Original Research Article

Field efficacy of insecticides against fall army worm, *Spodoptera frugiperda* (J. E. Smith) on maize (*Zea mays* L.)

Abstract:

The field investigation was carried out during the *Kharif* season 2021 and 2022 in Central Research Farm (CRF), Naini Agriculture Institute, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, Uttar Pradesh, India. The experiment was laid in Randomized Block Design with twelve treatments each replicated thrice *viz.*, Chlorantraniliprole 18.5 SC (0.5 ml/l), Lambda cyhalothrin 2.5% EC (10 ml/l), Thiamethoxam 25 WG (10 gm/kg), Profenophos 50 EC (3ml/l), Cypermethrin 10 EC (4 ml/l), Neem oil 3% (30 ml/l), *Verticilliumlecani*1.15 WP (15 ml/l), Spinosad 45 SC (0.3 ml/l), Emamectin benzoate 5 SG (0.40 gm/kg), Indoxacarb 15.8 EC (1.5 ml/l), NSKE 5% (50 ml/l) and control plot.The result on *Spodoptera frugiperda* larval population after first and second spray in kharif 2021 and kharif 2022 evaluated that all the treatments were significantly superior over the control. Among the all treatments Emamectin benzoate 5 SG (2.24), (0.82) and (3.61), (2.33) was recorded minimum larval population of the both spray followed by, Chlorantraniliprole 18.5 SC (2.41), (1.01) and (3.82), (2.46), Indoxacarb 15.8 EC (2.53), (1.13) and (3.92), (2.55), Thiamethoxam 25 WG (2.66), (1.26) and (3.99), (2.66), Lambda cyhalothrin 2.5% EC (2.73), (1.33) and (4.06), (2.73) and Spinosad 45 SC (2.86), (1.46) and (4.12), (3.79). In this Profenophos 50 EC (2.93), (1.53) and (4.19), (2.86), Cypermethrin 10 EC (2.99), (1.59) and (4.32), (2.99), *Verticilliumlecani*1.15 WP (3.06), (1.66) and (4.39), (3.06), Neem oil 3% (3.13), (1.73) and (4.46), (3.13), NSKE 5% (3.19), (1.79) and (4.55), (3.24) is found to be least effective than all the treatments and is significantly superior over the control (4.99), (6.19) and (6.40), (7.19).

Key words: Efficacy, Insecticides, Maize, *Spodopterafrugiperda*.

INTRODUCTION:

Maize, *Zea mays* L. is a member of the family: Poaceae also known as corn. It is one of the most flexible growing crops with greater adaptability to different agro-climatic conditions. Because of higher genetic yield potential among the cereals, this crop is globally

Comment [a1]: Change title to Evaluating Sustainable Solutions for Fall Armyworm Control in Maize Crops. Or Exploring Sustainable Strategies for Fall Armyworm Management in Maize Cultivation

Comment [a2]: Re write- The study occurred at CRF, Prayagraj, India during Kharif 2021-2022.

Comment [a3]: Include conclusion - In summary, Emamectin benzoate 5 SG proved highly effective in managing Spodoptera frugiperda in maize crops.

Comment [a4]: Include- Agricultural Study; Armyworm Control; Chemical Control; Crop Pest; Efficacy; Emamectin Solution; Pest Management; Pest Numbers; Pest Strategy; Season Study.

popular as the “Queen of cereals" **(Jeyaraman, 2017).** In around 5,000 BC, the maize crop originated in central Mexico. It is the day neutral, cross pollinated and C4 plant. Maize is an economically important cereal crop among the various cereals cultivated, which is generally cultivated in tropical as well as in sub-tropical parts of the world. Leafy stalks of maize produce ears, which contain the grain and are called kernels or seeds. The kernels of maize are most commonly used as starch in cooking. The six major types of maize (corn) are dent corn, pod corn, flint corn, popcorn, flour corn, and sweet corn **(Ferror*et al.*, 2009).**

The United States produces about 40 per cent of the world's harvest of maize; while other top producing countries include China, Brazil, Mexico, Indonesia, India, France and Argentina. Maize is the third most important food crop in India after rice and wheat, accounting for about 20 percent of the global area under cereals **(FAO, 2019).** India’s main maize producing states, that contributes more than 80 per cent of the total maize production are Andhra Pradesh (20.9 %), Karnataka (16.5 %), Rajasthan (9.9 %), Maharashtra (9.1 %), Bihar (8.9 %), Uttar Pradesh (6.1 %), Madhya Pradesh (5.7 %), Himachal Pradesh (4.4 %).

In 2017-18 the world maize production is estimated at about 1,047 million metric tonnes, cultivated in 186 m ha area by International Grain Council Report. Among the countries United States of America was stood first in maize production with 371.52 million tonnes followed by China (256 mt), Brazil (94.50 mt), European Union (59.50 mt), Argentina (42.50 mt), and India (26.50 mt). In Chhattisgarh, it is cultivated on an area of 207.82 ha with 254.13 million tons of output and 1693 kg per hectare of productivity **(Bateman *et al.*, 2018).**

Although about 139 insect pests cause varying degree of damage to maize crop, but only about a dozen of these are quite serious and require control measures, *i.e.*, maize stalk borer, pink stem borer, and shoofly are the insects of national importance, while the armyworm, jassid, thrips, pyrilla, grasshopper, white grub, cut worm, hairy caterpillar, termite, and the leaf miner are more serious pest of regional level **(NIPMP, 2001).** Amongst all, shoot fly, *Atherigonaorientalis*, Maize stem borer, *Chilopartellus*,Swimhoe and Pink stem borer, *Sesamiainferens*Wlaker are the most serious pest in India. In the past few years, a new pest, fall armyworm, has become an invasive challenge across the world. However, the relatively high damage by fall armyworm is occasionally reported **(Porter *et al.*, 2000).**

Fall armyworm causes economic losses in so many crops, such as maize, cotton, soybean and beans (**Pogue, 2002**). In maize, fall armyworm attacks in all stages of the plant, from seedling until tasseling and causing defoliation, killing young plant, resulting in grain

Comment [a5]: Re write -The fall armyworm (Spodoptera frugiperda) is a highly destructive pest that has garnered significant attention in recent years due to its devastating impact on agricultural crops worldwide. First reported in Africa in 2016, this invasive species has rapidly spread to different continents, causing substantial economic losses and food security concerns (Baudron et al., 2019).

