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EFFICACY OF BIOPESTICIDES AND INSECTICIDES AGAINST FALL ARMYWORM, *SPODOPTERA FRUGIPERDA* (LEPIDOPTERA: NOCTUIDAE) ON MAIZE

M. Mostafizur Rahman Shah[1*], Most. Sirajum Munira[1], Md. Forhad Hossen[1] and Md. Mahfuz Alam[2]

[1]Division of Entomology, Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur-5200.
[2]Crops Division, Bangladesh Agricultural Research Council, Farmgate, Dhaka-1215

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ABSTRACT

The fall armyworm (FAW), *Spodoptera frugiperda* was first recoded in Bangladesh on November 18, 2018, FAW had posed a major threat to maize production. To assess the effectiveness of different biopesticides and insecticides against FAW, a field study was conducted at the Bangladesh Wheat and Maize Research Institute (BWMRI) in 6 February 2020. The study tested virus-based bio-pesticides and newly formulated organic insecticides. Results showed that chemical insecticides were generally more effective than bio-pesticides in reducing infestation during the vegetative stage. However, during the reproductive stage, both chemical and bio-pesticide treatments significantly reduced cob infestation compared to untreated control plots. Among the tested insecticides, Spinosad 45SC (Tracer) provided effective control of small fresh windowpane (SFW) symptoms, maintaining low infestation levels throughout the growing stages, peaking 46% at six leaf stage (V6) and then reducing 0% at the tasseling stage. Incidence of infested whorl (IW), was minimal, with only minor occurrence at tasseling stage (10%). In contrast, *Spodoptera Nuclear Polyhedrosis Virus* (Spodo-NPV) was less effective at the early stages, showing high infestation levels of FAW symptoms at V6 (68%) and IW symptoms beginning at seven leaf stage (V7) (26%) and peaking at eight leaf stage (V8) (38%). However, SNPV proved effective in reducing both SFW and IW symptoms at the tasseling stage. *Spodoptera frugiperda MNPV* 32% (Fawligen) showed moderate control over immature larvae, with infestation levels decreasing from V6 (44%) at tasseling (0%). However, IW-type damages were more persistent, peaking at V8 (86%) and remaining at a significant level (10%) even at tasseling stage. In terms of yield, maize grain production was highest in plots treated with bio-pesticides. Fawligen-treated plots produced the highest yield (4594 ± 84 kg/ha), followed closely by Spodo-NPV (4522 ± 128 kgha^{-1}) and Spinosad 2.5% SC (Success) (4286 ± 285 kgha^{-1}). Based on these findings, Spodo-NPV and Fawligen are recommended for FAW control infesting maize crops, as they are both effective and safe for human health and environment.

Keywords: Fall Armyworm, Maize yield, Spinosad, *Spodoptera NPV Polyhedrosis Virus*, *Spodoptera frugiperda* MNPV, Chlorantraniliprole

*Corresponding author: *mmrshah.bwmri@gmail.com*

INTRODUCTION

Maize is the second most widely grown cereal crop in Bangladesh in terms of acreage and production. Its value has been rising steadily in recent years due to high demand from the poultry, dairy and fish farming industries. With its low production costs, higher profitability, strong demand in the poultry sector and resilience compared to other crops, many farmers have shifted from rice and wheat to maize cultivation (Kausar and Alam 2016). In addition to its use in animal feed, maize is also increasingly consumed by people in forms such as popcorn, baby corn and sweet corn. During the 2020-21 and 2021-22 *Rabi* and *Kharif* seasons, approximately 480,000 and 398,400 hectares of land were cultivated for maize, producing roughly 4.2618 and 4.1164 million metric tons of grain, respectively (BBS 2022). According to the 2023 report by the Department of Agricultural Extension (DAE), maize production reached 6.4220 million metric tons, covering an area of 496,882.34 hectares.

The intensification of maize cultivation, coupled with climate change, evolving resistance in plant pathogens, the introduction of invasive pests and indiscriminate pesticide use, has disrupted agro-ecosystem balance, highlighting the need for strategic management approaches in food production (Del 2017). Maize yields in Bangladesh are relatively low compared to other countries, primarily due to infestations by insect pests and diseases. Various pests attack maize at different growth stages, from planting to harvest. These include *Spodoptera* species, maize borers, jassids, and shoot flies. Among these, fall armyworm (*Spodoptera frugiperda* Smith) has gained particular attention for its potential to cause significant crop losses (Gondal *et al*. 2022). Growing crops with different growth cycles like summer-planted corn, cotton and millet during off-season periods creates conditions that allow *Spodoptera frugiperda* to move between plant species (Nagoshi 2009). This movement may explain why this pest has become more prevalent in crops where it was previously considered occasional or secondary insect pest (Barros *et al*. 2010).

