Zangpo et al. (2024). *Bhutanese Journal of Agriculture*, *7*(1), 44-61.

https://doi.org/10.55925/btagr.24.7104

Evaluation of Commercial Sex Pheromone Lures for Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) Monitoring in Bhutan

Tshelthrim Zangpo[d], Ugyen Dorji[d], Ratu Kinley[d], Thirtha Maya Ghalley[d], Chinta Mani Dhimal[d], Ugyen Dema[d], Pempa Lhamo Lepcha[d], Jigme Wangchuk[d], Nidup Dorji[d], Yeshey Dema[d]

ABSTRACT

The fall armyworm has rapidly spread to 11 Dzongkhags in Bhutan by September 2023 since its first detection in 2019. This concerning spread highlights the critical need for comprehensive monitoring strategies. However, there is still a notable gap in understanding the seasonal behavior of fall armyworm in Bhutan, including its response to commercially available sex pheromone lures. Hence, the current study aimed to evaluate the effectiveness of seven commercially available sex pheromone lures (SPFR2111, SPFR2112, SPFR2113, SPFR2114, SPFR2115, PCI and Ecotech) in monitoring fall armyworm in maize fields in Sarpang, Punakha and Chukha Dzongkhags in 2023. The study employed a descriptive observational approach to monitor fall armyworm moth populations in maize fields. Phero T-traps (funnel traps) with specific lures were placed fifty meters apart in maize fields at a density of five traps per acre and positioned approximately 1.5 meters above ground level. The number of fall armyworm moths and non- target species captured by seven lures differed across various locations. Overall, SFPR2114, PCI, and Ecotech lures were more effective in trapping fall armyworm moths based on mean ranks. The lure SPFR2113 and SPFR2112 captured the lowest number of non-target species, while PCI captured the highest number. The peak of fall armyworm moth capture was in April in all the monitoring locations, signifying the need for timely monitoring and scouting during this vulnerable crop growth stages. The study's findings suggest the use of SPFR2114, SPFR2113, SPFR2112 and Ecotech lures for monitoring fall armyworm populations in Bhutan, particularly during the crucial period of April when there is a notable surge in moth captures for effective fall armyworm monitoring.

Keywords: *Maize; Monitoring; Pheromone lures; Population abundance; Spodoptera frugiperda*

Corresponding author: tzangpo@moal.gov.bt

[d] National Plant Protection Centre, Department of Agriculture, Ministry of Agriculture and Livestock

1 Introduction

The fall armyworm (FAW), *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is a polyphagous pest that damages over 300 plants from 76 families (Montezano et al., 2018). Higher FAW damage is observed in maize, sorghum, rice, cotton, and pasture grasses (Montezano et al., 2018). It was first detected in Africa in 2016 and subsequently spread to Asia (Goergen, Kumar, Sankung, Togola, & Tamò, 2016; Sharanabasappa. et al., 2018; FAO, 2019). The rapid worldwide spread can be attributed to its robust flying ability (capable of covering over 100 km per night), high fecundity rate (with a single FAW female laying up to 1000 eggs), and broad host range (Murúa, Molina-Ochoa, & Coviella, 2006; Song et al., 2020). Furthermore, FAW do not diapause hence they can migrate to new places with suitable environmental conditions (Du Plessis, Schlemmer, & Van den Berg, 2020). Currently, two genetic strains of *S. frugiperda* i.e., corn strain and rice strain have been reported in Africa (Goergen et al., 2016). In Bhutan, FAW was first observed damaging maize in Dabchegang and Pepchu villages in Guma Gewog and Mendugang in Dzomi Gewog in Punakha in September 2019 (Mahat, Mitchell, & Zangpo, 2021). Currently, FAW has been detected damaging maize in 15 Dzongkhags (Chukha, Punakha, Paro, Thimphu, Mongar, Dagana, Wangdiphodrang, Lhuentse, Sarpang, Trashigang, Trashi Yangtse, Samdrup Jongkhar, Tsirang, Zhemgang and Trongsa).

FAW cause direct yield losses by feeding on the ears of the maize and cobs (Harrison, 1984) as well as indirect losses through defoliation (Day et al., 2017). Furthermore, FAW feeding on grains can attract saprotrophic and pathogenic fungi leading to mycotoxin contamination (Farias et al., 2014). Approximately 18 million tonnes/year of corn were lost to FAW damage in 12 African countries (Harrison et al., 2019), making up 21–53% of annual corn production (Montezano et al., 2018). Hence, it is crucial to develop sustainable monitoring strategies to manage FAW (Gebreziher & Gebreziher, 2020).

Pest monitoring is a crucial starting point in designing Integrated Pest Management (IPM) Programme (Prasad & Prabhakar, 2012). Pheromone based monitoring and surveillance are crucial for early detection of pests, aiding in forecasting their movement (Prasanna, Huesing, Eddy, & Preschke, 2018). Moreover, pheromone trapping saves time by reducing laborious sampling and unnecessary insecticide use (Cruz, Figueiredo, & Silva, 2010). Early detection and timely crop protection measures, facilitated by sex pheromone trapping, are pivotal for successful FAW management. The female FAW releases sex pheromones by exposing the last abdominal segments (Cruz-Esteban, Rojas, & Malo, 2017), which triggers mating behaviour in males (Jacobson, Redfern, Jones, & Aldridge, 1970). This sexual communication between male and female moths is used in pest identification, mass trapping and mating disruption (Cardé & Minks, 1995; Witzgall, Kirsch, & Cork, 2010). Synthetic compounds emulating natural FAW pheromones (lure) in traps attract and trap male moths. Most of the commercial FAW lures contain three pheromone components: Z9-14: OAc; Z11-16: OAc; and Z7-12: OAc (Bratovich, Saluso, Murúa, & Guerenstein, 2019).