The ability of fall armyworm to infest a wide range of host plants, with a strong preference for maize (Garcia et al., 2021), and its remarkable capacity to develop resistance to chemical pesticides (Liu et al., 2018) have made it a formidable agricultural adversary. Recent studies (2018-2023) underscore the urgency of developing effective and sustainable management strategies to mitigate the damage caused by this pest (Chidawanyika et al., 2022).

Researchers and agricultural communities worldwide are actively investigating various approaches, such as biological control methods (Hailu et al., 2020), the development of genetically resistant crop varieties (Xue et al., 2018), and integrated pest management tactics (Day et al., 2021). Understanding the latest advancements in fall armyworm research is crucial for addressing the challenges posed by this pest and ensuring global food security in an ever-changing agricultural landscape.

damage and subsequently reduces quantity and quality of yield. Their damage appears as ragged-edged holes on leaves and tassels. Severe feeding by FAW, may give the appearance of corn that has been damaged by hail. When an outbreak takes place, the severity of the problem is compounded by the ability of FAW to damage a range of vegetative to reproductive plant structures, creating the opportunity to cause devastating crop losses**.** The recent studies conducted by Center for Agriculture and Bioscience International (CABI), which was done in 12 maize-producing African countries showed that without proper management, FAW can cause maize yield losses ranging from 8-21 million tonnes.

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith) belongs to the order Lepidoptera and family Noctuidae is native to tropical and subtropical regions of the Americas. It was reported for the first time from the African continent, in Nigeria, Sao Tomé, Benin and Togo region **(Goergen *et al*., 2016).** In India, fall armyworm (FAW) was firstly reported in the research fields of maize at the University of Agricultural and Horticultural Sciences, Shimoga, Karnataka **(Sharanabasappa, 2018).** In Chhattisgarh the *Spodoptera frugiperda* was first reported at Raipur **(Deole and Paul, 2018).** The name "fall armyworm" originates by their nature of damage, where infestations sometimes resemble as an army, as they move across large agriculture fields and earned their common name by eat all plant matter and the yen counter in their wide dispersals, like a large army **(Smith, 1797).** Due to its migratory behavior the fall armyworm was known as a sporadic pest.

Materials and Methods:

The experiment was conducted during *kharif* season 2021 and 2022 at Central Research Farm (CRF), SHUATS, Prayagraj, Uttar Pradesh, India in a Randomized Block Design with twelve treatments replicated three times using variety Shivam in a plot size of (2m×2m) at a spacing of (60×20cm) with a recommended package of practices excluding plant protection. The treatments used in experiment are *viz.,* Chlorantraniliprole 18.5 SC (0.5 ml/l), Lambda cyhalothrin 2.5% EC (10 ml/l), Thiamethoxam 25 WG (10 gm/kg), Profenophos 50 EC (3ml/l), Cypermethrin 10 EC (4 ml/l), Neem oil 3% (30 ml/l), *Verticilliumlecani*1.15 WP (15 ml/l), Spinosad 45 SC (0.3 ml/l), Emamectin benzoate 5 SG (0.40 gm/kg), Indoxacarb 15.8 EC (1.5 ml/l), NSKE 5% (50 ml/l) and control.

Two sprays were carried out at interval of 15 days during the experiments to asses the effectiveness of insecticides when the *Spodoptera frugiperda* larval population. The economic threshold level or ETL (when control measures have to be taken to prevent from

Comment [a6]: Include -The objectives of this study are to assess the efficacy of various treatments against the fall armyworm (Spodoptera frugiperda) in maize crops during the Kharif seasons of 2021 and 2022, emphasizing the need for effective pest management strategies.

Comment [a7]:

Comment [a8]: Re write-In the Indian context, the fall armyworm (FAW), scientifically known as Spodoptera frugiperda, poses a significant threat to agriculture, particularly to maize crops. Smallholder farmers, who constitute a substantial portion of the Indian agricultural community, are especially vulnerable to the ravages of this invasive pest. FAW's voracious appetite for maize, a staple crop in many regions of India, can lead to substantial yield losses and, consequently, impact the livelihoods of smallholder farmers (Nair et al., 2019).

The necessity for sustainable control measures against FAW cannot be overstated. Traditional reliance on chemical pesticides to combat FAW infestations has its limitations, as the pest has demonstrated the ability to develop resistance to chemical treatments (Nagoshi et al., 2018). This resistance, coupled with concerns about the environmental and health impacts of pesticides, underscores the urgency of adopting sustainable and eco-friendly strategies for FAW management.

For smallholder farmers, who often lack the resources and knowledge to combat FAW effectively, sustainable pest control methods can be a game-changer. Implementing integrated pest management (IPM) approaches that combine cultural practices, biological control agents, and low-risk chemical treatments can empower smallholder farmers to protect their maize crops more effectively (Prasanna et al., 2018).

Investing in research and extension services that provide smallholder farmers with access to the latest FAW management techniques is crucial for enhancing their resilience and ensuring food security. Furthermore, efforts to develop maize varieties with inherent resistance to FAW through conventional breeding or biotechnological approaches are underway (Kolawole et al., 2020), offering a promising avenue for sustainable pest control in India.

pest population increase and keep them from economic injury level (EIL) of the pest is the benchmark level. There are 3 ETL levels of FAW which are following: A) 1-2 Larvae per each whorl. B) 5% to 6% Seedling are cut. C) 1st 30 days young plants show 15% whorl infestation **Tahir *et al.*, (2020).**Five plants were randomly selected in each treatment and observation was taken one day before spraying application three, sevenand fourteen-day spraying.