The fall armyworm (*S. frugiperda*) is an invasive and highly destructive insect pest that originated in the America but has since spread globally. It was first reported in African regions such as Benin, Togo, and Nigeria (Nagoshi *et al*. 2019)

before reaching various states in India and subsequently spreading throughout Asia. Recently, the fall armyworm has also been detected in Bangladesh (Alam *et al*. 2018). In maize crops, the FAW causes substantial production losses due to the voracious feeding behavior of its larvae and its presence throughout the crop cycle. Yield losses can range from 34% to 40%, depending on the plant's developmental stage (Cruz 2002). The last three larval stages of the fall armyworm are especially damaging, consuming up to 98% of the maize crop. The larvae tend to feed on nearly all parts of the plant, showing a strong preference for reproductive components, particularly in the final instar stage. During the maize whorl stage, larvae reside inside the whorl, feeding on leaves and stems. This feeding behavior can suppress proper tassel formation or induce it prematurely. Larval injury to the cob silk reduces the chances of pollination and lowers the number of kernels per ear. FAW larvae also damage the cob directly by tunneling and feeding on kernels, which weakens the attachment at the ear base. After feeding, leaves display irregular white markings and a mesh-like appearance due to the larvae's chewing mouthparts, which promotes fungal growth (Acharya *et al*. 2020).

This species poses a serious threat to food security in Bangladesh, highlighting the urgent need for an effective and comprehensive management strategy to control this destructive pest. It is essential to conduct studies evaluating the effectiveness of chemical insecticides on target pests, as the adaptability of a population can vary with different developmental stages (Cruz 2002). Research on *Helicoverpa armigera* (Lepidoptera: Noctuidae) has shown that young caterpillars are highly susceptible to insecticides, whereas control efficacy declines significantly when insects reach more advanced stages. Additionally, in field conditions, insect generations are often asynchronous, with individuals at various developmental stages coexisting in the same area (Lucchini 1977). Managing this pest has required frequent insecticide applications, leading to the development of resistance in *S. frugiperda* populations to various products (Wang *et al.* 2018). This increased reliance on chemical control has also raised environmental concerns (Michelotto *et al*. 2017).

These studies are essential insights for managing pest species effectively (Sosa-Gómez and Omoto 2012). Given the significant threat posed by the Fall Armyworm (FAW) caterpillar and the limited research on chemical control efficacy

in maize production, this study aimed to assess the performance of some selected biopesticides and newly formulated chemical insecticides in controlling *S. frugiperda* under field conditions.

MATERIALS AND METHODS

This study was carried out at the research field of Bangladesh Wheat and Maize Research Institute (BWMRI) in 6 February 2020. The variety, Khoi Bhutta (popcorn) was used for this study. Insecticides used in this study are biopesticides and new molecule synthetic compounds with high LD_{50} values which signify decreased toxicity.

Maize field: A power-operated tractor was used to prepare the land, making sure that the tilling was deep enough, loose, and fine enough to promote healthy seed germination. The spacing between maize seeds was 25 cm and 60 cm from row to row. The rate of fertilizers was applied for one hectare of land as 260 kg of urea, 180 kg of TSP, 180 kg of MoP, 150 kg of gypsum, 10 kg of zinc sulfate, 8 kg of boric acid, and 100 kg of magnesium sulfate. One-third of urea along with all other fertilizers were applied during final land preparation prior to sowing. Half of the remaining urea is applied 30 days after planting (at the stage of 6 leaves), and the other half is applied 60 days after sowing, when the male flowers (tassels) appear. Weeding and irrigation were carried out as needed. The size of the experimental plot was 10m by 10m.

Treatments: The treatments, including biopesticides and synthetic new molecule insecticides were used in this study viz., Spodo-NPV (*Spodoptera Nuclear Polyhedrosis Virus*) @ 0.2g/ L water, Fawligen (*Spodoptera frugiperda* MNPV32%) @0.3ml/L water, Tracer 45SC (Spinosad 45%) @ 0.4ml/L water, Coragen 18.5% SC (Chlorantraniliprole) @0.5ml/ L water, Success 2.5%SC (Spinosad) @ 1.3ml/L water and Untreated control (Table 1). Four times spraying was planned to begin at 30 days after sowing and continued 7 days after that. Secondly, at 60 days after sowing and spraying was continued 7 days after that.

Leaf infestation: Leaf infestation data was collected in situ condition after the incidence of fall armyworm infestation. Data was collected from five spots of each

plot as maintained "W" pattern method. Ten plants per plot were examined, and the number of FAW-infested plants-either Small Fresh Windowpane (SFW) or Infested Whorl (IW)-was noted. Attach on that the top three leaves were considered as new infestation.

