



**BIO-ECOLOGICAL STUDIES AND MANAGEMENT OF FALL
ARMYWORM, *Spodoptera frugiperda* (J.E. Smith) ON MAIZE, *Zea
mays* L. IN NAGALAND**

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

By

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ARMYWORM, *Spodoptera frugiperda* (J.E. Smith) ON MAIZE, *Zea
mays* L. IN NAGALAND**

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Submitted

In partial fulfillment of the requirements for the Degree of Doctor of
Philosophy in Entomology of Nagaland University

Nagaland University
August 2025

I, Yengkhom Suraj Singh, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this Thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other University/Institute. This is being submitted to the Nagaland University for the degree of Doctor of Philosophy in Entomology.

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CERTIFICATE – I

This is to certify that the thesis entitled “**Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland**” submitted to Nagaland University in partial fulfillment of the requirements for the award degree of Doctor of Philosophy in Entomology is the record of research work carried out by Mr. Yengkhom Suraj Singh, Registration No. Ph.D./ENT/00334, under my personal supervision and guidance.

The result of the investigation reported in the thesis has not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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CERTIFICATE – II

**VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN
ENTOMOLOGY**

This is to certify that the thesis entitled “**Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland**” submitted by Mr. Yengkhom Suraj Singh, Admission No. Ph-295/19 & Registration No. Ph.D./ENT/00334, to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Entomology has been examined by the Advisory Board and External examiner on

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LIST OF ABBREVIATIONS

/	Per
%	Per cent
ANOVA	Analysis of variance
⁰ C	Degree celsius
CD	Critical difference
cm	Centimeters
CV	Coefficient of variance
DAS	Days after sowing
df	Degree of freedom
E	East
<i>et al.</i>	And others
etc.	Etcetera
Fig.	Figure
g	Gram
ha	Hectare
<i>i.e</i>	Id est (That is)
ICAR	Indian Council of Agricultural Research
IPM	Integrated Pest Management
Max.	Maximum
mg	Milligram
Min.	Minimum
mm	millimetres
msl	Mean sea level
MSS	Mean Sum of Squares
N	North
NS	Non significant
NU	Nagaland University
R	Resistant
RH	Relative humidity
RBD	Randomized Block Design
S	Significant
S	South
SAS	School of Agricultural Sciences
Sem	Standard error mean
SMW	Standard Meteorological Week
SS	Sum of Squares
USDA	United States Department of Agriculture
<i>viz.</i>	Namely
W	West

ABSTRACT

The present investigation was undertaken at the Department of Entomology, SAS, Nagaland University, Medziphema campus during 2022 and 2023 to study the incidence, biology and management of fall armyworm, *Spodoptera frugiperda* on maize variety BIO-9637 Maharaja. Field trials were conducted in a randomized block design with three replications and ten treatments including a control. The incidence of fall armyworm infestation was first recorded in 24th SMW at 1.22 larvae/10 plants during 2022 and 1.32 larvae/10 plants during 2023. Initial leaf damage was recorded at 5.32% during 2022 and 5.78% during 2023. The infestation increased steadily reaching its peak at 83.86% on 28th SMW (2022) and 80.25% on 27th SMW (2023). Correlation analysis revealed that in both years, leaf damage and larval incidence were positively and significantly associated with maximum ($r=0.759^*$ and 0.850^* respectively) and minimum temperatures ($r=0.664^*$ and 0.832^* respectively), while relative humidity exerted a negative influence. Rainfall showed little effect. Adult catches in pheromone traps were consistently low (0.44 ± 0.53 during 2022 and 0.56 ± 0.53 during 2023) and did not align with field infestations, likely reflecting the migratory behavior of the moth after oviposition. Weekly monitoring clearly showed that rapid population build up occurred on 28th SMW (25.72 larvae/10 plants) and 27th SMW (22.75 larvae/10 plants) during 2022 and 2023, respectively, when higher temperatures favored the pest, followed by a decline in August as maize matured and humidity increased. The biology of the pest was studied in detail under laboratory conditions using maize leaves as food. Eggs were laid in clusters of one to two layers and hatched within about two days. Six larval instars were identified, with a mean total duration of 17.42 ± 0.32 days. The length of first, second, third, fourth, fifth and sixth instar and pupal stages were 1.63, 3.16, 6.50, 4.95, 15.99, 31.38 and 14.77 mm, respectively. The pupal stage lasted 7.43 ± 0.14 days. Distinct sexual dimorphism was observed, with males having characteristic wing markings while females were duller. The oviposition period lasted for 4.15 ± 0.54 days. Adult longevity was about 9.15 ± 0.82 days in females and slightly shorter in males (8.85 ± 0.64 days). The total life cycle from egg to adult death was completed in 35.29 ± 0.90 (male) and 36.30 ± 1.22 (female) days. Laboratory bioassays revealed that Emamectin benzoate and Chlorantraniliprole

were highly effective, achieving complete larval mortality within 72 hours. When combined with entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae*, these chemicals provided enhanced mortality compared to fungi alone. Pooled analysis confirmed that Emamectin benzoate induced 80.59 per cent leaf damage reduction followed by *M. anisopliae* + Emamectin benzoate (68.50%), Chlorantraniliprole (59.15%), *Beauveria bassiana* + Emamectin benzoate (55.76%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% SC (51.45%), *Beauveria bassiana* + *Metarhizium anisopliae* (51.21%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (50.71%), *Metarhizium anisopliae* (43.52%) and *Beauveria bassiana* (43.19%). Similarly, the highest larval population reduction was 77.39 per cent by Emamectin benzoate and least by *Beauveria bassiana* (39.52 %). From the study it can be concluded that the fall armyworm is a serious pest of maize in Nagaland with incidence closely linked to weather parameters. The pest completes its life cycle in just over one month and shows rapid buildup during warm conditions in July. Among the management options, Emamectin benzoate 5% SG is the most effective treatment, while Chlorantraniliprole and combinations of *M. anisopliae* with Emamectin benzoate are suitable alternatives. Entomopathogenic fungi alone offer limited suppression but their integration with chemical insecticides enhances efficacy.

Key words: *Spodoptera frugiperda*, Population dynamics, Biology, *Beauveria bassiana* and *Metarhizium anisopliae*, Emamectin benzoate, Chlorantraniliprole

CHAPTER I
INTRODUCTION

INTRODUCTION

Maize (*Zea mays* L.) ranks as one of the most vital cultivated crops, offering remarkable versatility and the ability to thrive in diverse agro-climatic environments. It is the third most significant grain crop globally, following rice and wheat. Often referred to as the “Queen of cereals,” maize possesses broad adaptability and holds the highest genetic yield potential among cereal crops. India ranks 4th in area and 7th in production, representing around 4 per cent of world maize area and 2 per cent of total production (DACNET, 2020). During 2018-19 in India, the maize area reached 9.2 million ha in area producing 27.8 million MT with the productivity of 2965 kg/ha (IIMR, 2021). Madhya Pradesh and Karnataka possess the largest maize cultivation area among Indian states, each accounting for 15 per cent, followed by Maharashtra, Rajasthan, Uttar Pradesh, and others. Bihar ranks as the third greatest maize producer in India, following Karnataka and Madhya Pradesh. The utilization pattern of maize reflects a growing global demand, with applications in food (9.53%), feed (49.60%), industrial usage (23.51%), and ethanol production (14.07%) during the period of 2014-15. Maize consumption in India has increased at an annual growth rate of 2.93 per cent over the last seven years from 16.65 million tonnes in 2007-2008 to 19.1 million tonnes in 2013-14 (USDA, 2014).