Result and Discussion:

Efficacy of *Spodoptera frugiperda Kharif* 2021 (First Spray).

Three Days After Spraying:

The data on the larval population of fall armyworm on three days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (2.86) followed by T_1 Chlorantraniliprole 18.5 SC (2.93), T_{10} Indoxacarb 15.8 EC (3.00), T_3 Thiamethoxam 25 WG (3.13), T_2 Lambda cyhalothrin 2.5% EC (3.20) and T_8 Spinosad 45 SC (3.33). In this T_4Profenophos 50 EC (3.40), T_5 Cypermethrin 10 EC (3.46), T_7*Verticilliumlecani*1.15 WP (3.53) T_6 Neem oil 3% (3.60) T_{11} NSKE 5% (3.66) is found to be least effective than all the treatments and is significantly superior over the T_0 control (4.60).

Seven Days After Spraying:

The data on the larval population of fall armyworm on seven days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (1.86) followed by T_1 Chlorantraniliprole 18.5 SC (2.06), T_{10} Indoxacarb 15.8 EC (2.20), T_3 Thiamethoxam 25 WG (2.33), T_2 Lambda cyhalothrin 2.5% EC (2.40) and T_8 Spinosad 45 SC (2.53). In this T_4Profenophos 50 EC (2.60), T_5 Cypermethrin 10 EC (2.66), T_7*Verticilliumlecani*1.15 WP (2.73) T_6 Neem oil 3% (2.80) T_{11} NSKE 5% (2.86) is found to be least effective than all the treatments and is significantly superior over the T_0 control (4.93).

Fourteen Days After Spraying:

Comment [a9]: Re write-The study was conducted in the Kharif seasons of 2021 and 2022 at the Central Research Farm (CRF), located at SHUATS (Sam Higginbottom University of Agriculture Technology and Sciences) in Prayagraj, Uttar Pradesh, India. A Randomized Block Design was employed with twelve different treatments, each of which was replicated three times. The experimental plots consisted of the maize variety Shivam, and each plot measured 2 meters by 2 meters. Plant-to-plant spacing was maintained at 60 cm by 20 cm, following the recommended package of agricultural practices, excluding plant protection measures.

The twelve treatments applied in the experiment included the following insecticides and treatments: Chlorantraniliprole 18.5 SC (0.5 ml/l), Lambda cyhalothrin 2.5% EC (10 ml/l), Thiamethoxam 25 WG (10 gm/kg), Profenophos 50 EC (3 ml/l), Cypermethrin 10 EC (4 ml/l), Neem oil 3% (30 ml/l), Verticilliumlecani 1.15 WP (15 ml/l), Spinosad 45 SC (0.3 ml/l), Emamectin benzoate 5 SG (0.40 gm/kg), Indoxacarb 15.8 EC (1.5 ml/l), NSKE 5% (50 ml/l), and a control (no treatment).

Two insecticide sprays were applied at a 15-day interval during the experiment to evaluate their effectiveness in controlling the larval population of Spodoptera frugiperda. The economic threshold level (ETL) for fall armyworm (FAW), which represents the point at which control measures should be implemented to prevent the pest population from reaching the economic injury level (EIL), was considered. There are three ETL levels for FAW:

A) 1-2 larvae per each whorl.
B) 5% to 6% seedlings are cut.
C) Within the first 30 days, young plants exhibit a 15% whorl infestation (Tahir et al., 2020).

For each treatment, five plants were randomly selected, and observations were recorded one day before the application of each spray, as well as at three, seven, and fourteen days after each spraying.

The data on the larval population of fall armyworm on fourteen days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (2.00) followed by T_1 Chlorantraniliprole 18.5 SC (2.26), T_{10} Indoxacarb 15.8 EC (2.40), T_3 Thiamethoxam 25 WG (2.53), T_2 Lambda cyhalothrin 2.5% EC (2.60) and T_8 Spinosad 45 SC (2.73). In this T_4Profenophos 50 EC (2.80), T_5 Cypermethrin 10 EC (2.86), T_7*Verticilliumlecani*1.15 WP (2.93) T_6 Neem oil 3% (3.00) T_{11} NSKE 5% (3.06) is found to be least effective than all the treatments and is significantly superior over the T_0 control (5.46).

Overall Mean of First Spray:

The data on the larval population of fall armyworm on mean (3rd, 7th and 14th DAS)days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (2.24) followed by T_1 Chlorantraniliprole 18.5 SC (2.41), T_{10} Indoxacarb 15.8 EC (2.53), T_3 Thiamethoxam 25 WG (2.66), T_2 Lambda cyhalothrin 2.5% EC (2.73) and T_8 Spinosad 45 SC (2.86). In this T_4Profenophos 50 EC (2.93), T_5 Cypermethrin 10 EC (2.99), T_7*Verticilliumlecani*1.15 WP (3.06) T_6 Neem oil 3% (3.13) T_{11} NSKE 5% (3.19) is found to be least effective than all the treatments and is significantly superior over the T_0 control (4.99).

Efficacy of *Spodoptera frugiperda Kharif* 2021 (Second Spray).

Three Days After Spraying:

The data on the larval population of fall armyworm on three days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (1.13) followed by T_1 Chlorantraniliprole 18.5 SC (1.46), T_{10} Indoxacarb 15.8 EC (1.60), T_3 Thiamethoxam 25 WG (1.73), T_2 Lambda cyhalothrin 2.5% EC (1.80) and T_8 Spinosad 45 SC (1.93). In this T_4Profenophos 50 EC (2.00), T_5 Cypermethrin 10 EC (2.06), T_7*Verticilliumlecani*1.15 WP (2.13), T_6 Neem oil 3% (2.20) T_{11} NSKE 5% (2.26) is found to be least effective than all the treatments and is significantly superior over the T_0 control (5.86).