Currently, the FAW seasonal activity in Bhutan is still notably underexplored. Despite global attention to FAW management, there exists a significant gap in understanding its behaviour in Bhutan. This gap extends to investigating FAW's response to different commercially available sex pheromone lures. Hence, this research aimed to address the dual knowledge gaps by investigating into the uncharted territory of FAW's seasonal activity patterns in Bhutan using commercially available sex pheromone lures and simultaneously examining the potential of different lures as a mean of enhancing FAW monitoring strategies. Thus, this study aims to contribute not only to the local understanding of FAW dynamics but also to the broader global discourse on integrated pest management practices.

2 Materials and Methods

2.1 Study sites

The monitoring was conducted in 2023 in maize fields across multiple gewogs: Samphelling (Khempaithang and Sonamthang) in Chukha, Guma (Dapchagang) in Punakha, Gakiling (Rilanthang and Khopitar) and Singye (Shariphu and Yarpheling) in Sarpang Dzongkhag.

2.2 Pheromone traps and lures

Phero T-traps (Funnel trap) with specific lure were used for trapping male fall armyworm moths. A total of seven commercial pheromone lures manufactured by three companies were used in the study. These included the FAW Lure produced by Gaiagen Technologies Private Limited in India (PCI), Harmony Ecotech Private Limited (Ecotech) and the SPFR2111, SPFR2112, SPFR 2113, SPFR 2114, and SPFR2115 lures, all manufactured by Pherobank BV based in the Netherlands (Figure 1).

Figure 9. Different lures used for monitoring

2.3 Traps and lures deployment in the field

This study employed a descriptive observational approach, focusing on monitoring fall armyworm captures with different pheromone lures in farmers' fields without altering any variables like maize varieties or fertilizer application. Phero T-traps (Funnel trap) with specific lure were placed 50-meter apart in the maize field and approximately 1.5 meters above ground level. Five pheromone traps per acre was used for trapping from seedling stage until crop maturity. The height of the pheromone traps was adjusted according to the growth stage of the maize plants, with the traps being raised as the maize plants matured. This was done so that the scent of the pheromone lure is carried across the tops of the maize plants by the wind. Pheromone lures were changed monthly using nitrile gloves to prevent contamination as well as lures losing strength over time generating misleading trap catches.

Table 1. Study sites and types of lures used

Dzongkhag	Gewog	Study site	Altitude	Types of lures used	Study period
Sarpang	Gakidling	Rilangthang	690 m	SPFR2111 and SPFR2112	March – June, 2023
Sarpang	Gakidling	Khopitar	752 m	SPFR2113, SPFR2114, SPFR2115, and PCI	March – June, 2023
Sarpang	Singye	Shariphu	326 m	SPFR2111, SPFR2112, SPFR2113, and PCI	March – June, 2023
Sarpang	Singye	Yarpheling	326 m	SPFR2114 and SPFR2115	March – June, 2023
Chukha	Samphelling	Khempaithang	305 m	'PCI' and Ecotech lures	February – June 2023
Chukha	Samphelling	Sonamthang	288 m	'PCI' and Ecotech lures	February – June, 2023

Punakha	Guma	Dapchagang	1350 m	SPFR2111, SPFR2112, SPFR2113, SPFR2114 and SPFR2115	March – June 2023

2.4 Data collection

All the male fall armyworm moths captured in the traps were emptied at fortnightly intervals and recorded. They were identified in the laboratory based on the morphological characteristics. Beneficial insects such as parasitoids, predators, and spiders trapped were collectively recorded as 'beneficial insect species'. All other captured pest's species such as *Spodoptera spp., Mythimna spp., Phragmites spp.* and *Helicoverpa* s*pp*., were recorded as "other pest species".

The categories 'beneficial insect species' and "other pest species" were merged to create a new category 'non-target species" to assess the species specificity of the different lures. To assess changes in FAW population and abundance, the sum of male moth captures from different traps in each village was calculated fortnightly. This was done for precise monitoring of population shifts during the study, irrespective of lure differences.

2.5 Statistical Analysis

JASP 0.18 was used for the analyses of the pheromone trap data. The analyses were performed for whole study period data for overall performance of the lures, and fortnightly analyses for differences in trap captures for all the study sites as site specific comparisons due to use of non-uniform treatments in different sites. The trap captures of different categories were subjected to Kruskal-Wallis H test (with Dunn's post hoc test if significance were observed) for Data from Dabchegang, Gakidling and Singye while data from Sampheling was subjected to Mann-Whitney U test (with post hoc-Wilcoxon signed-rank test if significance was observed) at 95% confidence. These tests were performed because data did not follow a normal distribution, even after applying transformations (log10(x+0.5), log10(x+0.05), and log(x+1)). The significant pairs of lures were further ranked after adjusting p-value (Bonferroni corrections).