In India, maize is mostly cultivated during two seasons: the rainy season (kharif) and the winter season (rabi). Kharif maize accounts for around 83 percent of the maize area in India, whereas rabi maize constitutes 17 per cent of the maize area. More than 70 per cent of kharif maize is cultivated under rainfed conditions, facing numerous biotic and abiotic stressors. The stress prone ecology contributes towards lower productivity of kharif maize (2706 kg/ha) as compared to rabi maize (4436 kg/ha), which is predominantly grown under assured ecosystem (IIMR 2021).

Maize contains about 72 per cent starch, 10 per cent protein and 4 per cent lipid (Inglett, 1970). Maize is enriched with vitamins (thiamine, niacin, riboflavin, pantothenic acid, pyridoxine) and nutrients essential for diet. It also contains oils, resin, salt, fibres and mucilage substances (Kumar and Jhariya, 2013). It also contains significant quantities of vitamin E, calcium and phosphorus although maize

protein is deficient in two key amino acids: lysine and tryptophan. The most suitable temperature for maize ranges from 18°C and 27 °C respectively.

Due to the diverse characteristics of maize, it is cultivated throughout a broad spectrum of weather conditions and elevations (up to 2,700 meters above sea level). Maize can be cultivated in all climates; nevertheless, tropical and subtropical regions account for a greater proportion of corn production than temperate areas. Maize may be cultivated effectively in a range of soils, from loamy sand to clay loam. Soils rich in organic matter, possessing high water retention capacity and neutral pH, are deemed optimal for enhanced productivity (Parihar *et al.*, 2011).

Maize is the second most important crop next to rice and grown in all the districts of Nagaland where it is cultivated in an area of 69,070 ha producing around 136,900 MT (DES, 2019). Maize is influenced by numerous abiotic and biotic stressors. Among these constraints, insect pests represent the most significant impediment to the successful growth of maize from germination to harvest. Estimates of crop losses due to insect pests in India are 18 per cent (Dhaliwal *et al.*, 2015). Sarup *et al.* (1987) listed 130 insect species damaging maize, while Mathur (1991) reported about 250 species of insect and mite pests have been reported damaging this crop out of which only half a dozen is of economic importance which threatens to limit the production of this crop.

Major limiting insect pests are maize stem borer, *Chilo partellus* Swinhoe; pink stem borer, *Sesamia inferens* Walker; two species of shoot fly, *Atherigona nuquii* Steyskal and *Atherigona soccata* Rund; armyworm, *Mythimna seprata* Walker; maize cob borer, *Helicoverpa armigera* and maize aphid, *Rhopalosiphum maidis* Fitch which cause economic yield losses during different seasons all over the country (Siddiqui and Marwaha, 1994).

Globally, the fall armyworm (FAW) *Spodoptera frugiperda* was first reported in early 2016 in West Africa (Nigeria, São Tomé and Príncipe) (Goergen *et al.*, 2016), followed by confirmation across central (Cock *et al.*, 2017; Nagoshi *et al.*, 2017), southern (Jacobs *et al.*, 2018) and eastern (Otim *et al.*, 2018) sub-Saharan Africa, middle east (FAO, 2019), India (Ganiger *et al.*, 2018; Sharanabasappa *et al.*,

2018). As of September 2021, over 70 African and Asian nations have reported FAW (Czepak *et al.*, 2019). In January 2020, FAW was trapped in Australia's special biosecurity zone in the Torres Strait islands of Saibai and Erub, and confirmed on 3 February 2020, and on mainland Australia in Bamaga on 18 February 2020 (FAO, 2020).

Within India, the attack of this invasive pest was reported recently for the first time infesting maize crop in the research fields of maize at the University of Agricultural and Horticultural Sciences, Shimoga, Karnataka during 2018 (Ganiger *et al.*, 2018) and spread quickly to many other states (Singh, 2019), including northeast India which was first reported during late March 2019 in Lunglei district of Mizoram and West Tripura district of Tripura state. Subsequently, it was detected causing massive outbreaks during April in Mizoram, Nagaland and later during early May in Meghalaya, Manipur, Sikkim and Arunachal Pradesh (Firake *et al.*, 2019).

Fall armyworm, *Spodoptera frugiperda* belongs to the insect order Lepidoptera under the family Noctuidae. The name is derived from the movement of the larvae in military column formation *en masse*, devouring crops and leaving no vegetation (Casmuz *et al.*, 2010). As a highly polyphagous pest, *S. frugiperda* larvae feed on a total of 353 different host plants belonging to 76 plant families, including Poaceae, Asteraceae and Fabaceae (Montezano *et al.*, 2018). *S. frugiperda* comprises two genetically divergent host-adapted strains, namely the "rice-strain" and "corn-strain" (Dumas *et al.*, 2015), however it predominantly causes significant economic harm to maize, sorghum, cotton, and soybean crops (Hardke *et al.*, 2015). Polyphagous insects like the Fall Armyworm (FAW) demonstrate fluctuating growth, development, and reproductive success contingent upon the host plant consumed during the larval phase, with the FAW larval diet influencing various fitness metrics, including larval survival, body mass, and adult oviposition (Barros *et al.*, 2010).

The primary host plants of *S. frugiperda* are globally significant agricultural crops: rice, maize, and wheat are cultivated worldwide, whilst sorghum is extensively grown in many regions of Asia and Africa (Dias *et al.*, 2016; Montezano

et al., 2018). Invasive FAW populations consider maize to be a more favorable host crop than millet, rice, or tobacco (Barros *et al.*, 2010).

Spodoptera frugiperda infests maize plants at all developmental phases, from seedling to tasseling, leading to defoliation and mortality of young plants, which ultimately diminishes both the quantity and quality of the harvest. In Latin America, fall armyworm is recognized as one of the major pests of maize, causing heavy economic losses annually, with infection levels of up to 70 per cent (Valdez-Torres *et al.*, 2012). As a cutworm, plant losses could be as high as 55 per cent, with seedling losses up to 60 per cent and yields of 64 days old plants could be reduced by 34 per cent due to this pest (Oerke, 2006).

Management of insect pests using chemicals seems promising but is not sustainable. Microbial control agents are compelling alternatives to chemical pesticides, as they effectively disrupt pest populations without posing risks to human health or the environment. As microbial control agents have complex mode of action, it is very difficult for a pest to develop resistance against these agents (Abdel *et al.*, 2018). The predominant microbiological agents are viruses, bacteria, nematodes, and fungus, which are utilized globally with significant efficacy and success. Among them, entomopathogenic fungi fill an extremely important niche for control of insect pests due to easy delivery, improving formulation, vast number of pathogenic strains known, and easy engineering techniques (Butt, 2001 and Goettel *et al.*, 2010). It is a significant category of bio-agents that interact with insects inhabiting various environments, including freshwater, soil surfaces, and aerial locations.

Entomopathogenic fungi are frequently documented as responsible for significant epizootics in nature, serving as the most adaptable biological control agents and being environmentally safe (Carruthers *et al.*, 1987). There are more than 700 species of fungi belonging to 9 genera that infect insects (Charnley *et al.*, 1989). Numerous entomopathogenic fungi, especially *Beauveria bassiana* and *Metarhizium anisopliae*, are employed as biological control agents against insects, including gregarious pest species.

