

## Evaluation of soil- based non chemical formulations against fall armyworm, *Spodoptera frugiperda* (J.E.Smith) on maize in Manipur condition

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The fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is an invasive lepidopteran pest of global significance, posing severe threats to maize production due to its rapid reproduction, wide host range, and adaptability to diverse environmental conditions. Conventional chemical control remains the dominant management approach but is increasingly constrained by resistance development, ecological concerns, and potential health risks. The present study aimed to evaluate the efficacy of selected non-chemical insecticidal formulations mixed with soil for its management under field conditions during the *kharif* season of 2023-24 at the College of Agriculture, Central Agricultural University, Imphal. Among the treatments, T<sub>4</sub> (soil + *Bacillus thuringiensis* var. *kurstaki* @ 50 mL/kg soil) recorded the lowest leaf damage (4.27, 2.07, and 2.00), minimum percent plant infestation (29.33%, 20.33%, and 10.00%), and lowest larval population (0.13, 0.10, and 0.07 larvae per ten plants) at 7, 14, and 21 DAT, respectively. All treatments performed significantly better than the untreated control, with T<sub>4</sub> (soil + *Bacillus thuringiensis* var. *kurstaki*) recording the lowest cob damage (1.11) and the highest grain yield (86.36 q/ha) with an increase of 34.92 q/ha over control. Overall, soil application of *Bacillus thuringiensis* var. *kurstaki* can be considered a promising eco-friendly option for managing *S. frugiperda* in maize.

**Keywords:** *Bacillus thuringiensis*, Bait, Maize, Soil, *Spodoptera frugiperda*

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Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), designated as a formidable threat by the Food and Agriculture Organization of the United Nations (FAO), is an extensive migratory pest indigenous to tropical and sub-tropical regions of the Americas. Belonging to the family Noctuidae under the order Lepidoptera, it was first reported to invade Central and Western Africa in 2016<sup>1</sup>. In Asia, it was initially detected in India in 2018, causing significant agricultural devastation<sup>2</sup>. Over time, *S. frugiperda* has proliferated to various other regions of the country<sup>3</sup>, with the propensity to outcompete other major maize stem borers and defoliators<sup>4</sup>. Its highly adaptable nature, coupled with its high dispersal and reproduction rates, could enable the pests to invade over 70 countries globally<sup>5</sup>. As a polyphagous pest, *S. frugiperda* consumes over 350 plant species, inflicting severe damage on economically important cultivated crops such as maize, rice, sorghum, sugarcane, cotton, and various vegetables<sup>6</sup>. Economically, the pest has posed annual loss ranging from 22-67% worldwide<sup>7</sup>.

In India, it has emerged as a primary agricultural pest, significantly impacting maize cultivation and resulting in substantial economic losses<sup>8</sup>. The pest affects maize at all phases of growth, from seedling to ear development. This can result in considerable yield losses, while feeding on the ear can reduce both the quality and yield of the crop.

The rapid spread of this pest in India has led to numerous recommendations of chemical insecticides as a foliar application, recognized as the most effective method for controlling this pest<sup>9</sup>. However, the concealed feeding behaviour within the whorl portion of maize hinders insecticides from effectively reaching the target area<sup>10</sup> and as a result, strategies are essential to make the insecticides reach the leaf whorl. Despite their widespread use, the indiscriminate application of insecticides has raised serious concerns including harmful residues, environmental contamination, and health risks. Moreover, repeated exposure has contributed to the development of resistance in *S. frugiperda* populations, thereby reducing the long-term effectiveness of insecticides<sup>11</sup>.

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Therefore, identifying suitable non-chemical insecticidal formulations and biological control agents, along with efficient application methods, is crucial for developing effective integrated pest management (IPM) strategies against *S. frugiperda*. Traditional practices such as whorl application of sand, soil, and ash have been adopted by farmers in Africa<sup>12</sup> and America<sup>13</sup>; however, their efficacy under field conditions remains poorly understood. Furthermore, limited scientific information is available on the effectiveness of these practices when combined with biological insecticides under field conditions. In this context, the present study aimed to evaluate the effectiveness of soil- and sand-based application methods, alone and in combination with selected non-chemical insecticides, in managing *S. frugiperda* with respect to larval population, leaf damage, and yield in maize.