Cob infestation: Cob samples were taken from 2m by 3 rows (2 m × 1.8 m = 3.6 m^2) of maize plants in the field once the cobs had matured. A 3.6 m^2 unit area was used to record the number of plants, cobs, percentage of infested cobs, intesity of cob infestation and yield data. From one plot, three samples were taken. For every treatment, nine samples (3 samples x 3 replications) were created. A visual scale was used to collect data on the percentage of cob infestations and the scales were then converted to percentage damage (Williams *et al*. 2006). Percent cob infestation was calculated using following formula:

$$\text{Percent cob infestation} = \frac{\text{Number of infested cobs}}{\text{Total number of cobs}} \times 100$$

The percentage intensity of the infestation was determined by the area of a cob that was infested. Data on grain yield were taken into account with a moisture content of 14% and expressed as kilogram per hectare.

Table 1. Bio pesticides and insecticides applied against Fall Armyworm in maize production.

Treatments (Trade name)	Active ingredient	Manufacturer	Doses (ml/l water)	Group	WHO hazard category
Spodo-NPV	Spodoptera Nuclear Polyhedrosis Virus	Ispahani Agro Ltd, BD	0.2g/ l	Microbial pesticide	III
Fawligen	Occlusion bodies of *Spodoptera frugiperda* MNPV-3AP2: 32%; Other ingredients: 68%	AgBiTech LLC, TX 76155, USA	0.3ml/ l	Microbial pesticide	III
Tracer	Spinosad 45%	Auto crop care Ltd, BD	0.4ml/l	Newer	III
Coragen	Chlorantraniliprole 18.5%	Petrochem Agro-Industries Ltd, BD	0.5ml/ l	Newer	U
Success	Spinosad 2.5%	Auto crop care Ltd, BD	1.3ml/l	Newer	III
Untreated control	Water	-	-	-	-

III= slightly hazardous, U= unlikely to present acute hazard

Data analysis: Three replications were considered as part of the Randomized Complete Block Design (RCBD) design used in this study. CropStat 7.2 was used to analyze the data using balanced analysis of variance. Five spots in each plot, each with ten plants in compliance, were used to calculate the mean data of leaf infestation. Each figure represents a single treatment and three replications of each treatment were used. After being converted into square root values, the data on the percentage of leaf infestation was examined. Three locations from each plot were used to collect data for the yield and yield contributing attributes; each spot was kept at a size of 2 m × 1.8 m (3 rows) = 3.6 m^2 unit area. ANOVA was used to analyze the percentage data at the 5% level of significance.

RESULTS AND DISCUSSION

Effect of bio pesticides and insecticides on Fall armyworm infestation in maize: The Table 2 illustrated the efficacy of different treatments (Spodo-NPV, Fawligen, Tracer, Coragen, Success, and a Control) on FAW infestation at various maize plant growth stages: four leaf stage (V4), six leaf stage (V6), seven leaf stage (V7), eight leaf stage (V8) and tasseling stage. For each stage and treatment, percent infestation values were recorded with significance levels indicated. In the maize growth stages, mainly focused on two specific symptoms: Small Fresh Windowpane (SFW) like damage caused by immature FAW larvae and Infested Whorl (IW) like damage caused by mature FAW larvae. The significance of differences was assessed with Least Significant Difference (LSD) values and P-values, with significant differences denoted at a 1% level (**).

After application of pesticides, *Spodoptera Nuclear Polyhedrosis Virus* (SNPV) was not so effective at initial stages SFW infestation begins at 4% in the V4 stage, peaks at 68% in the V6 stage and reduces significantly, reaching 0% by the tasseling stage. In the IW symptoms there was no infestation at V4 and V6 stages, started at the V7 stage (26%) and infestation rise sharply to 38% by V8 before dropping to 6% by the tasseling stage. But effective in reducing both SFW and IW symptoms at the tasseling stage. Total infestations were low, with a notable peak of 68% at the V6 stage. This suggests that while SNPV offers some control, it might not prevent early infestations effectively. SNPV showed mixed effectiveness, reducing infestation at tasseling stage but with higher levels at earlier stages. This aligns with

findings on biopesticides, which often need repeated applications to maintain low pest levels (Geisler *et al*. 2024).

Spodoptera frugiperda MNPV32% (Fawligen) showed a moderate control over immature larvae starts with 8% infestation at V4, with a peak of 44% at V6 before falling to 0% at the tasseling stage. But IW type damages were more persistent, infestation were absent in early stages, but rises to 86% at V8 before reducing to 10% at tasseling stage. Total incidence showed high infestation at V8 with 90%, indicating substantial efficacy at early stages but less control at V8. Fawligen's high infestation levels during V6 and V8 stages suggest its limited efficacy in controlling mid-stage infestations, though it provided eventual control. Studies have shown that Fawligen can be effective under specific conditions but may require supplementary treatments at high-pressure pest environments (Prasanna *et al.* 2018).

On the other hand, chemical pesticides provided strong control over both SFW and IW symptoms. Tracer effectively controlled SFW symptoms with low levels of infestation throughout the stages, begins with no infestation at V4, spikes at 46% at V6, and remains low afterward, reaching 0% by the tasseling stage. IW symptoms were negligible; there is no infestation at early stages, with a peak only at the tasseling stage (10%). Total infestations showed generally low infestation, with a slight peak in V6 and minimal infestation afterward, showing effective control overall. Tracer's low infestation rates and maintained control through tasseling stage reflect its effectiveness, especially as a spinosad-based pesticide known for rapid pest control with minimal environmental impact (Wang *et al.* 2021).