The integration of specific strains of entomopathogenic fungi with selective insecticides can enhance control efficacy, reduce the quantity of insecticides needed, mitigate environmental contamination risks, and postpone the development of insecticide resistance in pest populations (Ambethgar *et al.*, 2009). Application of insecticide in combination with entomogenous fungi or separately, may affect effectiveness of later through their effect on growth, sporulation and germination (Beevi *et al.*, 1987). The integration of entomopathogenic fungi with low application rates of insecticides has been shown to improve their efficacy (Meyling *et al.*, 2018). Ibrahim *et al.* (2017) found that the utilization of combination of *Bacillus thuringiensis*, emamectin benzoate and methomyl with *B. bassiana* is feasible for the control of polyphagous insect, *S. littoralis* especially at the second larval instar. Moreover, the combination of insecticide and entomopathogenic fungi is more deleterious to the insect than application of insecticides or entomopathogenic fungi alone (Abdel *et al.*, 2018).

Maize agriculture serves as the foundation for numerous developed nations, such as the USA, although its productivity remains significantly low in India. The significant disparity between potential and productivity presents substantial opportunities for the management of crop production and protection strategies. Many scientists are trying to find ways to double the maize production by 2025 (Yadav *et al.*, 2016).

Considering the aforementioned factors and acknowledging the significance of this insect problem, the present investigation **“Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland”** has been planned with the following objectives:

- 1) To study the population dynamics of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) and its correlation with the weather parameter in maize.
- 2) To study the biology of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) using natural diet in Nagaland weather condition.

- 3) To study the combine effect of some insecticides on fall armyworm, *Spodoptera frugiperda* (J.E. Smith).

CHAPTER II

REVIEW OF LITERATURE

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A brief review related to the investigation entitled “**Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland**” has been presented here below.

2.1 To study the population dynamics of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) and its correlation with the weather parameter in maize.

Pair *et al.* (1986) studied about the fall armyworm distribution and population dynamics in the south eastern states in the USA and concluded that the conditions following extremely low winter temperatures may influence FAW populations more than extreme low temperatures alone. The synchrony of emerging FAW adults at overwintering sites timed with the availability and amounts of susceptible stages of corn planted in more northerly areas may be the most important factors determining the magnitude of FAW populations each year throughout the southeastern states.

Nagoshi and Meagher (2004) captured the male fall armyworm moths in pheromone traps over a 16 to 24 months’ period in order to study the seasonal distribution of Fall armyworm host strains in agricultural and turf grass habitats in Southern Florida. Traps set in agricultural regions revealed that populations peaked in the Spring (March-May) and Fall (October-December), with a significant decline in numbers during the summer (July-October) and a smaller reduction in mid-winter (January). Significant variations in the host strain distribution at these times may have been caused by seasonal and strain-specific population patterns. Although sweet corn was present throughout this time, only the rice-strain unexpectedly showed an increase in capture rates during the fall. Both strains had significant numbers of captures during the spring peak.

Robert and Rod (2004) studied on the population dynamics and occurrence of *Spodoptera frugiperda* host strains in southern Florida to know the its preferred habitats throughout the year and a detailed description of seasonal changes in population numbers using molecular markers and pheromone traps and reported that

corn strain moths are limited in their habitat choice while rice strain moths have a substantially broader range.

Camilo *et al.* (2019) investigated the population dynamics of *Spodoptera frugiperda* during 2014-2016 in Colombia and reported that FAW could generate higher resistances to the plants with the endotoxin Cry1F.

Dhar *et al.* (2019) studied the occurrence of fall armyworm, *S. frugiperda* both in Rabi and summer maize. More damage was observed in summer maize as compared to Rabi maize with the maximum infestation of 27.56 per cent.

Meena *et al.* (2019) examined the seasonal occurrence of the fall armyworm on maize during the monsoon season in Udaipur. The infestation ranged from 193.35 to 20+5.59 plants/100 m². Instead of aggregating, the larvae had a uniform or nearly random pattern of spatial distribution.

Painkra *et al.* (2019) conducted a field survey on fall armyworm in order to determine the presence and infestation by the caterpillar on maize crop in northern zone of Chhattisgarh. The caterpillar was observed feeding on middle portion (leaf whorl) of the maize crop between 4-6 leaves stages with infestation rates of 25-30 and 30-35 per cent in knee high stage and 65-70 per cent in tassel stage, respectively.

Babu *et al.* (2019) investigated the population dynamics of fall armyworm on maize and sweet corn in south Rajasthan. The highest larval infestation was found during the crop's vegetative stage, or knee height stage, and continues up to the stage of cob development. In several hybrids, inbred lines of maize and sweet corn, the percentage damage ranged from 10 to 40 per cent.

Anandhi *et al.* (2020) studied the correlation of fall armyworm, *S. frugiperda* with weather parameters in maize ecosystem found the larval population had significant positive correlation with maximum temperature of both same (r=0.32 to 0.45) and previous week (r=0.21 to 0.52) at all the locations. Minimum temperature of same week and the week before had no significant correlation at location. Rainfall from the same week (r=-0.36 to -0.47) and previous week (-0.19 to -0.24) were significant and negatively correlated. They also studied the seasonal dynamics and

spatial distribution of fall armyworm on maize in Cauvery Delta Zone in 2020. Compared to Rabi (0.66 to 2.60 larvae/plant), the larval population was found maximum during Kharif (0.99 to 3.66 larvae/plant). The highest larval populations were recorded in the 27th standard mean week (3.13 to 3.66 larvae/plant) during Kharif and the 45th standard mean week (2.01 to 2.60 larvae/plant) during Rabi.

Kumar *et al.* (2020) reported seasonal incidence of maize fall armyworm *S. frugiperda* in both Kharif and Rabi season. The second fortnight of October, 2019 showed the lowest incidence (10%) of *S. frugiperda* and the first fortnight of November, 2019 showed the highest incidence (72%). In the Perambalur district, the larval population showed significant positive correlation with the maximum temperatures ($r = 0.7205$) and negative correlation with relative humidity ($r = 0.6739$) and rainfall ($r = -0.8293$), in both Kharif and Rabi.

Paul and Deole (2020) noted the seasonal occurrence of fall armyworm infesting Maize crops. It first occurred in the second week of September, during the 37th SMW, with a mean population of 0.12 larvae/plant. The highest population was seen in the fourth week of September, with a mean population of 0.56 larvae/plant. The maximum temperature ($r = 0.586$) showed a significant positive correlation with the fall armyworm and abiotic parameters during Kharif 2018.

Reddy *et al.* (2020) conducted an experiment in Sabour, Bhagalpur, Bihar on seasonal incidence and life cycle studies of fall *S. frugiperda* in maize. According to seasonal incidence studies, the incidence of fall armyworm reached at peak of 35.43 per cent infestation in the third week of August, when the crop was 45 days old during Kharif 2019 and the peak infestation of 26.45 per cent was noticed at 82 days old crop during Rabi 2019-20 in the fourth week of February.

Suby *et al.* (2020) studied the spread of fall armyworm (*S. frugiperda*) in India and stated that fall armyworm is quickly becoming the most devastating pest to maize. Its quick spread to more than 90 per cent of maize-growing regions of diverse agro-ecologies of India. FAW has also been reported in other crops like Sorghum and millets with varying degrees of economic loss.