### Materials and Methods

The field experiment was conducted at Agricultural Research Farm, Andro, Central Agricultural University which is located 24° 25' N latitude and 93° 56' E longitude with an elevation of 790 metres above mean sea level. The soil of the experimental site was clay loam in texture with a pH of 5.5. All the recommended agronomic practices for raising the maize including weeding, cultural practices etc., were followed to keep the plants healthy. Maize seeds (RE-55) were collected from All India Coordinated Research Project on Maize, College of Agriculture, Iroisemba, Central Agricultural university, Imphal. The crop was sown on 15<sup>th</sup> July 2023. The experiment was laid out in randomized block design (RBD) comprised ten treatments, viz., soil @ 0.5g/plant, soil + URO insecticide @ 5 mL/kg soil, soil +lime @ 800 g+200 g, soil + *Bacillus thuringiensis* var. *kurstaki* @ 50 mL/kg soil, soil + *Metarhizium*

*anisopliae* @ 65 g/kg soil, soil + *Beauveria bassiana* @ 65 g/kg soil, sand @ 0.5 g/plant, bait (soil + jaggery + sand + water) @ 600 g + 130 g + 70 g + 200 mL, chlorantraniliprole 18.5 SC (check) @ 0.4 mL/l of water and untreated control. Each treatment was replicated thrice. The maize variety, RE-55, was sown in plot size of 3m x 3m at a spacing of 60 cm x 25 cm for each treatment. The crop was maintained weed-free by two hand weeding, the first at 30-40 days after sowing (DAS) and the second at 50-60 DAS. No chemical weed control was adopted. The treatments were applied once at 47 DAS, coinciding with the period of *S. frugiperda* incidence. During spraying, insecticides were directed specifically at the whorl region using knapsack sprayer. The application of soil mixed with insecticidal formulations was done by using hand gloves (Plate 1). The crop was harvested at 104 DAS, when the cobs were mature enough. Harvesting was done manually by hand picking. Soil and sand were sterilized in an autoclave to remove or kill all forms of microorganisms such as fungi, bacteria, viruses, etc., at a temperature of 121°C and 16 psi for 180 min or (2) 90 min cycles.

### Data observation and statistical analysis

Observations were recorded on 10 pre-determined plants/plot, leaving those in the border rows. Pre-treatment leaf damage, larval count and percent plants infested and whorls feeding injury on 1-9 scale. Post-treatment larval count, percent plants infested and leaf damage rating using Davis scores at 7,14, 21 days after each application. Cob damage rating at harvest based on 1-9 Davis scale and grain yield/plot at 12% moisture were recorded based on the rating scale given by Davis and Williams<sup>14</sup>. The mean values of the data were subjected to statistical analysis after appropriate transformations to determine treatment effects using analysis of variance

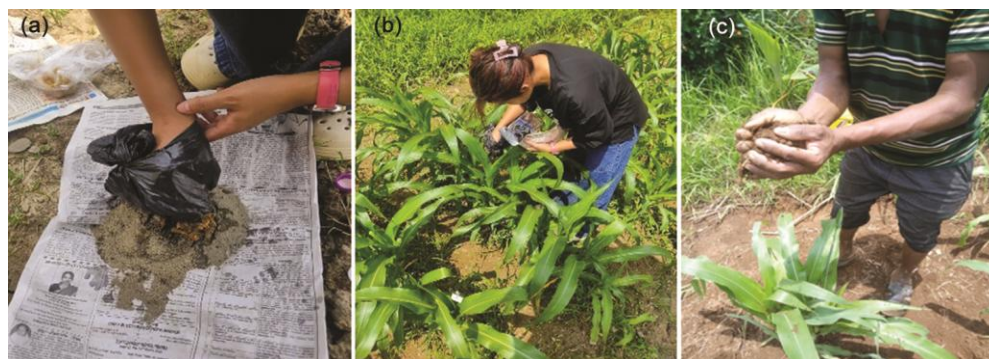


Fig. 1 — (a & b) Application of soil mixed with biopesticides on the maize plant, (c) soil application on the plants

(ANOVA). Treatment means were compared using the critical difference (CD) at the 5% level of significance.