Chlorantraniliprole (Coragen 18.5% SC) maintained good control SFW symptoms showed a low initial infestation, peaking at 44% in the V6 stage before declining to 0% at tasseling stage and IW symptoms was minimal, with a small peak at V8 (4%) and 8% at tasseling stage. Total infestations remains low, suggesting effective control. Coragen's consistent pest suppression aligns with prior studies highlighting chlorantraniliprole's efficacy in targeting FAW without harming beneficial insects (Huang *et al.* 2020). Its extended control through multiple growth stages emphasizes its reliability.

Success 18.5% SC also provided consistent control showed a reduction in SFW symptoms started with 6% infestation, peaks at 52% at V6 and remains low

afterward and IW Infestation is minimal, with minor peaks in later stages but reaches 0% at the tasseling stage. Total infestations showed moderate control with a lower infestation profile than untreated Control. Success effectively reduced infestation at tasseling stage, though it had slightly higher peaks than other chemical treatments. This indicated that might be beneficial as part of an integrated pest management (IPM) approach (Mendesil *et al*. 2024).

Finally, the control group experienced the highest levels of both SFW and IW Infestation begins low but reaches the highest levels by V8 (94%) and remains high at the tasseling stage (46%). Total infestations remained high throughout the stages, highlighting the need for effective control measures. Lack of treatment in the control plot resulted in severe infestation indicating the importance of applying pesticides.

Overall, SNPV and Fawligen had showed less capability to control both immature and mature larvae of FAW. That might be high temperature in that period (month of April 2020) where virus based bio-pesticides did not function effectively. The results show that Tracer and Coragen treatments were most effective in reducing FAW infestation across growth stages, with low infestation levels observed throughout. SNPV and Fawligen also provide control but have higher infestation peaks during the V6 and V8 stages. The Control group shows persistently high infestation, underscoring the necessity of treatments to manage FAW effectively.

These results demonstrate that Coragen and Tracer provided the most consistent control across different growth stages, effectively reducing infestation at tasseling stage. The biocontrol agents SNPV and Fawligen also contributed to pest suppression but showed fluctuating efficacy, especially at the V6 and V8 stages, which aligns with challenges in achieving full pest control with biopesticides at high-pest-pressure environments (Lacey *et al*. 2015). The untreated Control group experienced consistently high infestation, emphasizing the necessity of pest management strategies. Without intervention, FAW causes significant yield and quality losses, and integrated approaches combining chemical and biocontrol methods may optimize pest management effectiveness (De Groote *et al*. 2020).

Effect of bio pesticides and insecticides on plant growth, yield contributing characters and cob infestation in maize: Table 3 summarized the detailed analysis

of the data on plant population, cob count, cob infestation, and infestation intensity in maize after applying various treatments. This information provides insight into how different treatments affect plant productivity and pest infestation levels.

Plant number/3.6 m²: Across all treatments, the number of plants per 3.6 m² was fairly consistent, ranging from 24.8 (Fawligen) to 26.4 (Coragen). The untreated Control had 25.2 plants, indicating that treatment applications did not significantly show the impact on plant population density.

Cob number/3.6 m²: Cob number varied slightly, with Success produced the highest average number of cobs (27.6 per 3.6 m²) followed by Fawligen (27.0) and Coragen (27.0), while the Control had the lowest (23.6). Treated plots showed an increase in cob number compared to the control. Success treated plot had the highest cob number increase over control at 16.95%, followed closely by Coragen and Fawligen (both at 14.41%). The increase in cob count suggests that insecticide applications potentially reduced pest pressure, allowing plants to allocate more resources toward reproductive growth, resulting in higher cob counts. The increase in cob count suggests that insecticide applications potentially reduced pest pressure, allowing plants to allocate more resources toward reproductive growth, resulting in higher cob counts.

Table 2. Mean percent infestation of FAW observed at different stages of plant growth after treatments application

Treatments	Infestation types	Percent infestation				
		V4 (26.3.2020)	V6 (5.4.2020)	V7 (12.4.2020)	V8 (20.4.2020)	Tasseling (4.5.2020)
SNPV	SFW	4.0 (1.5)	68.0 (8.2)	6.0 (1.9)	4.0 (1.5)	0.0 (0.7)
	IW	0.0 (0.7)	0.0 (0.7)	26.0 (4.9)	38.0 (6.1)	6.0 (2.2)
	Total	4.0 (1.5)	68.0 (8.2)	32.0 (5.5)	42.0 (6.4)	6.0 (2.2)
Fawligen	SFW	8.0 (2.5)	44.0 (6.6)	22.0 (4.7)	4.0 (1.5)	0.0 (0.7)
	IW	0.0 (0.7)	0.00 (0.7)	36.0 (6.0)	86.0 (9.3)	10.0 (2.7)
	Total	8.0 (2.5)	44.0 (6.6)	58.0 (7.6)	90.0 (9.5)	10.0 (2.7)