Sunitha *et al.* (2021) studied the seasonal incidence of fall armyworm during Kharif, 2019. Fall armyworm oviposition began to be noticed on the 34th SMW and peaked on the 40th SMW. The fall armyworm larval population started during the 35th SMW and subsequently increased to a peak of 1.67 larvae plant⁻¹ during the 41st SMW. The 41st SMW witnessed the highest plant infestation (60%) and leaf damage severity rating (3.13). According to the correlation analysis, the egg masses of fall armyworm was positively correlated with both minimum temperature and wind speed ($r=0.668$ and $r=0.529$), while the larval population showed significant positive correlation with maximum temperature ($r=0.029$). The plant infestation caused by fall armyworm showed significant negative correlation with maximum temperature ($r=0.633$) and positive correlation with both morning relative humidity and evening relative humidity ($r=0.678$ and $r=0.664$).

Warkad *et al.* (2021) evaluated the seasonal fluctuations in fall armyworm and its natural enemies on maize and reported that the third week of March (11th SMW) had the maximum larval population (1.60 larvae/ plant) and damaged plant (82.50%). The lowest damaged plants were noticed during the initial days of the cropping season and increased reaching peak at the crop maturity (50th SMW). The damaged plants ranged from 20 to 82.50 per cent during December to March months. The percentage of infested cobs varied from 14.50 to 46.50 per cent.

Zhang *et al.* (2021) conducted a field investigation in tropical and subtropical regions of China and reported that FAW larval density was significantly correlated with the seasonal temperature of the location surveyed.

Alam *et al.* (2022) found that the peak activity of fall armyworm on rabi maize was observed in 12th SMW, March 2021 with mean larval population and percent mean leaf damage of 4.8 larvae/plant and 46.0 per cent of leaf damage/plant respectively. The correlation analysis depicted that both larval population and percent leaf damage of fall armyworm, *S. frugiperda* showed significant positive correlation with maximum temperature (°C) but non-significant with while relative humidity showed non-significant negative correlation but rainfall showed significant

negative correlation with both larval population ($r = -0.475^*$) and percent leaf damage and ($r = -0.533^*$).

Darshan and Prasanna (2022) reported that fall armyworm was an invasive polyphagous pest. They carried out a roving survey during the 2019-20 Kharif and Rabi cropping seasons at 15 days' interval. The larval counts and per cent infestation was 0.30 to 0.44 larvae/plant and 23.10 to 33.77 per cent, respectively.

Jaiswal *et al.* (2022) investigated on the pest complex and extent of damage caused by fall armyworm (*S. frugiperda*) during Kharif, 2019 on maize crop. The highest percentage of dead hearts (60%) were recorded during the 38th SMW and 39th SMW. Later, during 42nd SMW, the lowest dead heart percentage was noted (10%).

Nivetha *et al.* (2022) reported that the incidence of FAW commenced in the 38th week of the season (0.52 larvae/plant) and progressively escalated, peaking in the 44th week (1.20 larvae/plant), which corresponded with the highest percentage of infestation (53.72%) in rabi, 2019. The occurrence of FAW in summer 2020 commenced at the 8th MSW (0.69 larvae/plant), peaked at the 12th MSW (1.69 larvae/plant), coinciding with the highest percentage of infection (58.33%). Correlation analysis during the rabi season indicated a significant positive correlation between larval population and infestation with evening relative humidity ($r = 0.727$), whereas maximum temperature, minimum temperature, and rainfall demonstrated a negative association with the larval incidence and infestation of *S. frugiperda*. In the summer season, correlation study revealed a positive link with maximum temperature ($r = 0.675$), whereas minimum temperature, morning humidity, evening humidity, and rainfall exhibited a negative correlation.

Sarma *et al.* (2022) reported that fall armyworm has spread to locations at 1,222 above mean sea level in the northeast region of India. In Biswanath district, Assam 15.2-64.3 per cent of infestation on maize was found in farmers' field, while 2.15 per cent was found in the Biswanath College of Agriculture. The larvae from the field gathered were free of any larval parasites. Many farmers noticed that maize had a high insect incidence.

Sharath *et al.* (2022) observed the utilization of female sex pheromones for management of insect pests through mass trapping of males as an important tool for ecofriendly pest management and reported that the highest trap catches were recorded during the July third week which capturing 16.32 moths/trap/week and the lowest number of moths were captured during third week of September (0.18 moths/trap/week).

Tiku *et al.* (2023) reported that the incidence of FAW exhibited a highly significant positive association with minimum temperature and evening relative humidity. The maximum temperature showed a significant positive correlation, whereas rainfall and evaporation showed a significant negative correlation with the population build-up of FAW.

2.2. To study the biology of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) using natural diet in Nagaland weather condition.

Deole and Paul (2018) studied the biology of fall armyworm on maize. The life cycle of fall armyworm was completed in about 28-35 days. The duration of larval, pre pupal, pupal and adult stages was 14-16, 1-2, 6-8 and 5-7 days, respectively.

Silva *et al.* (2017) studied the development of FAW using different food sources in the laboratory by feeding newly hatched larvae with soybean, cotton, maize, wheat, and oat leaves. He reported that even though *S. frugiperda* was considered to be polyphagous, it was closely associated with grasses (maize, wheat, oat) however, its food intake regulation appeared to be triggered by a complex of different mechanisms.

Kalleshwaraswamy *et al.* (2018) studied the life cycle of fall armyworm, *S. frugiperda*. They found that female was laying eggs with the fecundity 1,064 eggs. The duration of Incubation, larval and pupal phases were noted to be from 2-3, 14-19 and 9-12 days, respectively. Under laboratory conditions, it was found that total life cycles of male and female were 32-43 and 34-46 days, respectively.

Sharanabasappa *et al.* (2018) studied on the life history of *Spodoptera frugiperda* (J.E. Smith) under laboratory conditions by feeding it on hosts like sorghum, cabbage, tomato, groundnut and sugarcane. They observed the off seasonal survival, host range, spread and concluded that gravid female was laying eggs with the fecundity 1,064 eggs. Incubation, total larval and pupal period were observed to be from 2-3, 14-19 and 9-12 days, respectively. The total life cycle of male and female were reported to be 32-43 and 34-46 days, respectively.

Montezano *et al.* (2019) evaluated the developmental parameters of *S. frugiperda* under controlled conditions. The average length of time for the egg, larval, prepupal and pupal stages were 2.69, 13.73, 1.43 and 9.24 days, respectively. Egg, larval, prepupal and pupal stage survival rates were 97.40, 98.33, 99.32 and 97.95 per cent, respectively.

Ahir *et al.* (2020) investigated the biology of fall armyworm on maize. The female was seen laying eggs, with a fecundity of 1082 eggs on average. According to records the incubation, total larval, pupal, pre oviposition, oviposition and post oviposition periods ranged from 2-3, 13-20, 8-12, 3-4, 2-3 and 4-5 days, respectively. The male and female life cycle were observed to be 32-44 and 35-47 days, respectively. The male to female sex ratio was 1:1.30.