3 Results and Discussion

3.1 Fall armyworm trap capture

The result presented in Table 2 shows variability in the trapping efficiency of the lures in different study sites. In Gakidling, SPFR2114 was preferable (Table 3). In Singye, the lure PCI was preferable (Table 4). The lures from Harmony Ecotech showed similar efficiency to PCI for trapping fall armyworm in Sampheling (Table 5).

Table 2. Fall armyworm moth (number) captured by different lures in various locations

Gewog	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	46	17	12	64	95	x	x	234
Gakidling	4	18	21	64	20	25	x	152
Singye	9	38	21	30	17	62	x	177
Sampheling	x	x	x	x	x	1,130	639	1,769
Total	59	73	54	158	132	1,217	639	2,332

*Note: The symbol "x" is used to indicate where no specific lure was used.

The principle component of the female sex pheromone of *S. frugiperda* is (Z)-9-tetradecenyl acetate (Z9-14:Ac) and (Z)-7-dodecenyl acetate (Z7-12:Ac) (Tumlinson, Mitchell, Teal, Heath, & Mengelkoch, 1986). The variability in trapping outcome may have resulted from variations in pheromone composition of lures developed for FAW within a specific geographical regions (El-Sayed et al., 2003; Batista-Pereira et al., 2006). For example, sex pheromone lures manufactured in Central America were not effective in trapping in Brazil (Andrade et al., 2000) and Mexico (Malo et al., 2001). Weather factors such as temperature, evaporation and wind speed can also impact the trap catch by influencing the insect activity (Muthukumar & Kennedy, 2021). Furthermore, habitat composition such as different maize varieties and crops grown in the vicinity of pheromone trapping site could have influenced the response of the males to pheromone lures (Cruz-Esteban, Rojas, & Malo, 2020). The results of individual locations are highlighted below.

Dabchegang, Guma: The trap captures were not significantly [H = 2.143 (4, n = 125), p = 0.710] different amongst the different lures for the overall season.

Gakidling: The overall data comparisons showed significant differences [H17.358, (5, n=30), p = 0.004]. The Dunn's post hoc showed a significant difference between the pairs SPFR2111-SPFR2114 ($p < 0.001$, $p_{bonf} = 0.002$). From the post hoc comparisons, the lure SPFR2114 was preferable.

Table 3. Dunn's post hoc comparisons for means of male FAW moths captured by different lures in Gakidling

Comparison	Z	W_i	W_j	p_{bonf}
PCI - SPFR2111	1.091	125.956	112.678	1.000
PCI - SPFR2112	-1.641	125.956	145.933	1.000
PCI - SPFR2113	-0.732	125.956	134.867	1.000
PCI - SPFR2114	-2.734	125.956	159.233	0.094
PCI - SPFR2115	-0.688	125.956	134.333	1.000
SPFR2111 - SPFR2112	-2.732	112.678	145.933	0.094
SPFR2111 - SPFR2113	-1.823	112.678	134.867	1.000
SPFR2111 - SPFR2114	-3.825	112.678	159.233	0.002
SPFR2111 - SPFR2115	-1.779	112.678	134.333	1.000
SPFR2112 - SPFR2113	0.909	145.933	134.867	1.000
SPFR2112 - SPFR2114	-1.093	145.933	159.233	1.000
SPFR2112 - SPFR2115	0.953	145.933	134.333	1.000
SPFR2113 - SPFR2114	-2.002	134.867	159.233	0.680
SPFR2113 - SPFR2115	0.044	134.867	134.333	1.000
SPFR2114 - SPFR2115	2.046	159.233	134.333	0.612

Singye: Significant differences in overall trap captures were seen (H = 13.412, df = 5, = 270, *p* = 0.02), particularly in the PCI-SPFR2111 pair (p_bonf = 0.012).

Table 4. Dunn's post hoc comparisons for different lures in Singye gewog

Comparison	Z	W_i	W_j	p_{bonf}
PCI - SPFR2111	3.355	158.778	115.100	0.012
PCI - SPFR2112	1.048	158.778	145.133	1.000
PCI - SPFR2113	1.851	158.778	134.678	0.962
PCI - SPFR2114	2.016	158.778	132.533	0.657
PCI - SPFR2115	2.458	158.778	126.778	0.209
SPFR2111 - SPFR2112	-2.307	115.100	145.133	0.316
SPFR2111 - SPFR2113	-1.504	115.100	134.678	1.000
SPFR2111 - SPFR2114	-1.339	115.100	132.533	1.000
SPFR2111 - SPFR2115	-0.897	115.100	126.778	1.000

SPFR2112 - SPFR2113	0.803	145.133	134.678	1.000
SPFR2112 - SPFR2114	0.968	145.133	132.533	1.000
SPFR2112 - SPFR2115	1.410	145.133	126.778	1.000
SPFR2113 - SPFR2114	0.165	134.678	132.533	1.000
SPFR2113 - SPFR2115	0.607	134.678	126.778	1.000
SPFR2114 - SPFR2115	0.442	132.533	126.778	1.000

Sampheling: The overall FAW capture of the two lures was significantly different ($p = 0.049$, z = -1.98, Md Ecotech = 6, Md PCI = 15, n1 = n2 = 24).