Treatments	Infestation types	Percent infestation				
		V4 (26.3.2020)	V6 (5.4.2020)	V7 (12.4.2020)	V8 (20.4.2020)	Tasseling (4.5.2020)
Tracer	SFW	0.0 (0.7)	46.0 (6.5)	2.0 (1.2)	2.0 (1.2)	0.0 (0.7)
	IW	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	10.0 (2.7)
	Total	0.0 (0.7)	46.0 (6.5)	2.0 (1.2)	2.0 (1.2)	10.0 (2.7)
Coragen	SFW	2.0 (1.2)	44.0 (6.6)	6.0 (1.9)	0.0 (0.7)	0.0 (0.7)
	IW	0.0 (0.7)	0.0 (0.7)	2.0 (1.2)	4.0 (1.5)	8.0 (2.5)
	Total	2.0 (1.2)	44.0 (6.6)	8.0 (2.5)	4.0 (1.5)	8.0 (2.5)
Success	SFW	6.0 (1.9)	52.0 (7.2)	12.0 (2.8)	2.0 (1.2)	0.0 (0.7)
	IW	0.0 (0.7)	0.0 (0.7)	4.0 (1.5)	6.0 (1.9)	0.0 (0.7)
	Total	6.0 (1.9)	52.0 (7.2)	16.0 (3.6)	8.0 (2.2)	0.0 (0.7)
Control	SFW	54.0 (7.3)	80.0 (8.9)	10.0 (2.7)	2.0 (1.2)	0.0 (0.7)
	IW	0.0 (0.7)	0.0 (0.7)	58.0 (7.5)	94.0 (9.7)	46.0 (6.6)
	Total	54.0 (7.3)	80.0 (8.9)	68.0 (8.1)	96.0 (9.8)	46.0 (6.6)
LSD at 5%	SFW	1.79	1.93	2.27	1.65	0.00
	IW	0.00	0.00	1.60	1.69	1.87
	Total	1.79	1.93	2.15	1.85	1.87
P	SFW	**	ns	Ns	ns	Ns
	IW	ns	ns	**	**	**
	Total	**	ns	**	**	**

Values in the parentheses were transformed into square root, ** = significant at 1% level, ns = non-significant. SFW = Small Fresh Windowpane, IW denoted as Infested Whorl, V4 =four leaf stage, V6=Six leaf stage, V7=Seven leaf stage, V8= Eight leaf stage and Tasseling= Tasseling stage

Cob infestation (%) and percentage decrease in infested cobs over control: Rate of cob infestation ranged from a low of 12.2% in the Coragen treatment to a high of 22.9% in the untreated control. Notably, Coragen had the most effective in reducing infested cobs, indicating strong efficacy in limiting pest impact on cobs. The Control group had the highest infestation rate, suggesting that pest control measures significantly showed impact on cob quality. In terms of percentage decrease in infested cobs over control, Coragen treatment achieved the highest reduction (46.72%), indicating strong efficacy against pests. Fawligen and SNPV also showed substantial decreases (28.82% and 33.62%, respectively). This suggests that Coragen may have superior effectiveness in reducing cob infestation in maize.

Infestation intensity: Infestation intensity was markedly higher in the untreated control plot, with an average of 14.6%, compared to treated plots, which ranged between 3.4% (Fawligen) and 4.6% (Success). Coragen and Tracer also exhibited reduced infestation intensity, aligning with their lower cob infestation rates. The reduction in intensity suggests that treatments, particularly Fawligen, are effective not only lowering infestation rates but also reducing the severity of pest damage to the maize cobs.

The results demonstrate that Coragen was the most effective treatment in reducing cob infestation (12.2%) and keeping infestation intensity low (4.2%). This aligns with studies showing that Coragen, an insecticide with chlorantraniliprole as the active ingredient, provides potent, targeted action against fall armyworm (FAW) and minimizes crop damage in maize, effectively protecting yield and quality (Wang *et al*. 2023).

Fawligen, a bio-pesticide based on entomopathogenic viruses, also performed well, with the lowest infestation intensity (3.4%). Biopesticides like Fawligen effectively target pests without harming beneficial organisms or the environment. They are increasingly being adopted for sustainable agriculture due to their targeted pest control and minimal environmental impact (Lacey *et al*. 2015). While Tracer and Success showed reasonable control of cob infestation and reduce intensity, Success treated plot had slightly higher infestation (17.4%) than other treatments. However, it resulted the highest cob production (27.6 cobs per unit area). The higher cob number may reflect improved plant health due to treatment application but could also be due to environmental conditions favoring cob formation in the particular

plot. In contrast, the untreated control had the highest levels of cob infestation (22.9%) and intensity (14.6%). These results highlight the necessity of pest control measures against FAW, as untreated plots not only have higher pest damage but may also experience yield losses. Studies corroborate that untreated maize plots can experience substantial yield loss due to FAW, with reductions in cob quality and size directly reduce marketability (De Groote *et al.* 2020).