Ashok *et al.* (2020) conducted a life table study of *S. frugiperda* in maize under controlled conditions. according to the study, the total length of the larval stage was 14.48 days, the duration of I, II, III, IV, V and VI instar larvae were 2.55, 2.12, 2.08, 2.00, 2.04 and 3.69 days, respectively with a pupal period of 8.24 days and adult longevity of 12.6 days and 11.1 days, respectively for female and male.

Kalyan *et al.* (2020) investigated the biological parameters of FAW under laboratory conditions and reported that the mean incubation, larval, pupal, pre oviposition, oviposition and post-oviposition period were 3.30, 16.97, 8.96, 3.47, 2.96 and 6.13 days, respectively. The mean adult longevity of male and female was 10.67 and 13.00 days whereas the mean total life cycle was 37.68 days.

Paul and Deole (2020) reported that the incubation, total larval and pupal period of FAW under laboratory conditions ranged from 2-4, 14-16 and 8-10 days respectively and the total life cycle of the moth ranged from 29-35 days.

Reddy *et al.* (2020) examined the fall armyworm life cycle during Rabi 2019-20, they found that the incubation time ranged between 2 to 3 days. The larval period was between 15 and 18 days, with the first to fourth instars having a range of 2-3 days, the fifth and sixth instars having a range of 3-4 days and 3-5 days, respectively. Pupal period lasted for 8-10 days and adults lived for 6-8 days.

Vishwakarma *et al.* (2020) reared FAW under laboratory conditions and reported that the mean incubation, total larval and pupal period were 2.5, 18.25, 10.00 days respectively. The male and female adult longevity was reported to be 6.00 and 10.5 days respectively. The mean total life cycle of male and female were 39.5 and 40.2 days, respectively.

Janwa *et al.* (2021) reported that the incubation, total larval, pre-pupal, pupal, pre-oviposition, oviposition and post oviposition periods, male and female longevity of fall armyworm were 2-3, 13-20, 1-2, 9-13, 3-4, 2-3, 4-5, 7-10 and 10-12 days, respectively. The male and female life cycle take 37-46 and 40-49 days, respectively to complete. The average fecundity of female was 996 eggs and the sex ratio was 1.30:1.

Kranthi *et al.* (2021) studied the biology of fall armyworm on sugarcane. They found that the mean incubation period was 2.47 ± 0.051 days. The larva went through six instars in total. The total larval period lasted for about 15 to 19 days with a mean of 16.82 ± 0.236 days. The mean prepupal and pupal periods were 2.55 ± 0.054 and 8.22 ± 0.075 days, respectively. Female and male moths lived an average of 11.36 ± 0.314 and 7.59 ± 0.137 days, respectively. The pre oviposition, oviposition and post ovipositional days varied from 3-4, 3-4, 4-5 days with respective means of 3.48 ± 0.054 , 3.39 ± 0.240 and 4.48 ± 0.075 days. The average number of eggs laid by a female moth was 544.18 ± 12.53 .

Ramzan *et al.* (2021) recorded the developmental duration of each stage of *S. frugiperda* reared on maize leaves under laboratory conditions. The embryonic period was 2.32 ± 0.22 days. While the total larval period was 14-16 days and the duration of 1st, 2nd, 3rd, 4th, 5th and 6th larval instars were 2.37, 2.09, 2.01, 2.02, 2.27 and 5.10 days, respectively. Female moths were reported to live longer compared to male.

Maharani *et al.* (2021) conducted a study to determine the development period, survival, reproduction, and life table of *S. frugiperda* on maize and rice leaves under laboratory condition and reported that the larvae of *S. frugiperda* that fed on maize had a larger body size than those fed on rice where the female longevity at 25.7 °C from the egg until imagos death on maize and rice were 44.55 and 50.25 days, respectively while that of the male were 43.79 and 48.61, respectively.

Reddy *et al.* (2021) reported that the total larval duration of FAW was 18.02 days, wherein first, second, third, fourth, fifth and sixth instar were 2.6, 2.7, 2.5, 2.4, 2.7 and 5.1 days respectively. The pupal period lasted for 9.92 days. The pre oviposition, oviposition and post oviposition period were found to be 10, 3.02, 4.40 days respectively. Mean longevity of males was 9.10 days while in case of females, it was 11.52 days. The total life cycle of male and female was completed in 40.34 and 42.76 days, respectively.

Siddhpara *et al.* (2021) investigated the biology of FAW on maize under laboratory conditions. The incubation period was 2.40 ± 0.50 days. The larvae passed through six instars, lasting 14.90 ± 1.47 days in total. The duration of pupal stage was 9.30 ± 0.65 days, and it was observed both with or without earthen cocoon. Male and female adults lived an average of 7.90 ± 0.84 and 10.60 ± 1.22 days, respectively. The entire lifecycle was finished in 34.50 ± 1.80 days for males and 37.20 ± 2.52 days for females.

Tiwari and Deole (2021) conducted a study on life cycle of fall armyworm, *S. frugiperda* on maize at Raipur, Chhattisgarh. According to investigation the average life cycle of *S. frugiperda* took 34.5 ± 0.72 days in laboratory condition. Six larval instars were present and the larval stage lasted 16.65 ± 0.16 days. The duration of

pupation was noted as 6.30 ± 0.14 days. Adult female longevity was noted as 9.05 ± 0.19 days, while the longevity of adult male noted 6.15 ± 0.13 days.

. Akoijam *et al.* (2022) studied the life cycle of fall armyworm under Manipur conditions and reported that the adult male and female could live for 32-40 and 29-34 days, respectively. The female could lay an around 1700-2000 eggs in its lifespan with an egg mass of 180-200. Larvae had six instars with the larval period of 18-19 days and pupal period of 8-9 days.

Dubale *et al.* (2022) reported that the incubation, total larval, pre-pupal and pupal period of FAW, *S. frugiperda* ranged from 2-3, 14-18, 1-2 and 8-10 days, respectively. The preoviposition, oviposition and post oviposition period ranged from 2-3, 3-5 and 2-3 days, respectively. The total life cycle of male and female ranged from 34-38 and 37-39 days, respectively. The female adult survived for 9.8 days with a range of 9-11 days compared to male (8.7 days) with a range of 7-11 days.

Gopalakrishnan and Kalia (2022) evaluated the biological parameters of FAW on four different hosts, maize, cotton, castor and cauliflower. Results showed that the shortest life cycle of 32.8 ± 0.52 days in males and 34.1 ± 0.43 days in females was observed on maize and cotton was the least preferred host with longer life cycle of 49.5 ± 0.50 days.

Hong *et al.* (2022) conducted a detailed study on the biological parameters of *S. frugiperda* reared on maize cultivars, field maize, sweet maize and waxy maize under controlled conditions. The findings revealed that all the maize cultivars had six instars of larval development. Significant effects of the host plant were found in the duration of larval stage 10.83 ± 0.14 , 11.015 ± 0.15 and 11.28 ± 0.05 days when fed with sweet maize, waxy maize and field maize, respectively. The life cycle lasted for 28.11 ± 0.40 days in field maize, 27.16 ± 0.37 days in sweet maize and 28.41 ± 0.34 days in waxy maize.

Rajisha *et al.* (2022) reported that the incubation, the total larval and the pupal periods were found to be 2-3, 13-20 and 7-11 days, respectively. Male and female life spans were 33-46 and 35-47 days, respectively.