Table 5. Wilcoxon test for comparison of means of male FAW moths captured at Sampheling

Measure 1	Measure 2	Test	Statistic	z	p	Effect Size	SE Effect Size
Ecotech	PCI	Wilcoxon	65.500	-1.980	0.049	-0.482	0.239

**Note.* For the Wilcoxon test, effect size is given by the matched rank biserial correlation.

3.2 Efficacy of the lures in relation to species specificity

Beneficial insects captured by different lures

The capture of beneficial insects varied across various locations, depending on the type of lure used (Table 6). PCI lure captured the highest number of beneficial insects (n=255). Numerous studies have demonstrated that FAW pheromone lures capture non-target insects such as beneficial species and other insect pests (Adams, Murray, & Los, 1989; Malo et al.,2001;Reyes-Prado, Segura, Martínez-Peralta, & Sosa, 2020). The sparse captures of beneficial insects might be attributed to a case of mistaken identity, where they could misinterpret the fall armyworm pheromone scent as their own, needing further investigation. Moreover, some beneficial insects are generalist predators or parasitoids that feed on various insects, including fall armyworm, and their attraction to pheromone lures may result from the presence of fall armyworm, also needing further investigation. The limited capture of beneficial insects further suggests that the use of lures may not adversely impact beneficial insect populations.

Table 6. Beneficial insects (number) captured by different lures in various locations

Location	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	0	1	0	0	0	x	x	1
Gakidling	29	58	35	24	27	208	x	381
Singye	57	29	42	43	30	23	x	224

Sampheling	x	x	x	x	x	24	65	89
Total	86	87	77	67	57	255	65	694

*Note: The symbol "x" is used to indicate where no specific lure was used.

The results of individual site are highlighted below.

Dabchegang: Only in one incidence was the capture of beneficial insect (*Chelonus spp.*) was seen for SPFR2112. No other lures captured the beneficial insects.

Gakidling: Beneficial (generalist natural enemy species) insects were caught by all the traps which had the lures for the study. There were no significant differences between the trapping of the beneficial insects [H= 66.813 (5, n = 30), p = 0.235].

Singye: Beneficial insects were also captured by all the lures used. There were no significant differences among the trap captures for beneficial insects [H = 4.067(5, n = 30), p = 0.54] for overall data.

Sampheling: The beneficial insects were also captured by the lures but no significant differences between the captures of the two lures [p = 0.89, z = 1.74, Md Ecotech = 1.5, Md PCI = 0, n1 = n2 = 24].

Other pest species captured by different lures

The lure SPFR2111 captured the highest number of other pest species followed by lure SPFR2115 and lure SPFR2112 (Table 7). The Harmony EcoTech and PCI lures captured fewer other moth species than others. The other pests' species trapped were *Phragmites spp., Spodoptera spp., Helicoverpa spp*., and *Mythimna spp*.

Table 7. Number of other pest species captured by the lures in various locations

Location	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	0	0	0	0	0	x	x	0
Gakidling	24	5	5	7	12	4	x	57
Singye	9	9	7	6	7	3	x	41
Sampheling	x	x	x	x	x	1	5	6
Total	33	14	12	13	19	8	5	137

*Note: The symbol "x" is used to indicate where no specific lure was used.

Dabchegang: No other pest species were captured during the study period.

Gakidling: Other pests' species such as *Mythimna spp.* and *Spodoptera spp.* were trapped. There was significant difference in the trap capture of other moth species [H = 11.185 (5, n = 30), p = 0.048] but post hoc comparisons with adjusted p-values showed no significant differences among the trap captures.

Singye: There were no significant differences in the trap capture of other moth species [H = 2.5 (5, n = 30), p = 0.775]. Other pest species captured belonged to *Phragmites spp.*, *Mythimna spp.* and *Spodoptera spp.*

Sampheling: There was no significant differences in the trap capture of other pest species [p = 0.35, z = 1.095, Md Ecotec = Md PCI = 0, n1 = n2 = 24].

Non-target species captured by different lures

The result presented in Table 8 show the number of non-target species captured by seven lures in various location. The non-target species captured were beneficial insects like *Chelonus spp.* and other pests' species such as *Mythimna spp.* and *Spodoptera spp.*

Table 8. Non-target species captured by lures in various locations

Location	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	0	1	0	0	0	x	x	1
Gakidling	1007	295	172	448	605	1,380	x	3,907
Singye	534	247	132	587	408	1,005	x	2,913
Sampheling	x	x	x	x	x	45	78	123
Total	1,541	543	304	1,035	1,013	2,430	78	6,944

*Note: The symbol "x" is used to indicate where no specific lure was used.

Guma: The only incidence of non-target species trapped was seen for one trap with lure SPFR2112 where an adult *Chelonus spp.* was trapped.

Gakidling: The trap captures were significantly different [H = 23.032 (5, n = 30), p < 0.001] in the pairs PCI-SPFR2112 (p_{bonf} = 0.022), PCI-SPFR2113 (p_{bonf} < 0.001) and SPFR2111-SPFR2113 ($p_{bonf =}$ 0.01) (Table 9). SPFR2113 and SPFR2112 lures caught the fewest non-target species on average, while PCI lure had the highest number of non-target species captures.