Seven Days After Spraying:

Comment [a10]: Remember this is not thesis, re write as -The assessment of fall armyworm (Spodoptera frugiperda) larval population efficacy following the initial spray during the 2021 Kharif season displayed significant results. Three days after spraying, all treatments demonstrated remarkable superiority over the control. Among these treatments, the most effective in controlling the fall armyworm population were Treatment 9 with Emamectin benzoate 5 SG (2.86), followed closely by Treatment 1 with Chlorantraniliprole 18.5 SC (2.93), and Treatment 10 with Indoxacarb 15.8 EC (3.00). Additionally, Treatment 3 with Thiamethoxam 25 WG reported a larval population of 3.13, Treatment 2 with Lambda cyhalothrin 2.5% EC recorded 3.20, and Treatment 8 with Spinosad 45 SC resulted in a population of 3.33. In contrast, Treatment 4 with Profenophos 50 EC displayed a slightly higher larval population of 3.40, while Treatment 5 with Cypermethrin 10 EC reported 3.46, and Treatment 7 with Verticilliumlecani 1.15 WP observed 3.53. Treatment 6, incorporating Neem oil 3%, reported a population of 3.60, and Treatment 11, featuring NSKE 5%, showed a larval population of 3.66. All these treatments were significantly superior to the control, which had the highest larval population of 4.60.

Seven days after the initial spray, similar patterns emerged with all treatments continuing to be significantly superior to the control. Treatment 9, with Emamectin benzoate 5 SG, displayed a larval population of 1.86, followed by Treatment 1, with Chlorantraniliprole 18.5 SC, at 2.06, and Treatment 10, with Indoxacarb 15.8 EC, at 2.20. Furthermore, Treatment 3, utilizing Thiamethoxam 25 WG, recorded a larval population of 2.33, while Treatment 2, incorporating Lambda cyhalothrin 2.5% EC, showed a population of 2.40. Treatment 8, featuring Spinosad 45 SC, resulted in a larval population of 2.53. Conversely, Treatment 4, with Profenophos 50 EC, reported 2.60, and Treatment 5, using Cypermethrin 10 EC, exhibited 2.66. Treatment 7, involving Verticilliumlecani 1.15 WP, reported a population of 2.73, while Treatment 6, with Neem oil 3%, recorded 2.80. Treatment 11, featuring NSKE 5%, observed a larval population of 2.86, remaining significantly superior to the control, which displayed a population of 4.93.

Fourteen days after the initial spray, the data showcased a similar trend with all treatments significantly outperforming the control. Treatment 9, utilizing Emamectin benzoate 5 SG, reported a larval

The data on the larval population of fall armyworm on seven days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (0.60) followed by T_1 Chlorantraniliprole 18.5 SC (0.73), T_{10} Indoxacarb 15.8 EC (0.80), T_3 Thiamethoxam 25 WG (0.93), T_2 Lambda cyhalothrin 2.5% EC (1.00) and T_8 Spinosad 45 SC (1.13). In this T_4Profenophos 50 EC (1.20), T_5 Cypermethrin 10 EC (1.26), T_7*Verticilliumlecani*1.15 WP (1.33) T_6 Neem oil 3% (1.40) T_{11} NSKE 5% (1.46) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.13).

Fourteen Days After Spraying:

The data on the larval population of fall armyworm on fourteen days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (0.73) followed by T_1 Chlorantraniliprole 18.5 SC (0.86), T_{10} Indoxacarb 15.8 EC (1.00), T_3 Thiamethoxam 25 WG (1.13), T_2 Lambda cyhalothrin 2.5% EC (1.20) and T_8 Spinosad 45 SC (1.33). In this T_4Profenophos 50 EC (1.40), T_5 Cypermethrin 10 EC (1.46), T_7*Verticilliumlecani*1.15 WP (1.53) T_6 Neem oil 3% (1.60) T_{11} NSKE 5% (1.66) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.60).

Overall Mean of Second Spray:

The data on the larval population of fall armyworm on mean (3rd, 7th and 14th DAS)days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (0.82) followed by T_1 Chlorantraniliprole 18.5 SC (1.01), T_{10} Indoxacarb 15.8 EC (1.13), T_3 Thiamethoxam 25 WG (1.26), T_2 Lambda cyhalothrin 2.5% EC (1.33) and T_8 Spinosad 45 SC (1.46). In this T_4Profenophos 50 EC (1.53), T_5 Cypermethrin 10 EC (1.59), T_7*Verticilliumlecani*1.15 WP (1.66) T_6 Neem oil 3% (1.73) T_{11} NSKE 5% (1.79) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.19).

Efficacy of *Spodoptera frugiperda Kharif* 2022 (First Spray).

Three Days After Spraying:

Comment [a11]: Re write- Following the 2021 Kharif season's initial spray against Spodoptera frugiperda (fall armyworm), observations made three, seven, and fourteen days after treatment highlighted significant effectiveness among all used treatments over the control group. The lowest larval population occurred in Treatment 9 (Emamectin benzoate 5 SG) on days three (1.13), seven (0.60), and fourteen (0.73) after spraying. Similarly, this trend was maintained in the overall mean of larval populations, displaying Treatment 9 as the most effective (0.82) compared to the control's higher larval counts (5.86). Other treatments showed varying degrees of effectiveness over the control, emphasizing Emamectin benzoate's efficacy in controlling fall armyworm infestations during the study.

The data on the larval population of fall armywormon three days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (4.13) followed by T_1 Chlorantraniliprole 18.5 SC (4.20), T_{10} Indoxacarb 15.8 EC (4.26), T_3 Thiamethoxam 25 WG (4.33), T_2 Lambda cyhalothrin 2.5% EC (4.40) and T_8 Spinosad 45 SC (4.46). In this T_4Profenophos 50 EC (4.53), T_5 Cypermethrin 10 EC (4.66), T_7*Verticilliumlecani*1.15 WP (4.73), T_6 Neem oil 3% (4.80) T_{11} NSKE 5% (4.86) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.00).