Overall, these findings suggest that Coragen and Fawligen are effective in managing FAW infestation while promoting sustainable crop health. The non-significant results for plant number and cob count indicate that treatment effects on FAW were more directly associated with reduced infestation intensity rather than plant or cob density.

Table 3. Effect of insecticides on growth, yield contributing characters and cob infestation in maize crop

Treatments	Plant number/ 3.6m²	Cob number/ 3.6m²	Cob number increased over control (%)	Infested cob (%)	Infested cob decreased over control (%)	Intensity (%)	Intensity decreased over control (%)
SNPV	25.8 ± 0.2	26.8 ± 0.9	13.56	15.2 ± 4.4	33.62	4.2 ± 1.5	64.38
Fawligen	24.8 ± 0.4	27.0 ± 0.7	14.41	16.3 ± 1.4	28.82	3.4 ± 0.5	76.71
Tracer	25.2 ± 0.5	26.8 ± 0.2	13.56	16.4 ± 3.0	27.95	4.2 ± 0.9	71.23
Coragen	26.4 ± 0.2	27.0 ± 0.8	14.41	12.2 ± 3.3	46.72	4.2 ± 0.6	71.23
Success	25.8 ± 0.7	27.6 ± 1.7	16.95	17.4 ± 1.4	24.02	4.6 ± 0.4	68.49
Control	25.2 ± 0.4	23.6 ± 0.7	-	22.9 ± 0.7	-	14.6 ± 3.5	-
LSD at 5%	1.28	2.58		6.87		4.79	
P	ns	ns		ns		**	

** denoted as significant at 1% level; ns for non-significant

Effect of various insecticides applied against Fall Armyworm in Maize: The Figure 1 illustrated the yield of maize crops (measured in kg/ha) following the application of different treatments aimed to controlling fall armyworm (FAW) infestations. The results were evaluated for statistical significance with an LSD at 5% and the significance level is denoted at 1% (**), indicating meaningful differences among the treatments.

Fawligen (a Biocontrol Agent) treatment achieved the highest yield in the study, 4594 ± 84 kg/ha. This yield indicated strong efficacy in pest suppression by

Fawligen, possibly due to its compatibility with the FAW lifecycle and ability to manage infestations with minimal crop damage.

Yield with SNPV treatment reached 4522 ± 128 kg ha^{-1}, indicating that SNPV provided effective pest suppression, supporting a high yield comparable to other biocontrol agents. This suggests that SNPV is a viable option for integrated pest management (IPM) as it successfully minimized yield losses due to FAW attack without the use of chemical pesticides. Tracer treatment resulted in a comparatively lower yield of 4183 ± 55 kg ha^{-1}. While Tracer effectively suppressed infestation in earlier growth stages, this lower yield suggested that it may not provide extended protection throughout the season. The data shows that Fawligen and SNPV were the most effective treatments in terms of yield, with 4594 ± 84 kg/ha and 4522 ± 128 kg ha^{-1}, respectively, demonstrating the effectiveness of biocontrol agents in managing FAW without sacrificing crop productivity. This aligns with findings from other studies that show biocontrol agents can sustain high yields while maintaining environmental sustainability (Prasanna *et al*. 2018). The success of these biocontrol treatments supports their integration into IPM programs, particularly in regions where FAW is prevalent.

Coragen (Chlorantraniliprole-based Insecticide) treatment resulted in a yield of 4153 ± 238 kg ha^{-1}, which is moderate but effective in reducing FAW damage to a significant extent. Chlorantraniliprole's targeted mode of action against borer insects like FAW likely contributed to a more stable yield compared to Tracer. Success (Spinosad-based Insecticide) treatment resulted in a yield of 4286 ± 285 kg ha^{-1}, which is close to Coragen's yield and suggests a moderate level of pest control. Spinosad has shown efficacy in controlling FAW, likely contributing to reduced crop damage and resulting higher yield.

Coragen and Success (yielding 4153 ± 238 kg ha^{-1} and 4286 ± 285 kg ha^{-1}, respectively) were effective at moderating FAW infestation and maintained yields above the untreated control plot. These insecticides are known for their targeted modes of action and are highly effective in protecting maize crops from FAW without causing significant harm to beneficial insects. This is especially valuable in IPM frameworks, where selective control agents like Coragen and Success can reduce environmental impact while effectively managing the pests (Huang *et al.* 2020).

Tracer (Spinosad-based Insecticide) resulted moderate yield (4183 ± 55 kg ha^{-1}), despite of its efficacy in suppressing infestation. Tracer's performance aligns with research indicating that while spinosad is effective against FAW at early stages, it may not provide sufficient season-long control, especially when pest pressure is high (Hertlein *et al*. 2011).