Table 9. Pairwise mean comparisons of the non-target species captured by different lures in Gakidling

Comparison	z	W_i	W_j	p_{bonf}
PCI - SPFR2112	3.180	26.500	8.800	0.022
PCI - SPFR2113	4.042	26.500	4.000	< .001
PCI - SPFR2114	2.246	26.500	14.000	0.371
SPFR2111 - SPFR2112	2.533	22.900	8.800	0.170
SPFR2111 - SPFR2113	3.395	22.900	4.000	0.010
SPFR2113 - SPFR2115	-2.299	4.000	16.800	0.322

Singye: There were significant differences [H = 25.986 (5, n = 30), p < 0.001] amongst the non-target species trap captures by different lures. The pairwise mean comparisons (Table 10) indicated the significant differences for the pairs PCI-SPFR2112 (p_{bonf} = 0.008), PCI-SPFR2113 (p_{bonf} < 0.001), and SPFR2113-SPFR2114 (p_{bonf} = 0.013). From the comparisons, SPFR2113 had the least mean trap capture of non-target insects while PCI had the largest mean trap capture.

Table 10. Pairwise mean comparisons for the non-target organisms captured by lures in Singye

Comparison	z	W_i	W_j	p_{bonf}
PCI - SPFR2112	3.448	27.600	8.400	0.008
PCI - SPFR2113	4.418	27.600	3.000	< .001
PCI - SPFR2115	2.479	27.600	13.800	0.198
SPFR2111 - SPFR2113	2.802	18.600	3.000	0.076
SPFR2112 - SPFR2114	-2.371	8.400	21.600	0.266
SPFR2113 - SPFR2114	-3.341	3.000	21.600	0.013

Sampheling: The trap captures of Harmony EcoTech and PCI were not significantly different (p = 0.215, z = 1.254, Md Harmony EcoTech = 2.5, Md PCI = 0.5, n1 = n2 = 24)

Seasonal dynamics of male fall armyworm moths

The seasonal population dynamics of the FAW population showed a consistent pattern across all the study sites, with peak trap capture observed around mid-April and then later declining towards May and June. The synchronized population rise in mid-April seems to be due to the availability of its primary host plant, young maize plants in all the monitoring sites. FAW damage was more severe at the young growing phase such as seedling and early whorl stages (Kareem, Anjorin, Odeyemi, & Akinbode, 2022). On contrary, their population declined during the late spring and early summer suggested a potential effect of heavy downpours on fall armyworm. Rainfall traps moths and drown them in maize whorls and pupation tunnels such as soils (Sims, 2008).

Dabchegang, Guma, Punakha

The FAW population at peaked at around mid-April (about 400 male moths). However, the trap capture declined towards the latter half of April and further declining through May, and June (Figure 2).

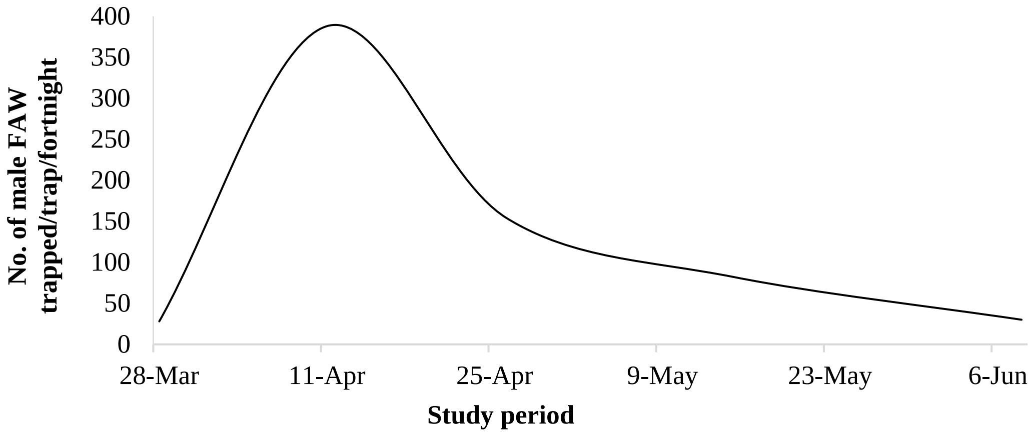

Figure 2. Population trend of male FAW moths at Dabchegang

Sampheling, Chukha

The trap capture of male FAW moths showed similar trend to that of Dabchegang, where the population showed peaked in the April and declined towards the end of the study period (Figure 3). The largest trap capture for Khempaithang was in later half of April (920 moths). The moth population declined towards June.