Seven Days After Spraying:

The data on the larval population of fall armywormon seven days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (3.26) followed by T_1 Chlorantraniliprole 18.5 SC (3.53), T_{10} Indoxacarb 15.8 EC (3.66), T_3 Thiamethoxam 25 WG (3.73), T_2 Lambda cyhalothrin 2.5% EC (3.80) and T_8 Spinosad 45 SC (3.86). In this T_4Profenophos 50 EC (3.93), T_5 Cypermethrin 10 EC (4.06), T_7*Verticilliumlecani*1.15 WP (4.13), T_6 Neem oil 3% (4.20) T_{11} NSKE 5% (4.26) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.40).

Fourteen Days After Spraying:

The data on the larval population of fall armywormon fourteen days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (3.46) followed by T_1 Chlorantraniliprole 18.5 SC (3.73), T_{10} Indoxacarb 15.8 EC (3.86), T_3 Thiamethoxam 25 WG (3.93), T_2 Lambda cyhalothrin 2.5% EC (4.00) and T_8 Spinosad 45 SC (4.06). In this T_4Profenophos 50 EC (4.13), T_5 Cypermethrin 10 EC (4.26), T_7*Verticilliumlecani*1.15 WP (4.33), T_6 Neem oil 3% (4.40), T_{11} NSKE 5% (4.53) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.80).

Overall Mean of First Spray:

The data on the larval population of fall armywormon mean (3rd, 7th and 14th DAS)days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (3.61) followed by T_1 Chlorantraniliprole 18.5 SC (3.82), T_{10} Indoxacarb 15.8 EC (3.92), T_3 Thiamethoxam 25 WG (3.99), T_2 Lambda cyhalothrin 2.5% EC (4.06) and T_8 Spinosad 45 SC (4.12). In this T_4Profenophos 50 EC (4.19), T_5 Cypermethrin 10 EC (4.32), T_7*Verticilliumlecani*1.15 WP (4.39), T_6 Neem oil 3% (4.46) T_{11} NSKE 5% (4.55) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.40).

Efficacy of *Spodoptera frugiperda Kharif* 2022 (Second Spray).

Three Days After Spraying:

The data on the larval population of fall armywormon three days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (2.73) followed by T_1 Chlorantraniliprole 18.5 SC (2.93), T_{10} Indoxacarb 15.8 EC (3.06), T_3 Thiamethoxam 25 WG (3.13), T_2 Lambda cyhalothrin 2.5% EC (3.20) and T_8 Spinosad 45 SC (3.26). In this T_4Profenophos 50 EC (3.33), T_5 Cypermethrin 10 EC (3.46), T_7*Verticilliumlecani*1.15 WP (3.53), T_6 Neem oil 3% (3.60) T_{11} NSKE 5% (3.80) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.93).

Seven Days After Spraying:

The data on the larval population of fall armywormon seven days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (2.13) followed by T_1 Chlorantraniliprole 18.5 SC (2.20), T_{10} Indoxacarb 15.8 EC (2.26), T_3 Thiamethoxam 25 WG (2.33), T_2 Lambda cyhalothrin 2.5% EC (2.40) and T_8 Spinosad 45 SC (2.46). In this T_4Profenophos 50 EC (2.53), T_5 Cypermethrin 10 EC (2.66), T_7*Verticilliumlecani*1.15 WP (2.73), T_6 Neem oil 3% (2.80) T_{11} NSKE 5% (2.86) is found to be least effective than all the treatments and is significantly superior over the T_0 control (7.26).

Fourteen Days After Spraying:

The data on the larval population of fall armywormon fourteen days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (2.13) followed by T_1 Chlorantraniliprole 18.5 SC (2.26), T_{10} Indoxacarb 15.8 EC (2.33), T_3 Thiamethoxam 25 WG (2.53), T_2 Lambda cyhalothrin 2.5% EC (2.60) and T_8 Spinosad 45 SC (2.66). In this T_4Profenophos 50 EC (2.73), T_5 Cypermethrin 10 EC (2.86), T_7*Verticilliumlecani*1.15 WP (2.93), T_6 Neem oil 3% (3.00), T_{11} NSKE 5% (3.06) is found to be least effective than all the treatments and is significantly superior over the T_0 control (7.40).

Overall Mean of Second Spray:

The data on the larval population of fall armywormon mean (3^{rd}, 7^{th} and 14^{th} DAS)days after spray revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armywormwas recorded in T_9Emamectin benzoate 5 SG (2.33) followed by T_1 Chlorantraniliprole 18.5 SC (2.46), T_{10} Indoxacarb 15.8 EC (2.55), T_3 Thiamethoxam 25 WG (2.66), T_2 Lambda cyhalothrin 2.5% EC (2.73) and T_8 Spinosad 45 SC (2.79). In this T_4Profenophos 50 EC (2.86), T_5 Cypermethrin 10 EC (2.99), T_7*Verticilliumlecani*1.15 WP (3.06), T_6 Neem oil 3% (3.13) T_{11} NSKE 5% (3.24) is found to be least effective than all the treatments and is significantly superior over the T_0 control (7.19).

Pooled Mean:

The data on the larval population of fall armyworm on pooled mean revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (2.25) followed by T_1 Chlorantraniliprole 18.5 SC (2.42), T_{10} Indoxacarb 15.8 EC (2.53), T_3 Thiamethoxam 25 WG (2.64), T_2 Lambda cyhalothrin 2.5% EC (2.71) and T_8 Spinosad 45 SC (2.80). In this T_4Profenophos 50 EC (2.87), T_5 Cypermethrin 10 EC (2.97), T_7*Verticilliumlecani*1.15 WP (3.04) T_6 Neem oil 3% (3.11) T_{11} NSKE 5% (3.19) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.19).

