbe, C. P. & Douglass, L. W. 1988. Effect of Aerial Application of Racemic Disparlure on Male Trap Catch and Female Mating Success of Gypsy Moth (Lepidoptera: Lymantriidae)1. *Journal of Economic Entomology,* 81**,** 268-273. https://academic.oup.com/jee/article-abstract/81/1/268/934810
33. Weddle, P. W., Welter, S. C. & Thomson, D. 2009. History of IPM in California pears--50 years of pesticide use and the transition to biologically intensive IPM. *Pest Management Science*,65**,**128792. https://onlinelibrary.wiley.com/doi/abs/10.1002/ps.1865
34. Whitfield EC, Lobos E, Cork A, Hall DR (2019) Comparison of different trap designs for capture of noctuid moths (Lepidoptera: Noctuidae) with pheromone and floral odor attractants. J Econ Entomol 112:2199–2206. https://doi.org/10.1093/ jee/ toz093
35. Williams DT, Jonusas G (2019) The influence of tree species and edge effects on pheromone trap catches of oak processionary moth *Thaumetopoea processionea* (L.) in the UK. Agric for Entomol 21:28–37. https://resjournals.onlinelibrary.wiley.com/doi/10.1111/afe.12300
36. Williams DT, Straw N, Townsend M, Wilkinson AS, Mullins A (2013) Monitoring oak processionary moth *Thaumetopoea processionea* L. using pheromone traps: the influence of pheromone lure source, trap design and height above the ground on capture rates. Agric for Entomol 15:126–134. https://doi.org/10.1111/afe.12005
37. Witzgall, P., Kirsch, P. & Cork, A. 2010. Sex pheromones and their impact on pest management. *Journal of Chemical Ecology,* 36**,** 80-100. https://link.springer.com/article/10.1007/s10886-009-9737-y

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