## Results and Discussion

### Larval count and percent plant infestation

The treatment chlorantraniliprole 18.5 SC, which served as the chemical check, recorded the lowest mean larval population at 7, 14, and 21 days after treatment (DAT) with 0.10, 0.03, and 0.0 larvae per ten plants, respectively, followed by the treatment soil + *Bacillus thuringiensis* var. *kurstaki* with mean larval populations of 0.13, 0.10, and 0.07 larvae per ten plants, respectively (Table 1). The remaining treatments varied from 0.17 to 0.33 larvae per ten plants. All the treatments including untreated plots were on par with each other. The highest larval population was recorded in untreated plot having 0.57 larvae per ten plants. Kalleshwaraswamy *et al.*<sup>15</sup> recorded that soil mixed with insecticide treatments significantly reduced the larval population of *S. frugiperda* at 7 and 15 days after imposition of treatments and also showed the highest larval percent mortality of more than 90% due to application of

insecticide mixed with soil compared to foliar spray alone.

The number of infested plants per ten plants was recorded in each plot, and percent plant infestation was calculated (Table 2). Pre-treatment infestation ranged from 33% to 45% with no significant differences among plots. Across the post-treatment period, the treatment T<sub>4</sub> (soil + *Bacillus thuringiensis* var. *kurstaki*) consistently showed the lowest plant infestation, starting with 29.33%, which further declined over time to 20.33% and ultimately to 10.00%. T<sub>9</sub> (chlorantraniliprole 18.5 SC) became more effective in the later stage, reducing infestation to 13.33%. In contrast, the untreated control plot (T<sub>10</sub>) consistently exhibited the highest infestation levels throughout the observation period.

### Extent of leaf damage and cob damage

Mean leaf damage recorded at 7 and 14 days after treatment ranged between 4.27 to 5.23, 2.07 to 3.20 and 2.00 to 2.4, respectively in treated plots where the treatment combination, soil + *Bacillus thuringiensis* var. *kurstaki* exhibited the lowest leaf damage of 4.27, 2.07 and 2.00, respectively followed by treatment chlorantraniliprole 18.5SC of 4.47 at 7 DAT and bait

Table 1 — Effect of various treatment combination on the population of *S. frugiperda* in maize during *Kharif*, 2023

Treatments	Dosage/ha	Mean population of <i>S. frugiperda</i> recorded during			
		DBT	7 DAT	14 DAT	21 DAT
T <sub>1</sub> - Soil	27.78 kg	1.03 (1.24)	0.20 <sup>b</sup> (0.84)	0.27 <sup>c</sup> (0.88)	0.20 <sup>c</sup> (0.84)
T <sub>2</sub> - Soil + URO insecticides	370.37 kg+1.78 L	1.07 (1.25)	0.17 <sup>ab</sup> (0.82)	0.13 <sup>b</sup> (0.79)	0.10 <sup>ab</sup> (0.77)
T <sub>3</sub> - Soil + lime (8:2)	296.29 kg+74.07 kg	1.20 (1.30)	0.23 <sup>b</sup> (0.85)	0.20 <sup>bc</sup> (0.84)	0.17 <sup>bc</sup> (0.82)
T <sub>4</sub> - Soil + <i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	370.37 kg+18.44L	0.70 (1.09)	0.13 <sup>a</sup> (0.80)	0.10 <sup>ab</sup> (0.77)	0.07 <sup>ab</sup> (0.75)
T <sub>5</sub> - Soil + <i>Metarhizium anisoplae</i>	370.37 kg+24.07 kg	0.93 (1.19)	0.23 <sup>b</sup> (0.85)	0.20 <sup>bc</sup> (0.84)	0.17 <sup>bc</sup> (0.81)
T <sub>6</sub> - Soil + <i>Beauveria bassiana</i>	370.37 kg+24.07 kg	1.03 (1.24)	0.33 <sup>c</sup> (0.91)	0.23 <sup>c</sup> (0.86)	0.20 <sup>c</sup> (0.83)
T <sub>7</sub> - Sand	27.78 kg	1.13 (1.28)	0.20 <sup>b</sup> (0.84)	0.17 <sup>bc</sup> (0.82)	0.13 <sup>b</sup> (0.79)
T <sub>8</sub> - Bait (soil + jaggery + sand + water)	222.22 kg+48.14 kg + 25.92 kg + 74 L	1.17 (1.29)	0.17 <sup>ab</sup> (0.81)	0.13 <sup>b</sup> (0.79)	0.10 <sup>ab</sup> (0.77)
T <sub>9</sub> - Chlorantraniliprole 18.5 SC	0.14 L	0.83 (1.15)	0.10 <sup>a</sup> (0.77)	0.03 <sup>+</sup> (0.73)	0.00 <sup>a</sup> (0.71)
T <sub>10</sub> - Untreated control	-	1.03 (1.24)	0.57 <sup>d</sup> (1.03)	0.30 <sup>d</sup> (0.89)	0.23 <sup>d</sup> (0.86)
SEm (±)		0.04	0.03	0.03	0.02
CD @0.05		0.13	0.09	0.07	0.07