Sharma *et al.* (2022) observed that the average incubation period was 3 days with an average fecundity of 979.43 eggs, larval (I to VI stage) and pupal development period were 14-25 days and 8-13 days, respectively. Adult longevity was 5.24 days for male and 6.9 days for female in absence of food and water, but longevity was increased by four-fold when 10% honey solution was fed (20.73 days for male and 22.78 days for female).

Marri *et al.* (2023) reported that the total larval duration of *S. frugiperda* throughout the six instar stages was 16–18 days, while the mean pupal weight were 0.25 ± 0.001 g and 0.35 ± 0.011 g for males and females, respectively. The mean pupal length was observed as 14.3 ± 0.16 mm for males and 17.2 ± 0.14 mm for females and pupal duration ranged from 8 to 14 days. Pupal duration ranged from 8 to 14 days, with a mean of 10.35 ± 0.26 days. The life cycle of males lasted 33–44 days and that of females lasted 36–49 days.

2.3 To study the combine effect of some insecticides on fall armyworm, *Spodoptera frugiperda* (J.E. Smith)

Rivero *et al.* (2018) studied the interaction of *Beauveria bassiana* and *Metarhizium anisopliae* with chlorpyrifos ethyl and spinosad in *S. frugiperda* larvae. They found that both insecticides enhanced the performance of the fungus when the insecticide and fungus were applied simultaneously and when spinosad was applied first. When Bb88 and spinosad were used together, synergistic mortality was seen, which led to 34% more dead larvae than the spinosad control (44%). Lastly, antagonistic effects were seen when Bb88 and chlorpyrifos were applied together, and when ETL was applied before chlorpyrifos, which reduced larval mortality by 27, 31 and 19 per cent, respectively.

Akutse *et al.* (2019) investigated the ovicidal effects of entomopathogenic fungal isolates on the fall armyworm *S. frugiperda*. Twenty entomopathogenic fungal isolates (14 *Metarhizium anisopliae* and 6 *Beauveria bassiana*) were examined for efficacy. The capacity of these isolates to kill FAW second instar larvae, eggs and neonate larvae that hatched from treated eggs was tested. The results revealed that, only *B. bassiana* ICIPE 676 caused moderate mortality of 30 per cent

to second instar larvae. *M. anisopliae* ICIPE 41 and ICIPE 7 outperformed all the other isolates, causing 96.5 and 93.7 per cent mortality to the neonate larvae, respectively. *M. anisopliae* ICIPE 78, ICIPE 40 and ICIPE 20 caused egg mortalities of 87, 83 and 79.5 per cent, respectively. The cumulated mortality of eggs and neonates was highest with *M. anisopliae* ICIPE 41 (97.5%).

Maduka (2019) carried out an experiment to know the effects of biopesticides on demographic parameters of fall armyworm in Morogoro Tanzania. Using biopesticides such as *Beauveria bassiana*, *Metarhizium anisopliae* and *Bacillus thuringiensis* on a commercialized maize variety, the developmental biology and demographic parameters of fall armyworm were determined. They observed significant variation in developmental durations of immature stages among treatments.

Mahankuda and Bhatt (2019) reviewed the potentialities of entomopathogenic fungus *Beauveria bassiana* as a biocontrol agent. High virulence, eco-friendliness, bio-persistence, host specificity and the improved biodiversity in controlled ecosystems that make it possible for them to be used as an eco-friendly part of IPM.

Akutse *et al.* (2020) studied on sustainable management of the fall armyworm by using insect pathogenic fungus and a pheromone trap. They evaluated the impact of 22 isolates entomopathogenic fungi (16 *Metarhizium anisopliae* and 6 *Beauveria bassiana*) on *S. frugiperda*. Among them two isolates with the lowest LT₅₀ values *B. bassiana* ICIPE 621 and *M. anisopliae* ICIPE7 caused 100 per cent mortality of the moths and had LT₅₀ values of 3.6±0.1 and 3.9±0.0 days, respectively.

Dhobi *et al.* (2020) reported that the treatments *B. bassiana* 5% WP (2.42 larvae/10 plants), azadirachtin 1500 ppm (2.46 larvae/10 plants) and *M. anisopliae* 1.15% WP (2.78 larvae/10 plants) with per cent plant damage of 22.74, 23.46 and 26.48 per cent, respectively were found effective in controlling the damage caused by fall armyworm, *S. frugiperda* and are superior over the control.

Ramanujam *et al.* (2020) reported that in their field trial results low percentages of plant infestation by FAW were observed after 3 sprays of *M. anisopliae* ICAR-NBAIR Ma-35 (20.28%) and *B. bassiana* ICAR-NBAIR Bb-45 (21.39%) compared to the control (66.94%). Compared to the control (10.18 Q ha⁻¹), *M. anisopliae* ICAR-NBAIR Ma-35 (27.08 Q ha⁻¹) and *B. bassiana* ICAR-NBAIR Bb-45 (22.68 Q ha⁻¹) had significantly higher cob yields.

Herlinda *et al.* (2020) examined soil samples from South Sumatra (Indonesia) to study the pathogenicity of entomopathogenic fungi against the maize pest, *S. frugiperda*. Fungi exploration was carried out in both lowlands and highlands and the obtained isolates were assessed for pathogenicity against the third instar larvae. *Metarhizium spp.* was found and 14 isolates were obtained. They revealed that every isolate was harmful to *S. frugiperda* larvae, with the most harmful ones killing 78.67 per cent of them and significantly suppressing the emergence of adults up to 81.2 per cent.

Ramos *et al.* (2020) evaluated the artificial establishment of *Beauveria bassiana* and *Metarhizium anisopliae* as endophytes in maize plants, and its effect in controlling the fall armyworm, *Spodoptera frugiperda* larvae. The results showed that *B. bassiana* was isolated more frequently from roots than from leaves and stems (25, 10 and 5 isolations, respectively), whereas *M. anisopliae* was only found on roots. The second instar larvae of both entomopathogenic fungi died (100%) due to their effects. Additionally, *B. bassiana* and *M. anisopliae* killed, 87 and 75 per cent of the fourth larval instars, respectively.

Deshmukh *et al.* (2021) studied on the field efficacy of insecticides for management of invasive *Spodoptera frugiperda* on maize in India and reported that chlorantraniliprole, emamectin benzoate and spinetoram are suitable as one of the components of Integrated Pest Management of fall armyworm.

Idrees *et al.* (2021) studied the effectiveness of entomopathogenic fungi on immature stages and feeding performance of fall armyworm, *S. frugiperda* larvae. They found that *Beauveria bassiana* ZK-5 caused the maximum egg mortality at 1 x 10⁶, 1 x 10⁷, 1 x 10⁸ conidia ml⁻¹, with rates of 40, 70 and 85.6 per cent, respectively.

Furthermore, at 1×10^8 conidia ml^{-1} , *B. bassiana* ZK-5 caused the highest neonate mortality of 54.3 per cent. Additionally, it decreased the feeding efficacy of *S. frugiperda* larvae in their first to third instar by 66.7 to 78.6 per cent at 1×10^8 conidia ml^{-1} .

Kumar and Mohan (2021) conducted an experiment to determine the bio-efficacy of some selected insecticides against fall armyworm in maize field condition and reported that Chlorantraniliprole was found highly effective in reducing the larval population and leaf damage with 90.43 per cent reduction in larval population, over untreated control.