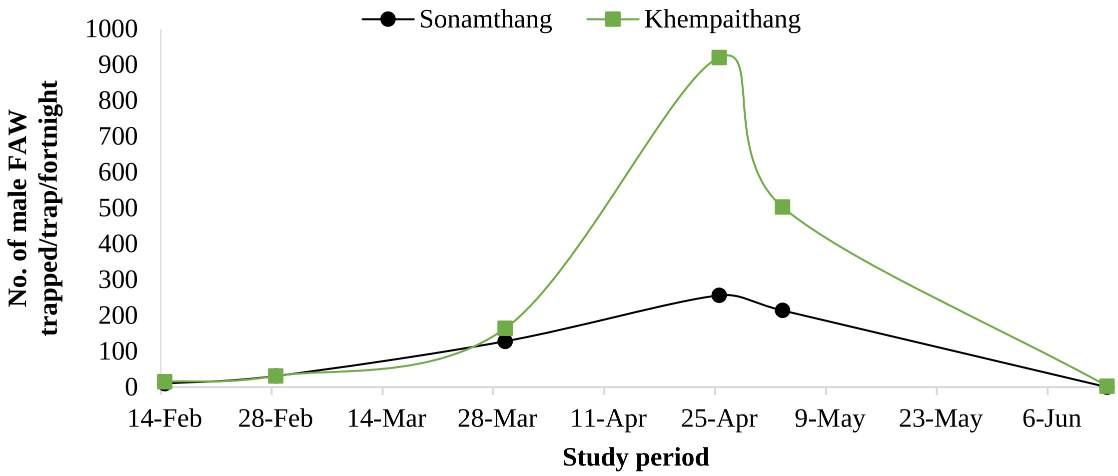

Figure 3. Population trend of male FAW moths at two villages of Sampheling, Chukha

Gakidling, Sarpang

The FAW moth population trend varied among the villages (Figure 4). At Rilangthang, the trap capture was highest (24 moths) towards the latter half of April and declined sharply towards June. At Khopitar, FAW population fluctuated throughout the study period. The peaks were seen in the first half of April (34 moths), first half of May (42 moths) and last half of May (23 moths).

Singye, Sarpang

The FAW population remained fairly minimal at Shariphu throughout the study period (Figure 4). The largest capture of FAW moths was seen in the first half of April (n=21 moths) and latter half of May (n=19 moths). For Yarpheling, the FAW population remained low in March and April but peaked in the latter half of May. The largest trap capture was 43 male FAW moths during the fourth week of May.

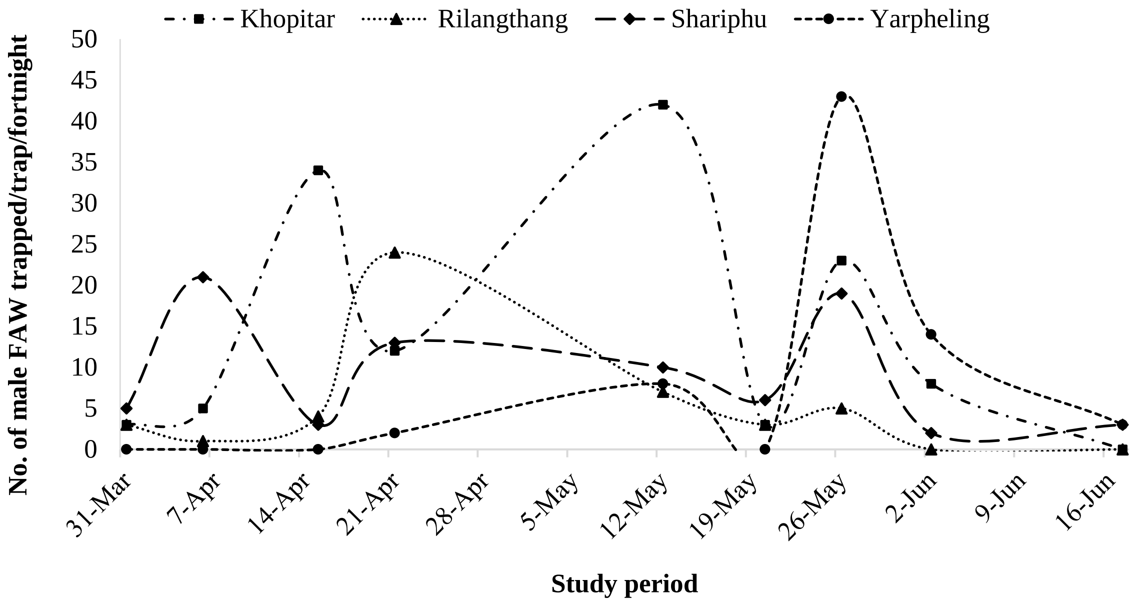

Figure 4. Population trend of male FAW moths in different villages of Gakidling and Singye, Sarpang

4 Conclusion

This study investigated the efficacy of seven pheromone lures in capturing fall armyworm moths in maize fields. Lure effectiveness varied across locations, but SFPR2114, PCI, and Ecotech lures caught the most fall armyworms. SPFR2113 and SPFR2112 caught the fewest non-target species, while PCI attracted the most. April saw peak moth captures in all locations, highlighting the need for monitoring and targeted control during this critical crop stage. Based on these findings, we recommend using SPFR2114, SPFR2113, SPFR2112, and Ecotech lures for fall armyworm monitoring in Bhutan, especially in April when captures spike. These lures can be valuable tools for early detection and studying population dynamics of fall armyworm. Their selectivity in attracting the target species while minimizing the capture of non-target beneficial insects makes them particularly suitable for precise monitoring. Understanding these population dynamics provides valuable insights for devising effective strategies to mitigate the impact of fall armyworm on maize during critical growth stages. Future studies should investigate factors impacting lure efficacy across various locations, explore integrating lures with other monitoring methods for holistic pest control, and evaluate the cost-effectiveness of lure-based strategies for smallholder farmers for sustainable crop protection.