Fig. in parentheses are square root transformed values, means followed by different letters are significantly differentiated at 5% level of significance, DBT- Days Before treatment, DAT- Days after treatment, NS- Non-significant, SEM – standard error, CD – critical difference

Table 2 — Effect of various treatment combinations on per cent plant infestation due to *S. frugiperda* during *kharif*, 2023

Treatments	Doses/ha	DBT	7 DAT	14 DAT	21 DAT
T <sub>1</sub> - Soil	27.78 kg	36.33	32.00 <sup>b</sup>	29.33 <sup>b</sup> (32.79)	19.33 <sup>b</sup> (26.08)
T <sub>2</sub> - Soil + URO insecticides	370.37 kg + 1.78 L	41.00	32.33 <sup>b</sup>	28.00 <sup>b</sup> (31.94)	21.33 <sup>bc</sup> (27.51)
T <sub>3</sub> - Soil + lime (8:2)	296.29 kg + 74.07 kg	45.00	37.67 <sup>c</sup>	32.00 <sup>c</sup> (34.41)	23.33 <sup>c</sup> (28.88)
T <sub>4</sub> - Soil + <i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	370.37 kg + 18.44 L	37.33	29.33 <sup>a</sup>	20.33 <sup>a</sup> (26.79)	10.00 <sup>a</sup> (18.43)
T <sub>5</sub> - Soil + <i>Metarhizium anisoplae</i>	370.37 kg + 24.07 kg	36.00	35.67 <sup>c</sup>	34.00 <sup>c</sup> (34.64)	17.33 <sup>b</sup> (24.60)
T <sub>6</sub> - Soil + <i>Beauveria bassiana</i>	370.37 kg + 24.07 kg	42.67	32.67 <sup>b</sup>	38.00 <sup>d</sup> (34.02)	22.00 <sup>c</sup> (27.97)
T <sub>7</sub> - Sand	27.78 kg	38.00	34.00 <sup>c</sup>	36.00 <sup>d</sup> (33.98)	24.00 <sup>c</sup> (29.33)
T <sub>8</sub> - Bait (soil + jaggery + sand + water)	222.22 kg + 48.14 kg + 25.92 kg + 74 L	33.00	30.67 <sup>a</sup>	24.67 <sup>ab</sup> (29.72)	15.33 <sup>ab</sup> (23.05)
T <sub>9</sub> - Chlorantraniliprole 18.5 SC	0.14 L	39.00	32.33 <sup>b</sup>	28.00 <sup>b</sup> (33.21)	13.33 <sup>a</sup> (21.42)
T <sub>10</sub> - Untreated control	-	45.00	48.00 <sup>d</sup>	47.33 <sup>e</sup> (35.00)	26.00 <sup>d</sup> (30.66)
	SEm(±)	NS	1.43	1.18	1.99
	CD @ 0.05	NS	4.25	3.49	5.91

Figure in parentheses are angular transformed values, means followed by different letters are significantly differentiated at 5% level of significance, DBT- Days before treatment, DAT- Days after treatment, NS- Non-significant, SEM – standard error, CD – critical difference

Table 3 — Effect of various treatment combinations on leaf damage and cob damage due to *S. frugiperda* in maize during *kharif*, 2023