Phani *et al.* (2021) investigated to find out the field efficacy of chlorantraniliprole at different doses against fall army worm in maize and reported that the highest reduction in percent of mean plant infestation (% ROC) of 84.52 & 83.24 over control was recorded in chlorantraniliprole @ 250 ml and 200 ml/ha after 2nd spraying respectively and concluded that chlorantraniliprole at the rate of 200 ml and 250 ml/ha are significantly effective against fall armyworm.

Naram *et al.* (2022) studied on the evaluation of bio-rational insecticides against *S. frugiperda* and reported that among different insecticides used, lowest per cent of leaf damage was observed in spinosad 45% SC 0.32 ml/L treated plot by 21.50 per cent which is statistically on par with emamectin benzoate 5% SG 0.5 g/L.

Rizvi and Deole (2022) invested the bio-efficacy of some selected insecticides against fall armyworm on sweet corn and among the insecticides treated, the highest per cent reduction in larval population was found in chlorantraniliprole 18.5% SC @ 27.75 ml a.i./ha with 71.67 per cent and 82.30 per cent after first and second sprays, respectively. The overall mean population of *S. frugiperda* was recorded as 0.49 larva/plant after first spray and 0.40 larva/plant after second spray.

Suganthi *et al.* (2022) investigated the bioefficacy, persistent toxicity and persistence of translocated residues of various insecticide seed treatments for the management of fall armyworm in maize. According to the investigation, highest protection was provided by chlorantraniliprole 62.5 FS @ 6 ml/kg of seeds, followed

by cyantraniliprole + thiamethoxam 19.8 FS, tetraniliprole 480 FS and tetraniliprole + fipronil 240 FS. Chlorantraniliprole residues persisted for more than 26 days, and cyantraniliprole + thiamethoxam residues persisted for more than 16 days in maize seedlings.

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CHAPTER III
MATERIAL AND METHODS

MATERIAL AND METHODS

The experimental study entitled “Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland” was conducted in the Experimental Farm of Department of Entomology, School of Agricultural Sciences, Nagaland University, Medziphema.

3.1 Experiment site

The experiment farm is located at Medziphema, a foothill of Nagaland at 25° 45’ 43” N latitude and 93° 53’ 04” E longitude at an elevation of 310 metres above mean sea level.

3.2 Climatic condition and soil types

The climate is moderate with maximum temperature ranges between 21°C to 32°C in summer and minimum temperature ranges of 8°C in winter. The annual average rainfall varies from 200 cm to 270 cm which mainly precipitates from April to October and from November to March the weather is dry. The climate is sub-tropical. The soil is sandy loam in texture, acidic in nature with pH ranging from 4.5-6.5.

3.3 Meteorological data

The weather data of different standard meteorological weeks (SMW) during the crop growth period was obtained from ICAR, Jharnapani, Nagaland and is presented in Table 2a, 2b, 2c and Fig. 1b.

3.4. Agronomical practices

All the recommended agronomic practices including cultural practices, fertigation, weeding, etc., were followed to keep the plants healthy.

3.5. Collection of seeds

The seeds were collected from the College of Agriculture, Central Agricultural University, Imphal.

3.6 Sowing

Maize seeds were subjected to line sowing with a spacing of 30 cm x 60 cm. Seeds were sown on 3rd June 2022 and 2nd June 2023, respectively.

3.6. Setting up of pheromone traps

Fall armyworm sex pheromone traps [(Z)- 9-tetradecen-1-ol acetate (Z)-11-hexadecen-1-ol acetate and (Z)-7-dodecen-1-ol acetate] was placed at 1.5m height, 18 days after sowing (Malo *et al.*, 2004) at the rate of 8 traps per acre.

3.7. Design and layout of the field

Randomized Block Design (RBD) field layout was used for insecticide treatments on maize with three replications. Ecological plots were maintained to observe the seasonal incidence of fall armyworm and to be used as food source for insects during biology study in the laboratory. The detail layout is presented below (Fig. 1a).

1	Crop	Maize
2	Variety used	BIO-9637 Maharaja
3	Experimental design	Randomized Block Design
4	Number of replication	3
5	Total Number of plots	30
6	Size of the plot	4.4 m X 3.8 m
7	Plot to plot spacing	0.5 m

8	Spacing between the replications	0.5 m
9	Spacing between the plant rows	60 cm
10	Spacing between the plants	30cm
11	Seed rate	20 kg ha ⁻¹
12	Method of planting	Line sowing

3.8. Materials and methodologies

The data on the incidence of fall armyworm as leaf infestation percentage, number of larva, number of adult and its correlation with the weather parameters were recorded.

3.8.1.1. Objective 1

3.8.1.1. Name of the experiment: To study the population dynamics of fall armyworm and its correlation with the weather parameters in kharif maize.

3.8.1.2. Location: The experiment was conducted at Entomological experimental farm at SAS, NU, Medziphema campus.

3.8.1.3. Methodology:

The readings were taken in a zig-zag positions, in the form of “W” pattern in the field (Prasanna *et al.*, 2018). The population per plant were expressed as the mean of three replications. Each replication data was the mean of data obtained from 10 plants.