5 Acknowledgement

We would like to express our sincere gratitude for the invaluable grant support provided by the Asian Food and Agriculture Cooperation Initiative (AFACI), Rural Development Administration of Korea. This generous financial assistance played a pivotal role in facilitating our research efforts, enabling us to carry out the current study effectively and with the necessary resources. We deeply appreciate AFACI's commitment to fostering research and development in the field of food and agriculture, and we are honored to have been beneficiaries of their support.

6 References

Adams, R. G., Murray, K. D., & Los, L. M. (1989). Effectiveness and Selectivity of Sex Pheromone Lures and Traps for Monitoring Fall Armyworm (Lepidoptera: Noctuidae) Adults in Connecticut Sweet Corn. *Journal of Economic Entomology*, *82*(1), 285–290. https://doi.org/10.1093/jee/82.1.285

Andrade, R., Rodriguez, C., & Oehlschlager, A. C. (2000). Optimization of a Pheromone Lure for *Spodoptera frugiperda* (Smith) in Central America. *Journal of the Brazilian Chemical Society*, *11*(6), 609–613. https://doi.org/10.1590/S0103-50532000000600009

Batista-Pereira, L. G., Stein, K., De Paula, A. F., Moreira, J. A., Cruz, I., Figueiredo, M. D. L. C., … Corrêa, A. G. (2006). Isolation, identification, synthesis, and field evaluation of the sex pheromone of the Brazilian population of *Spodoptera frugiperda*. *Journal of Chemical Ecology*, *32*(5), 1085–1099. https://doi.org/10.1007/s10886-006-9048-5

Bratovich, C., Saluso, A., Murúa, M. G., & Guerenstein, P. G. (2019). Evaluation of sex pheromone formulations to attract *Spodoptera frugiperda* (Lepidoptera: Noctuidae) adult males in Argentina. *Revista de La Sociedad Entomológica Argentina*, *78*(3), 7–14. https://doi.org/10.25085/rsea.780302

Cardé, R. T., & Minks, A. K. (1995). Control of moth pests by mating disruption: Successes and constraints. *Annual Review of Entomology*, *40*(1), 559–585. https://doi.org/10.1146/annurev.en.40.010195.003015

Cruz-Esteban, S., Rojas, J. C., & Malo, E. A. (2017). Calling behavior, copulation time, and reproductive compatibility of corn-strain fall armyworm (Lepidoptera: Noctuidae) from populations in Mexico. *Environmental Entomology*, *46*(4), 901–906. https://doi.org/10.1093/ee/nvx120

Cruz-Esteban, S., Rojas, J. C., & Malo, E. A. (2020). A pheromone lure for catching fall armyworm males (Lepidoptera: Noctuidae) in Mexico. *ACTA ZOOLÓGICA MEXICANA (N.S.)*, 1–11. https://doi.org/10.21829/azm.2020.3612271

Cruz, I., Figueiredo, M. L. C., & Silva, R. B. (2010). Monitoramento de Adultos *de Spodoptera frugiperda* (J. E. Smith) (Lepidoptera:Noctuidae) e Diatraea saccharalis (Fabricius) (Lepidoptera:Pyralidae) em Algumas Regiões Produtoras de Milho no Brasil. In *Documentos/Embrapa Milho e Sorgo*. https://doi.org/10.1017/CBO9781107415324.004

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., … Witt, A. (2017). Fall armyworm: Impacts and implications for Africa. *Outlooks on Pest Management*, *28*(5), 196–201. https://doi.org/10.1564/v28_oct_02

Du Plessis, H., Schlemmer, M.-L., & Van den Berg, J. (2020). The Effect of Temperature on the Development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects*, *11*(4), 228. https://doi.org/10.3390/insects11040228

El-Sayed, A. M., Delisle, J., De Lury, N., Gut, L. J., Judd, G. J. R., Legrand, S., … Trimble, R. M. (2003). Geographic variation in pheromone chemistry, antennal electrophysiology, and pheromone-mediated trap catch of North American populations of the obliquebanded leafroller. *Environmental Entomology*, *32*(3), 470–476. https://doi.org/10.1603/0046-225X-32.3.470

FAO. (2019). Report of first detection of *Spodoptera frugiperda*—Fall Armyworm (FAW) in Indonesia. Retrieved from IPPC Official Pest Report website: https://www.mendeley.com/catalogue/cf2d772d-4314-32a8-b884-dc7b362bfcc5/?userDocumentId=%7B6bec366e-ae96-4736-8ba9-c874703dfb05%7D

Farias, C. A., Brewer, M. J., Anderson, D. J., Odvody, G. N., Xu, W., & Setamou, M. (2014). Native Maize Resistance to Corn Earworm, *Helicoverpa zea*, and Fall Armyworm, *Spodoptera frugiperda*, with Notes on Aflatoxin Content. *Southwestern Entomologist*, *39*(3), 411–425. https://doi.org/10.3958/059.039.0303

Gebreziher, H. G., & Gebreziher, F. G. (2020). Effect of integrating night-time light traps and push-pull method on monitoring and deterring adult fall armyworm (*Spodoptera frugiperda*). *International Journal of Entomology Research*, *5*(1), 28–32.