Comment [a12]: This not thesis- In the context of the 2022 Kharif season's first spray for controlling Spodoptera frugiperda (fall armyworm), the assessment of larval populations was conducted at various time intervals. Three days post-spray, all treatments exhibited significant effectiveness compared to the control, with Treatment 9 (Emamectin benzoate 5 SG) recording the lowest larval population at 4.13. Subsequent observations on the seventh and fourteenth days maintained a similar pattern, where Treatment 9 consistently displayed the lowest larval populations, demonstrating its efficacy in controlling fall armyworm infestations. The overall mean of the first spray revealed a consistent trend, emphasizing the superior performance of Treatment 9 (3.61) over the control (6.00). The second spray application in the 2022 Kharif season also resulted in a notable reduction in larval populations, with Treatment 9 being the most effective three days post-spray (2.73). Seven and fourteen days post-spray, Treatment 9 exhibited the lowest larval populations, indicating its consistent efficacy. The overall mean for the second spray demonstrated that Treatment 9 (2.33) outperformed all other treatments, reiterating its effectiveness in controlling fall armyworm infestations. The pooled mean data reinforced Treatment 9's effectiveness in reducing larval populations (2.25), underscoring its superior performance over the control (6.19). This comprehensive study provides insights into the efficacy of various treatments in managing fall armyworm infestations during the Kharif 2022 season, with Treatment 9 (Emamectin benzoate 5 SG) emerging as a promising option for pest control.

Table: 1 Efficacy against *Spodoptera frugiperda Kharif*-2021

Treatments		Larval population on number basis/5 plants								Overall Mean
		One day before spray	After First Spray				After Second Spray			
			3 DAS	7 DAS	14 DAS	Mean	3 DAS	7 DAS	14 DAS	Mean
T_1	Chlorantraniprole 18.5 % SC	4.33	2.93^{fg}	2.06^{gh}	2.26^{gh}	2.41^{fg}	1.46^{g}	0.73^{fg}	0.86^{hi}	1.01^{fg}	1.71
T_2	Lambda Cyhalothrin 5% EC	4.40	3.20^{def}	2.40^{def}	2.60^{def}	2.73^{cdef}	1.80^{def}	1.00^{def}	1.20^{efg}	1.33^{cdef}	2.03
T_3	Thiamethoxam 25% WG	4.46	3.13^{efg}	2.33^{efg}	2.53^{efg}	2.66^{def}	1.73^{efg}	0.93^{ef}	1.13^{fg}	1.26^{def}	1.96
T_4	Profenophos 50% EC	4.40	3.40^{bcde}	2.60^{bcde}	2.80^{bcde}	2.93^{bcd}	2.00^{bcde}	1.20^{bcde}	1.40^{cde}	1.53^{bcd}	2.23
T_5	Cypermethrin 10% EC	4.53	3.46^{bcd}	2.66^{bcd}	2.86^{bcd}	2.99^{bcd}	2.06^{bcd}	1.26^{bcd}	1.46^{bcd}	1.59^{bcd}	2.29
T_6	Neem oil 3%	4.80	3.60^{bc}	2.80^{bc}	3.00^{bc}	3.13^{b}	2.20^{bc}	1.40^{bc}	1.60^{bc}	1.73^{b}	2.43
T_7	*Verticilliumlecani*1.15 % WP	4.60	3.53^{bc}	2.73^{bc}	2.93^{bc}	3.06^{bc}	2.13^{bc}	1.33^{bc}	1.53^{bcd}	1.66^{bc}	2.36

T_8	Spinosad 45% SC	4.53	3.33^{cde}	2.53^{cde}	2.73^{cde}	2.86^{bcde}	1.93^{cde}	1.13^{cde}	1.33^{def}	1.46^{bcde}	2.16
T_9	Emamectin benzoate 5 % SG	4.06	2.86^{g}	1.86^{h}	2.00^{h}	2.24^{g}	1.13^{h}	0.60^{g}	0.73^{i}	0.82^{g}	1.53
T_{10}	Indoxacarb 15.8% EC	4.20	3.00^{fg}	2.20^{fg}	2.40^{fg}	2.53^{efg}	1.60^{fg}	0.80^{fg}	1.00^{gh}	1.13^{efg}	1.83
T_{11}	NSKE 5 %	4.73	3.66^{b}	2.86^{b}	3.06^{b}	3.19^{b}	2.26^{b}	1.46^{b}	1.66^{b}	1.79^{b}	2.49
T_0	Control	4.20	4.60^{a}	4.93^{a}	5.46^{a}	4.99^{a}	5.86^{a}	6.13^{a}	6.60^{a}	6.19^{a}	5.59
F-test		**NS**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**
S.Ed (±)		0.21	0.14	0.12	0.13	0.18	0.13	0.14	0.12	0.16	0.43
C.D. (P=0.05)		-	0.29	0.26	0.28	0.38	0.27	0.30	0.26	0.34	1.16

DBS- Day Before Spraying, DAS- Day After Spraying, NS-Nonsignificant, S-Significant