Treatments	Dosage/ha	Mean leaf damage recorded during				Mean cob damage
		DBT	7 DAT	14 DAT	21 DAT	
T <sub>1</sub> - Soil	27.78 kg	6.20	4.57 <sup>b</sup>	3.20 <sup>b</sup>	2.30 <sup>ab</sup>	2.56 <sup>c</sup>
T <sub>2</sub> - Soil + URO insecticides	370.37 kg + 1.78 L	5.67	4.97 <sup>c</sup>	2.87 <sup>b</sup>	2.10 <sup>ab</sup>	1.89 <sup>b</sup>
T <sub>3</sub> - Soil + lime (8:2)	296.29 kg+74.07 kg	5.80	5.23 <sup>d</sup>	2.83 <sup>b</sup>	2.30 <sup>ab</sup>	2.56 <sup>c</sup>
T <sub>4</sub> - Soil + <i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	370.37 kg+18.44 L	5.20	4.27 <sup>a</sup>	2.07 <sup>a</sup>	2.00 <sup>a</sup>	1.11 <sup>a</sup>
T <sub>5</sub> - Soil + <i>Metarhizium anisoplae</i>	370.37 kg+24.07 kg	6.07	4.50 <sup>ab</sup>	2.80 <sup>b</sup>	2.27 <sup>ab</sup>	1.78 <sup>b</sup>
T <sub>6</sub> - Soil + <i>Beauveria bassiana</i>	370.37 kg+24.07 kg	5.93	4.67 <sup>bc</sup>	2.77 <sup>b</sup>	2.30 <sup>ab</sup>	2.22 <sup>bc</sup>
T <sub>7</sub> - Sand	27.78 kg	6.20	4.70 <sup>bc</sup>	2.93 <sup>b</sup>	2.40 <sup>b</sup>	2.45 <sup>c</sup>
T <sub>8</sub> - Bait (soil + jaggery + sand + water)	222.22 kg+48.14 kg+ 25.92 kg+74 L	5.60	4.90 <sup>c</sup>	2.57 <sup>ab</sup>	2.03 <sup>a</sup>	1.56 <sup>ab</sup>
T <sub>9</sub> - Chlorantraniliprole 18.5 SC	0.14 L	5.60	4.47 <sup>ab</sup>	2.60 <sup>ab</sup>	2.03 <sup>a</sup>	1.44 <sup>a</sup>
T <sub>10</sub> - Untreated control	-	6.30	5.40 <sup>e</sup>	4.73 <sup>c</sup>	3.73 <sup>c</sup>	2.89 <sup>d</sup>
SEm(±)		NS	0.17	0.15	0.10	0.17
CD@0.05		NS	0.51	0.45	0.30	0.50

Means followed by different letters are significantly different at 5% level of significance; DBT = days before treatment; DAT = days after treatment; NS = non-significant; SEM = Standard error of mean; CD = critical difference

(soil + jaggery + sand + water) of 2.57 and 2.03 at 14 and 21 DAT, respectively. However, all the treatments recorded significantly lower infestation by the pest in comparison to untreated plot. The mean cob damage data (Table 3) observed during the study showed that treated plots ranged from 1.11 to 2.56 were found to be significantly superior to the

untreated plot (2.89). The lowest cob damage incidence (1.11) was marked in treatment soil + *Bacillus thuringiensis* var. *kurstaki* followed by chlorantraniliprole 18.5 SC (1.44). The present study showed that using whorl application of insecticides mixed with soil/sand or spray had a significant effect on *S. frugiperda* larvae and consequently on maize

Table 4 — Harvest data of different treatment combinations against *S. frugiperda* in maize during *kharif*, 2023

Treatment	Dosage/ha	Yield Of maize (q/ha)	Additional returns from maize (q/ha)	Additional returns from maize (Rs.)	Cost (Rs)	Net additional return (Rs.)
T <sub>1</sub> - Soil	27.8 kg	55.22 <sup>bc</sup>	3.78	9450.00	3503.20	5946.80
T <sub>2</sub> - Soil + URO insecticides	370.37 kg+1.78 L	58.18 <sup>bc</sup>	6.74	16850.00	5110.80	11739.20
T <sub>3</sub> - Soil + lime (8:2)	296.29 kg+74.07 kg	59.44 <sup>bc</sup>	8.00	20000.00	19391.00	609.00
T <sub>4</sub> - Soil + <i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	370.37 kg+18.44 L	86.36 <sup>a</sup>	34.92	87300.00	24850.07	62449.93
T <sub>5</sub> - Soil + <i>Metarhizium anisoplae</i>	370.37 kg+24.07 kg	64.48 <sup>b</sup>	13.04	32600.00	3094.00	1660.00
T <sub>6</sub> - Soil + <i>Beauveria bassiana</i>	370.37 kg+24.07 kg	63.94 <sup>b</sup>	12.50	31250.00	3094.00	310.00
T <sub>7</sub> - Sand	27.8 kg	53.33 <sup>c</sup>	1.89	4725.00	3403.22	1321.78
T <sub>8</sub> - Bait (soil + jaggery + sand + water)	222.22 kg+48.14 kg+25.92 kg + 74 L	62.03 <sup>b</sup>	10.59	26475.00	7696.00	18779.00
T <sub>9</sub> - Chlorantraniliprole 18.5 SC	0.14 L	58.99 <sup>bc</sup>	7.55	18875.00	4412.00	14463.00
T <sub>10</sub> - Untreated control	-	51.44	-	-	-	-
	SEm (±)	4.1	-	-	-	-
	CD @ 0.05	12.43	-	-	-	-