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*(10). https://doi.org/10.1371/journal.pone.0165632

Harrison, F. P. (1984). The Development of an Economic Injury Level for Low Populations of Fall Armyworm (Lepidoptera: Noctuidae) in Grain Corn. *The Florida Entomologist*, *67*(3), 335. https://doi.org/10.2307/3494710

Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & van den Berg, J. (2019). Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*, Vol. 243, pp. 318–330. https://doi.org/10.1016/j.jenvman.2019.05.011

Jacobson, M., Redfern, R. E., Jones, W. A., & Aldridge, M. H. (1970). Sex pheromones of the southern armyworm moth: Isolation, identification, and synthesis. *Science, 170*(3957), 542–544. https://doi.org/10.1126/science.170.3957.542

Kareem, K. T., Anjorin, F. B., Odeyemi, O. O., & Akinbode, O. A. (2022). Fall armyworm (*Spodoptera frugiperda*) (J. E. Smith) (Lepidoptera: Noctuidae) infestation: maize yield depression and physiological basis of tolerance. *Journal of Plant Protection Research*, *62*(1), 12–21. https://doi.org/10.24425/jppr.2022.140294

Mahat, K., Mitchell, A., & Zangpo, T. (2021). An updated global COI barcode reference data set for Fall Armyworm (*Spodoptera frugiperda*) and first record of this species in Bhutan. *Journal of Asia-Pacific Entomology*, *24*(1), 105–109. https://doi.org/10.1016/j.aspen.2020.11.013

Malo, E. A., Cruz-Lopez, L., Valle-Mora, J., Virgen, A., Sanchez, J. A., & Rojas, J. C. (2001). Evaluation of Commercial Pheromone Lures and Traps for Monitoring Male Fall Armyworm (Lepidoptera: Noctuidae) in the Coastal Region of Chiapas, Mexico. *The Florida Entomologist*, *84*(4), 659. https://doi.org/10.2307/3496398

Montezano, D. G., Specht, A., Sosa-Gómez, D. R., Roque-Specht, V. F., Sousa-Silva, J. C., Paula-Moraes, S. V., … Hunt, T. E. (2018). Host Plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, *26*(2), 286–300. https://doi.org/10.4001/003.026.0286

Murúa, G., Molina-Ochoa, J., & Coviella, C. (2006). Population dynamics of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and its parasitoids in northwestern Argentina. *Florida Entomologist*, *89*(2), 175–182. https://doi.org/10.1653/0015-4040(2006)89[175:PDOTFA]2.0.CO;2

Muthukumar, M., & Kennedy, J. S. (2021). A Review of the Scientific Literature on the Use of Reproductive Pheromones in the Management of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Journal of Entomological Science*, Vol. 56, pp. 475–486. https://doi.org/10.18474/JES20-89

Prasad, Y. G., & Prabhakar, M. (2012). Pest monitoring and forecasting. In: D.P. Abrol and U. Shankar (Eds.), *Integrated Pest Management: Principles and Practice* (pp. 41–57). Wallingford UK: Cabi.

Prasanna, B. M., Huesing, J. E., Eddy, R., & Preschke, V. M. (2018). Fall Armyworm in Africa: A Guide for Integrated Pest Management, First Edition. Mexico, CDMX: CIMMYT. In *West Africa Regional Training of Trainers and Awareness Generation Workshop on Fall Armyworm Management, IITA, Cotonou, Bénin*.

Reyes-Prado, H., Segura, A. J. G., Martínez-Peralta, C., & Sosa, P. R. G. (2020). Non-target Insects Captured in Sex Pheromone Traps of *Spodoptera frugiperda* in Sorghum Surrounded by Other Crops and Weeds. *Southwestern Entomologist*, *45*(3), 643–648. https://doi.org/10.3958/059.045.0307

Sharanabasappa., Kalleshwaraswamy, C. M., Pravithra, H. B., Asokan, R., Magadeva Swamy,

H. M., Maruthi, M. S., … 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 Ecosystems*, *24*(1), 23–29. Retrieved from https://www.researchgate.net/publication/327704289%0Ahttp://www.indianjournals.com/ijor.aspx?target=ijor:pmhe&volume=20&issue=1&article=010

Sims, S. R. (2008). Influence of soil type and rainfall on pupal survival and adult emergence of the fall armyworm (Lepidoptera: Noctuidae) in southern Florida. *Journal of Entomological Science*, *43*(4), 373–380. https://doi.org/10.18474/0749-8004-43.4.373

Song, X. P., Liang, Y. J., Zhang, X. Q., Qin, Z. Q., Wei, J. J., Li, Y. R., & Wu, J. M. (2020). Intrusion of Fall Armyworm (*Spodoptera frugiperda*) in Sugarcane and Its Control by Drone in China. *Sugar Tech*, *22*(4), 734–737. https://doi.org/10.1007/s12355-020-00799-x

Tumlinson, J. H., Mitchell, E. R., Teal, P. E. A., Heath, R. R., & Mengelkoch, L. J. (1986). Sex pheromone of fall armyworm, *Spodoptera frugiperda* (J.E. Smith). *Journal of Chemical Ecology*, *12*(9), 1909–1926. https://doi.org/10.1007/bf01041855

Witzgall, P., Kirsch, P., & Cork, A. (2010). Sex Pheromones and Their Impact on Pest Management. *Journal of Chemical Ecology*, *36*(1), 80–100. https://doi.org/10.1007/s10886-009-9737-y