Table: 2. Efficacy against *Spodoptera frugiperda Kharif*-2022

Treatments		Larval population on number basis/5 plants								Overall Mean	Pooled Mean
		One day before spray	After First Spray				After Second Spray				
			3 DAS	7 DAS	14 DAS	Mean	3 DAS	7 DAS	14 DAS	Mean	
T_1	Chlorantraniprole 18.5 % SC	5.40	4.20^{f}	3.53^{gh}	3.73^{gh}	3.82^{gh}	2.93^{gh}	2.20^{f}	2.26^{gh}	2.46^{gh}	3.14^{b}	2.42^{cd}
T_2	Lambda Cyhalothrin 5% EC	5.60	4.40^{cdef}	3.80^{defg}	4.00^{defg}	4.06^{defg}	3.20^{defg}	2.40^{cdef}	2.60^{defg}	2.73^{efg}	3.39^{b}	2.71^{bcd}
T_3	Thiamethoxam 25% WG	5.53	4.33^{def}	3.73^{efg}	3.93^{efg}	3.99^{efg}	3.13^{efg}	2.33^{def}	2.53^{efg}	2.66^{fg}	3.32^{b}	2.64^{bcd}
T_4	Profenophos 50% EC	5.73	4.53^{bcdef}	3.93^{bcdef}	4.13^{cdef}	4.19^{cdef}	3.33^{cdef}	2.53^{bcdef}	2.73^{bcde}	$2.86c^{def}$	3.52^{b}	2.87^{bcd}
T_5	Cypermethrin 10% EC	5.73	4.66^{bcde}	4.06^{bcde}	4.26^{bcde}	4.32^{bcde}	3.46^{bcde}	2.66^{bcde}	2.86^{bcde}	2.99^{bcde}	3.65^{b}	2.97^{bcd}
T_6	Neem oil 3%	5.86	4.80^{bc}	4.20^{bc}	$4.40^{b}c$	4.46^{bc}	3.60^{bc}	2.80^{bc}	3.00^{bc}	3.13^{bc}	3.79^{b}	3.11^{bc}
T_7	*Verticilliumlecani*1 .15 % WP	5.80	4.73^{bcd}	4.13^{bcd}	4.33^{bcd}	4.39^{bcd}	3.53^{bcd}	2.73^{bcd}	$2.93b^{cd}$	3.06^{bcd}	3.72^{b}	3.04^{bcd}

T_8	Spinosad 45% SC	5.66	4.46^{bcdef}	3.86^{cdefg}	4.06^{cdefg}	4.12^{defg}	3.26^{cdefg}	2.46^{bcdef}	2.66^{cdef}	2.79^{def}	3.45^{b}	2.80^{bcd}
T_9	Emamectin benzoate 5 % SG	5.33	4.13^{f}	3.26^{h}	3.46^{h}	3.61^{h}	2.73^{h}	2.13^{f}	2.13^{h}	2.33^{h}	2.90^{b}	2.25^{d}
T_{10}	Indoxacarb 15.8% EC	5.46	4.26^{ef}	3.66^{fg}	3.86^{fg}	3.92^{fgh}	3.06^{fgh}	2.26^{ef}	2.33^{fgh}	2.55^{fgh}	3.23^{b}	2.53^{bcd}
T_{11}	NSKE 5 %	5.86	4.86^{b}	4.26^{b}	4.53^{b}	4.55^{b}	3.80^{b}	2.86^{b}	3.06^{b}	3.24^{b}	3.89^{b}	3.19^{b}
T_0	Control	5.40	6.00^{a}	6.40^{a}	6.80^{a}	6.40^{a}	6.93^{a}	7.26^{a}	7.40^{a}	7.19^{a}	6.79^{a}	6.19^{a}
F-test		NS	S	S	S	S	**S**	**S**	**S**	**S**	**S**	**S**
S.Ed (±)		0.19	0.20	0.17	0.17	0.15	0.18	0.20	0.18	0.15	0.35	0.04
C.D. (P=0.05)		-	0.42	0.36	0.35	0.33	0.38	0.41	0.37	0.32	0.95	0.10

DBS- Day Before Spraying, DAS- Day After Spraying, NS-Nonsignificant, S-Significant

DISCUSSION

Comment [a13]: Directly copied from thesis

Overall mean (first and second spray) *Spodoptera frugiperda* (*Kharif* 2021)

The data on the larval population of fall armyworm on overall mean (first and second spray)revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (1.53) followed by T_1 Chlorantraniliprole 18.5 SC (1.71), T_{10} Indoxacarb 15.8 EC (1.83), T_3 Thiamethoxam 25 WG (1.96), T_2 Lambda cyhalothrin 2.5% EC (2.03) and T_8 Spinosad 45 SC (2.16). In this T_4Profenophos 50 EC (2.23), T_5 Cypermethrin 10 EC (2.29), T_7*Verticilliumlecani*1.15 WP (2.36) T_6 Neem oil 3% (2.43) T_{11} NSKE 5% (2.49) is found to be least effective than all the treatments and is significantly superior over the T_0 control (5.59).

Among all the treatments, Emamectin benzoate 5 % SG was found to be most effective in managing the larval population of fall armyworm. The values obtained in the first and second spray were (2.24) and (0.82). These results are supported by **Appalanaidu and Kumar (2022)Phani Kumar *et al.*, (2021) and Bharadwaj *et al.*, (2020).** Chlorantraniliprole 18.5% SC was also found to be very effective in reducing the larval population of fall armyworm. The values obtained in the first and second spray were (2.41) and (1.01). The same results were observed by **Omprakash *et al.*, (2020)**and **Bharadwaj *et al.*, (2020)**. The application of Indoxacarb 15.8% EC reduced the larval population of fall armyworm. Where the observations of first and second sprays obtained were (2.53) and (1.13). These results are supported by **Deshmukh *et al.*,(2020)** and **Ravikumar *et al.*,(2022).** The efficacy of Thiamethoxam 25% WG on fall armyworm in first and second spray were (2.66) and (1.26). These results are as per the findings of **Mallapur *et al.*,(2019).**

The next best treatment was found to be Lambda Cyhalothrin 5% EC in which the efficacy values of first and second spray were (2.73) and (1.33) respectively to the similar findings of **Bharadwaj *et al.*, (2020).** The next best treatment was found to be Spinosad 45% SC in which the efficacy values of first and second spray were (2.86) and (1.46) respectively; these results were supported by **Mallapur *et al.*,(2019)**and **Sangle*et al.*, (2020).** The next effective treatment was found to beProfenophos 50% EC in which efficacy values of first and second sprays were (2.93) and (1.53) respectively; these results were supported by **Sangle*et al.*, (2020)**. The efficacy of Cypermethrin 10% EC on fall armyworm in first and second

spray were (2.99) and (1.59). These results are as per the findings of **Ravikumar *et al.*,(2022**).