yield. However, all insecticide treatments mixed with soil significantly reduced the larval population and leaf damage compared to untreated plots. Thus, it can be inferred that the insecticides mixed with soil provide higher yield and quality of maize, which may be due to lower infestation<sup>16</sup>. Babendreier *et al.*<sup>17</sup> in his previous studies have shown that soil application into the whorl directly targets the larvae; as a result, the larva tries to come out of the whorl, and hence larvae get damaged through abrasion to the cuticle. This result is in accordance with Divya *et al.*<sup>18</sup>, Kalleshwaraswamy *et al.*<sup>15</sup> and Nbyoyine *et al.*<sup>19</sup>, where the insecticides mixed with soil are more effective than spraying as they directly target the *S. frugiperda* larvae by abrasion to the cuticle.

#### Yield

Among all the treatments, soil + *Bacillus thuringiensis* var. *kurstaki* treatment recorded the highest yield (86.36 q/ha) with 34.92 q/ha increase in yield over control followed by soil + *Metarhizium anisoplae* with 64.48 q/ha showing 13.04 q/ha, increase in yield over control, respectively (Table 4). The present results are in line with the findings of Patel *et al.*<sup>20</sup>, who reported that the highest grain as well as yield was recorded from the plot treated with *B. thuringiensis* AAU strain – 1% AS (2868 and 4136 kg/ha) followed by *B. thuringiensis* 3.5% ES (commercial formulation) (2829 and 4099 kg/ha), respectively.

The present study showed the importance of application of soil + *Bacillus thuringiensis* var. *kurstaki* and bait (soil + jaggery + sand + water) were found to be effective which helps in minimising the

population of *S. frugiperda*. In addition to this, larvae come in direct contact with insecticides so, the application of insecticides with soil increase the effective control of *S. frugiperda*. After the whorl application of soil with insecticides, it holds the moisture and reduces the number of insecticidal sprays for better coverage of whorl and physical effects of soil. Hence, these results were helpful for an alternative to foliar application for the management of *S. frugiperda* in the maize ecosystem.

#### Conclusion

The present study demonstrated that soil-based application of non-chemical and biopesticide formulations can effectively manage *Spodoptera frugiperda* in maize under field conditions. Among the evaluated treatments, soil mixed with *Bacillus thuringiensis* var. *kurstaki* (T<sub>4</sub>) proved to be the most effective by significantly reducing larval population, leaf damage, plant infestation, and cob damage, while recording the highest grain yield (86.36 q/ha). Although the chemical check, chlorantraniliprole 18.5 SC showed effective pest suppression, the use of biopesticide-based formulations offers a safer and more sustainable alternative for fall armyworm management. The study further indicated that soil-mediated delivery of biopesticides into the maize whorl enhances contact with larvae and improves treatment efficacy. Therefore, soil application of *Bacillus thuringiensis* var. *kurstaki* may be incorporated as an eco-friendly component of integrated pest management (IPM) strategies for sustainable management of *S. frugiperda* in maize under Manipur conditions.

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### Author Contributions

All authors contributed equally to the conception and design of the study, data collection, and manuscript preparation.

### Conflict of Interest

The authors have no conflict of interest to disclose.

### Ethics statement

Not applicable.

### Informed consent / Prior informed consent

Not applicable.

### Data availability

Data will be made available by the corresponding author upon request.

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