The untreated control plot had the lowest yield of 3692 ± 184 kg ha^{-1}, demonstrating the severe impact of FAW infestations on crop productivity. This highlights the necessity of implementing pest management strategies to avoid substantial yield losses in FAW-prone areas. The untreated control yielding 3692 ± 184 kg ha^{-1}, showed the highest crop losses. This highlights the importance of active FAW management to prevent economic losses, as untreated crops face significant reductions in yield due to uncontrolled infestations. Research has established that FAW infestations can cause yield reductions of up to 40% if left untreated, underscoring the need for effective pest management strategies (Day *et al*. 2017).

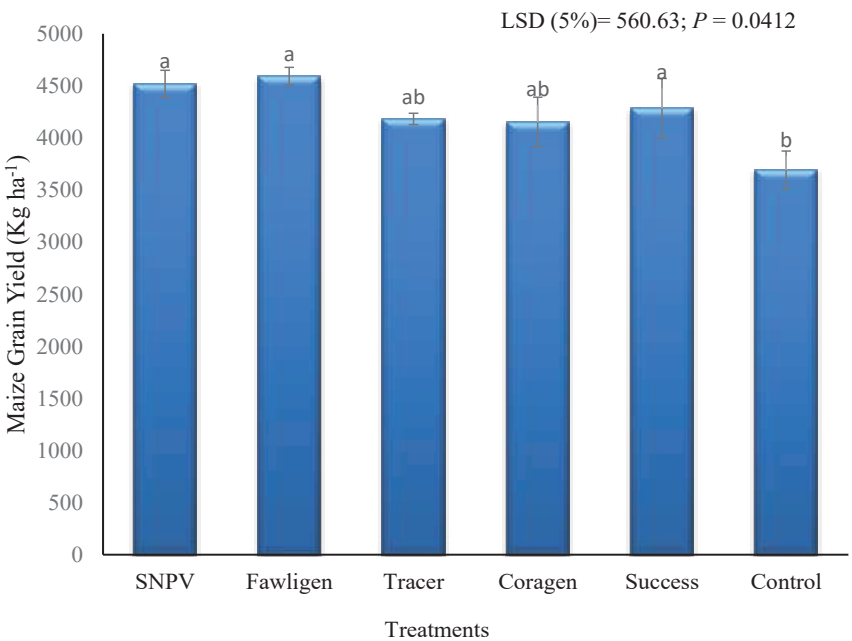


Fig. 1. Maize grain yield differed for using bio pesticides and insecticides applied for the management of Fall Armyworm.

Relationship between cob infestation (%)/3.6 m² and yield (kgha⁻¹) of maize: The data from Fig. 2 illustrated a linear relationship between the cob infestation (%)/3.6 m² and their yield per hectare (measured in kg). A negative correlation was evident between the cob infestation (%) and their yield. Specifically, for every one percent infestation increase in cob infestation (%)/3.6 m², the yield of maize per hectare decreases by 117.83 kg. A regression line was constructed to represent this association, formulated as y = -145.83x + 4748.7, where 'y' represented yield (kg ha⁻¹) and 'x' represented cob infestation (%)/3.6 m². The coefficient of determination, $R^2 = 0.7184$, indicated that 71.84% of the variability in maize yield per hectare was attributed to the variation in cob infestation (%)/3.6 m².