Overall mean (first and second spray) *Spodoptera frugiperda* (*Kharif* 2022)

The data on the larval population of fall armyworm on overall mean (first and second spray)revealed that all treatments were significantly superior over control. Among the treatments lowest larval population of fall armyworm was recorded in T_9Emamectin benzoate 5 SG (2.97) followed by T_1 Chlorantraniliprole 18.5 SC (3.14), T_{10} Indoxacarb 15.8 EC (3.23), T_3 Thiamethoxam 25 WG (3.32), T_2 Lambda cyhalothrin 2.5% EC (3.39) and T_8 Spinosad 45 SC (3.45). In this T_4Profenophos 50 EC (3.52), T_5 Cypermethrin 10 EC (3.65), T_7*Verticilliumlecani*1.15 WP (3.72) T_6 Neem oil 3% (3.79) T_{11} NSKE 5% (3.89) is found to be least effective than all the treatments and is significantly superior over the T_0 control (6.79).

Among all the treatments, Emamectin benzoate 5 % SG was found to be most effective in managing the larval population of fall armyworm. The values obtained in the first and second spray were (3.61) and (2.33). These results are supported by **Deshmukh *et al.*,(2020)** and **Ramesh and Tayde (2022).** Chlorantraniliprole 18.5% SC was also found to be very effective in reducing the larval population of fall armyworm. The values obtained in the first and second spray were (3.82) and (2.46). The same results were observed by **Omprakash *et al.*, (2020),) and Suthar *et al.*, (2020)**. The application of Indoxacarb 15.8% EC reduced the larval population of fall armyworm. Where the observations of first and second sprays obtained were (3.92) and (2.55). These results are supported by **Deshmukh *et al.*,(2020)** and **Ravikumar *et al.*,(2022).** The efficacy of Thiamethoxam 25% WG on fall armyworm in first and second spray were (3.99) and (2.66). These results are as per the findings of **Mallapur *et al.*,(2019).**

The next best treatment was found to be Lambda Cyhalothrin 5% EC in which the efficacy values of first and second spray were (4.06) and (2.73) respectively to the similar findings of **Bharadwaj *et al.*, (2020).** The next best treatment was found to be Spinosad 45% SC in which the efficacy values of first and second spray were (4.12) and (3.79) respectively; these results were supported by **Mallapur *et al.*,(2019)**and **Sangle*et al.*, (2020).** The next effective treatment was found to beProfenophos 50% EC in which efficacy values of first and second sprays were (4.19) and (2.86) respectively; these results were supported by **Sangle*et al.*, (2020)**. The efficacy of Cypermethrin 10% EC on fall armyworm in first and second

spray were (4.32) and (2.99). These results are as per the findings of **Ravikumar *et al.*,(2022)**.

Conclusion:

From the present study, the results showed that Emamectin benzoate 5% SG followed by Chlorantraniliprole 18.5% SC, Indoxacarb 15.8% EC are the most effective treatments against maize fall armyworm, pink stem borer and spotted stem borer and produced maximum yield and recorded the highest Cost-Benefit ratio compared to other treatments. Thiamethoxam 25% WG, Lambda Cyhalothrin 5% EC, Spinosad 45% SC and Profenophos 50% EC have shown average results in managing fall armyworm, pink stem borer and spotted stem borer. Cypermethrin 10% EC, *Verticilliumlecani*1.15 % WP, Neem oil 3%, NSKE 5 % found to be the least effective in managing all the pests of maize. Therefore, it is recommended to incorporate effective insecticides into existing Integrated Pest Management programs, with a focus on preventing issues such as insecticide resistance and pest resurgence. Botanical substances play a crucial role in Integrated Pest Management by reducing the indiscriminate use of pesticides that can harm the environment and have minimal impact on beneficial insects.

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Comment [a14]: Re write more scientifically-A comprehensive evaluation of the efficacy of various treatments against Spodoptera frugiperda infestations during the Kharif seasons of 2021 and 2022 revealed valuable insights. The analysis of the overall mean larval population data, considering both the first and second spray applications, highlighted the significant superiority of all treatments over the control group in both years.

In the 2021 Kharif season, the treatment that consistently outperformed the others was Emamectin benzoate 5 SG, with a recorded efficacy value of 1.53. This remarkable effectiveness was further supported by empirical data collected during the first spray (2.24) and second spray (0.82). These results align with previous research conducted by Deshmukh et al. (2020) and Ramesh and Tayde (2022).

Chlorantraniliprole 18.5 SC also displayed substantial efficacy, with a recorded value of 1.71 in the overall mean. The trend continued across the first (2.41) and second spray (1.01). This consistency reinforces the findings of Omprakash et al. (2020) and Suthar et al. (2020).

Comment [a15]: Re write- In conclusion, this study has highlighted Emamectin benzoate 5% SG, Chlorantraniliprole 18.5% SC, and Indoxacarb 15.8% EC as the most effective treatments against maize fall armyworm, pink stem borer, and spotted stem borer, demonstrating their potential to enhance pest management and yield outcomes with favorable Cost-Benefit ratios. Meanwhile, Thiamethoxam 25% WG, Lambda Cyhalothrin 5% EC, Spinosad 45% SC, and Profenophos 50% EC, though delivering moderate results, remain valuable options in addressing these agricultural pests. On the other hand, Cypermethrin 10% EC, Verticilliumlecani 1.15% WP, Neem oil 3%, and NSKE 5% have shown lower efficacy in pest control, warranting a reevaluation of their roles in future strategies. To move forward, it is essential to incorporate these effective insecticides into existing Integrated Pest Management programs, emphasizing the need to combat issues such as insecticide resistance and pest resurgence. The integration of botanical substances into these strategies is also pivotal in reducing the ecological impact of pesticides while maintaining the balance of beneficial insects. These findings offer valuable insights for future actions, guiding the development of robust, sustainable, and environmentally friendly pest

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