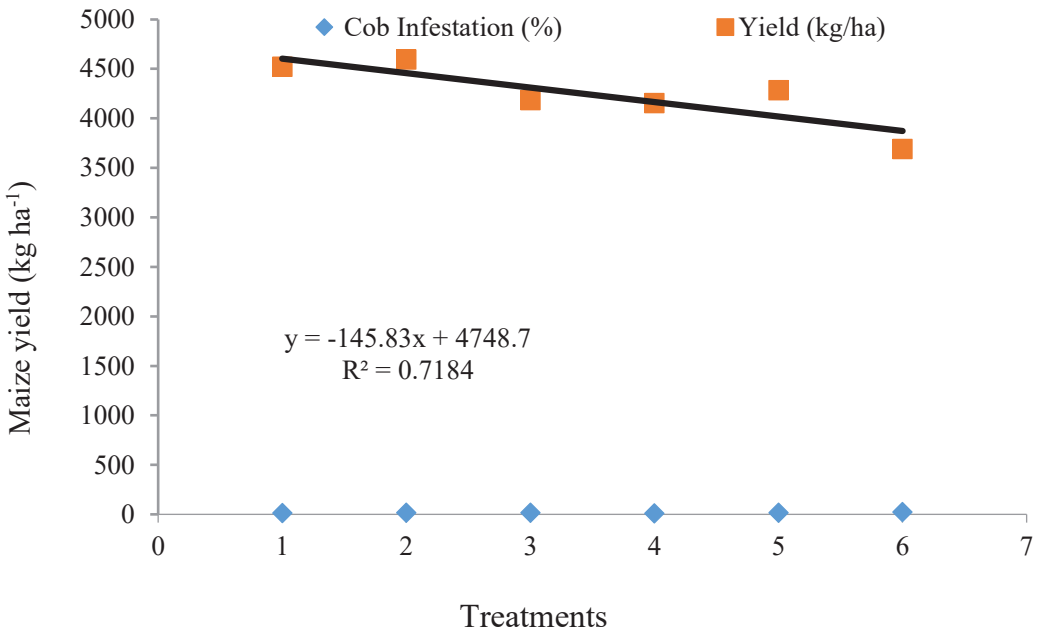


Fig. 2. Relationship between cob infestation (%)/3.6 m² and yield (kg ha⁻¹) of maize. Where, 'y' represented yield (kg ha⁻¹) and 'x' represented cob infestation (%)/3.6 m²

Relationship between total FAW infestation (%) and yield (kgha⁻¹) of maize: The relationship between the total FAW infestation (%) and yield per hectare (measured in kilogram) in the field was found to be linear (Fig. 3). There's a negative correlation between the width of total FAW infestation (%) and yield. Specifically, for every one percent increase in total FAW infestation (%), the yield of maize

per hectare decreases by 117.83 kg. A regression line was fitted to represent this relationship, expressed as y =-145.83x + 4748.7, where 'y' represented yield (kg ha^{-1}) and 'x' represented FAW infestation (%). The coefficient of determination, $R^2 = 0.7184$, indicated that 71.84% of the variability in maize yield per hectare was explained by the variation in FAW infestation.

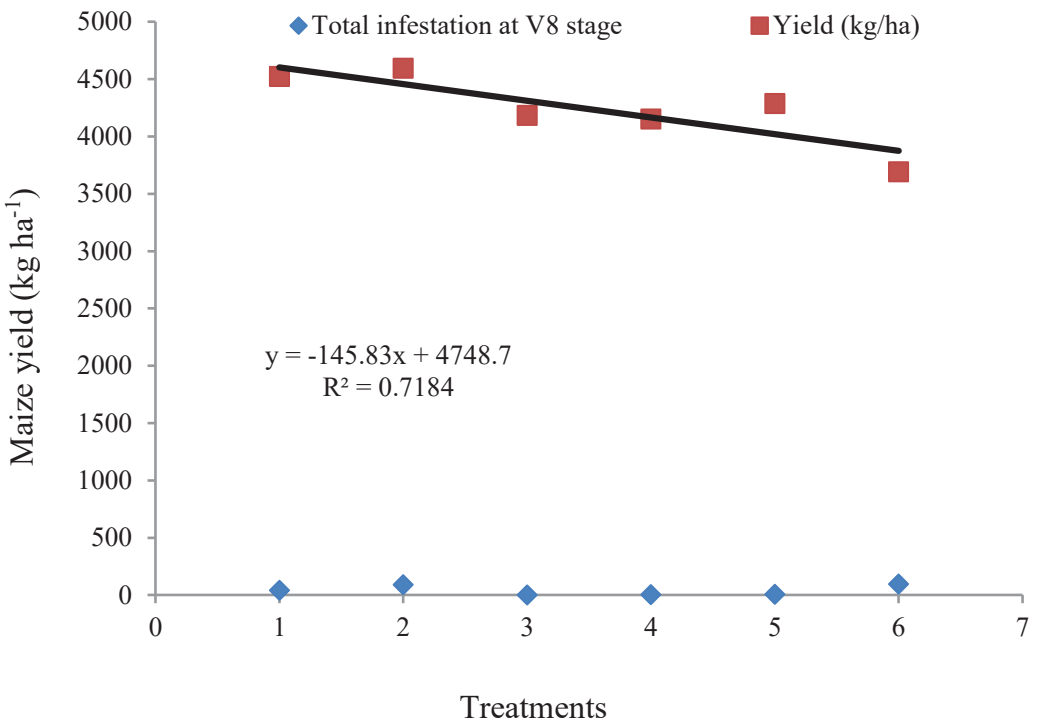


Fig. 3. Relationship between total FAW infestation (%) and yield (kg ha^{-1}) of maize grain. Where, 'y' represented yield (kg ha^{-1}) and 'x' represented total FAW infestation (%)

CONCLUSION

The application of biopesticides, such as SNPV and Fawligen, has proven highly effective in reducing FAW infestations and enhancing maize yields. Although infestation levels during the vegetative stage were somewhat higher with these treatments, SNPV and Fawligen demonstrated superior overall performance in FAW control and yield improvement. Tracer, Success, and Coragen were also effective

in managing FAW symptoms, though their impact on yield varied. Predictably, the control group showed consistently high infestation levels and the lowest yield, underscoring the critical importance of effective pest management in maize cultivation. Given the high yields, ecological safety, and health benefits associated with biopesticides, SNPV and Fawligen are particularly recommended for FAW management.

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