3.8.1.4. Observations taken

- Data collection on (FAW) caught by the pheromone baited trap was done

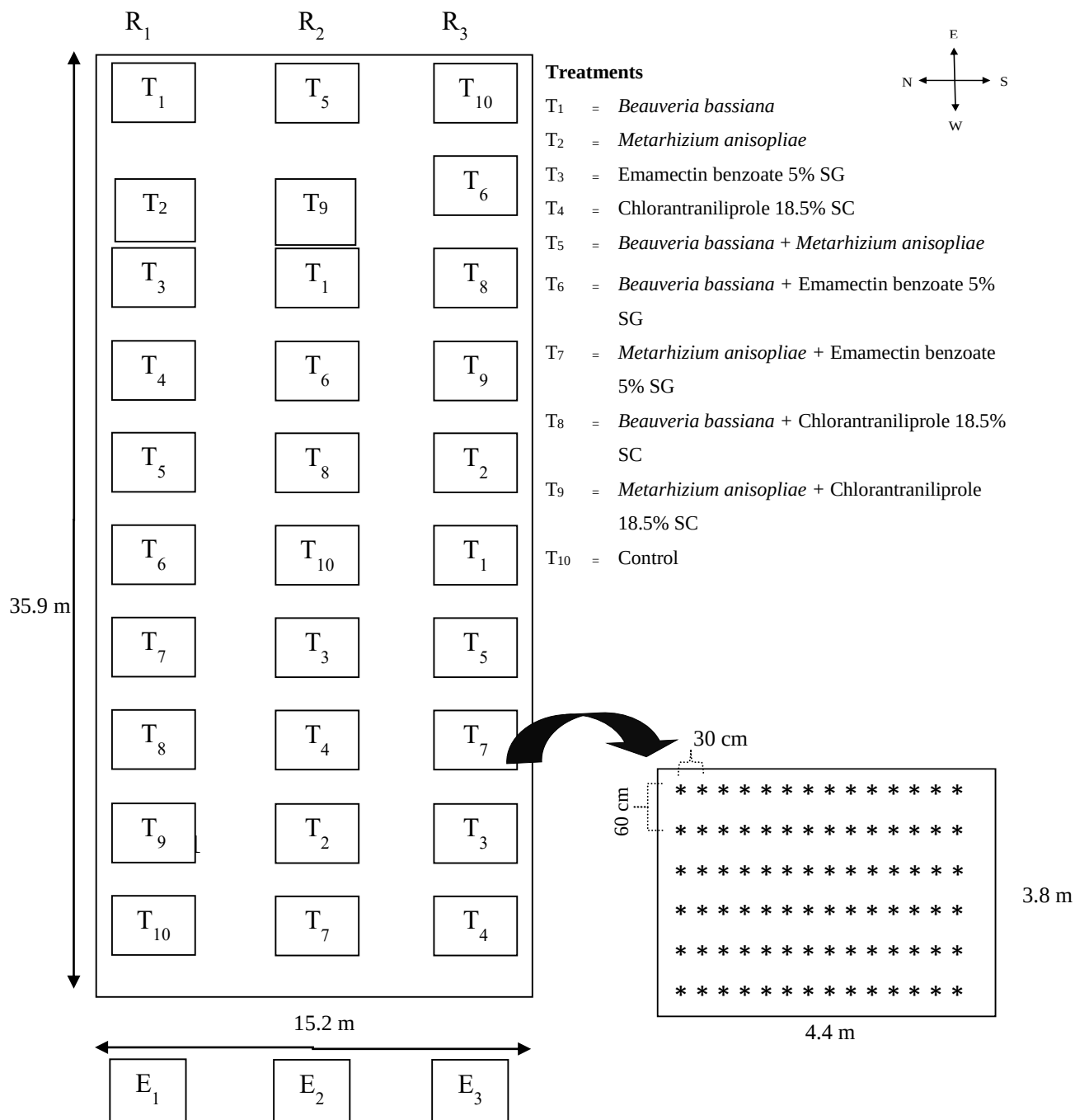


Fig. 1a Layout of the Experiment field in Randomised Block Design

between 06.00 and 07.00 hr.

- Larval count and per cent leaf damage was recorded once a week during the crop during the crop period.
- The per cent leaf infestation was calculated by visual assessing on any damage to plants attacked by *S. frugiperda* on a scale of 1-9 (Davis and Williams 1992):

$$I = \left(\sum_{i=0}^n nivi / NZ \right) \times 100 \%$$

where,

I= intensity of leaf damage

Z = Highest score (9)

N= number of plants observed

n= number of plants that have a “v” value

v = the value (score) of crop damage based on the criteria in Table 1 and Plate 3

Table 1. Leaf damage visual scoring in 0-9 scale (Davis and Williams, 1992)

Scale	Description
0	No visible leaf damage
1	Only pinhole damage on leaves
2	Pinhole and shot hole damage to leaf
3	Small elongated lesions (5–10 mm) on 1–3 leaves
4	Midsized lesions (10–30 mm) on 4–7 leaves
5	Large elongated lesions (>30 mm) or small portions eaten on 3–5 leaves
6	Elongated lesions (>30 mm) and large portions eaten on 3–5 leaves
7	Elongated lesions (>30 cm) and 50% of leaf eaten
8	Elongated lesions (30 cm) and large portions eaten on 70% of leaves
9	Most leaves with long lesions and complete defoliation observed

3.8.1.5. Statistical analysis

Data collected was entered and stored in a spreadsheet of Microsoft Excel and subjected to analysis of variance (ANOVA). Correlation between number of larva, moth catch and plant damage was calculated. The influence of weather factors on population density of fall armyworm was analysed by a simple correlation study (Rahmathulla, 2012). Correlation co-efficient (r) was calculated by using the formula as given by Fisher.

Table 2a. Meteorological data during the period of investigation, 2022

Date	MSW	Temperature (°C)		Relative humidity (%)		Total Rainfall (mm)
		Max	Min	Max	Min	
28 May - 3 June	22	33.29	23.29	92.86	64.71	22.50
4 June - 10 June	23	32.97	24.01	94.14	73.71	51.10
11 June - 17 June	24	30.30	23.27	94.71	73.57	46.70
18 June - 24 June	25	31.19	23.41	95.43	74.57	34.80
25 June - 1 July	26	33.26	24.89	93.29	67.57	9.90
2 July - 8 July	27	34.23	24.70	90.71	65.71	77.10
9 July - 15 July	28	34.13	24.49	90.00	68.86	22.90
16 July - 22 July	29	33.89	24.46	91.71	75.00	135.30
23 July - 29 July	30	31.79	23.17	96.00	69.71	135.30
30 July - 5 August	31	33.64	23.86	93.43	67.57	48.80
6 August - 12 August	32	33.27	23.89	96.00	71.43	114.70
13 August - 19 August	33	33.61	24.24	91.00	72.29	27.50
20 August - 26 August	34	34.11	24.46	93.86	68.43	64.20
27 August - 2 September	35	32.66	24.33	93.43	68.00	9.00

Source: ICAR, Jharnapani

Table 2b. Meteorological data during the period of investigation, 2023

Date	MSW	Temperature (°C)		Relative humidity (%)		Total Rainfall (mm)
		Max	Min	Max	Min	
28 May - 3 June	22	35.80	22.79	85.29	49.29	2.50
4 June - 10 June	23	36.94	24.07	84.14	61.00	77.10
11 June - 17 June	24	30.16	23.57	93.14	79.57	107.20
18 June - 24 June	25	30.19	23.64	91.71	77.00	63.20
25 June - 1 July	26	34.13	25.11	91.43	75.43	25.00
2 July - 8 July	27	34.01	24.94	89.71	64.57	59.60
9 July - 15 July	28	33.01	25.13	91.71	73.00	4.40
16 July - 22 July	29	33.37	25.07	93.57	72.14	41.50
23 July - 29 July	30	34.03	25.04	93.14	69.71	123.60
30 July - 5 August	31	34.21	25.09	92.14	74.43	112.30
6 August - 12 August	32	32.31	25.11	91.14	75.57	73.20
13 August - 19 August	33	32.97	25.29	92.14	73.71	41.90
20 August - 26 August	34	31.51	24.63	93.43	80.71	70.60
27 August - 2 September	35	32.57	24.53	93.00	67.14	16.20

Source: ICAR, Jharnapani

Table 2c. Meteorological data during the period of investigation, 2022 and 2023 (pooled)

Year 2022-23	Mean Standard Week	Temperature (°C)		Relative humidity (%)		Total Rainfall (mm)
		Max	Min	Max	Min	
28 May - 3 June	22	34.5	23.0	89.1	57.0	12.5
4 June - 10 June	23	35.0	24.0	89.1	67.4	64.1
11 June - 17 June	24	30.2	23.4	93.9	76.6	77.0
18 June - 24 June	25	30.7	23.5	93.6	75.8	49.0
25 June - 1 July	26	33.7	25.0	92.4	71.5	17.5
2 July - 8 July	27	34.1	24.8	90.2	65.1	68.4
9 July - 15 July	28	33.6	24.8	90.9	70.9	13.7
16 July - 22 July	29	33.6	24.8	92.6	73.6	88.4
23 July - 29 July	30	32.9	24.1	94.6	69.7	129.5
30 July - 5 August	31	33.9	24.5	92.8	71.0	80.6
6 August - 12 August	32	32.8	24.5	93.6	73.5	94.0
13 August - 19 August	33	33.3	24.8	91.6	73.0	34.7
20 August - 26 August	34	32.8	24.5	93.6	74.6	67.4
27 August - 2 September	35	32.6	24.4	93.2	67.6	12.6

Source: ICAR, Jharnapani

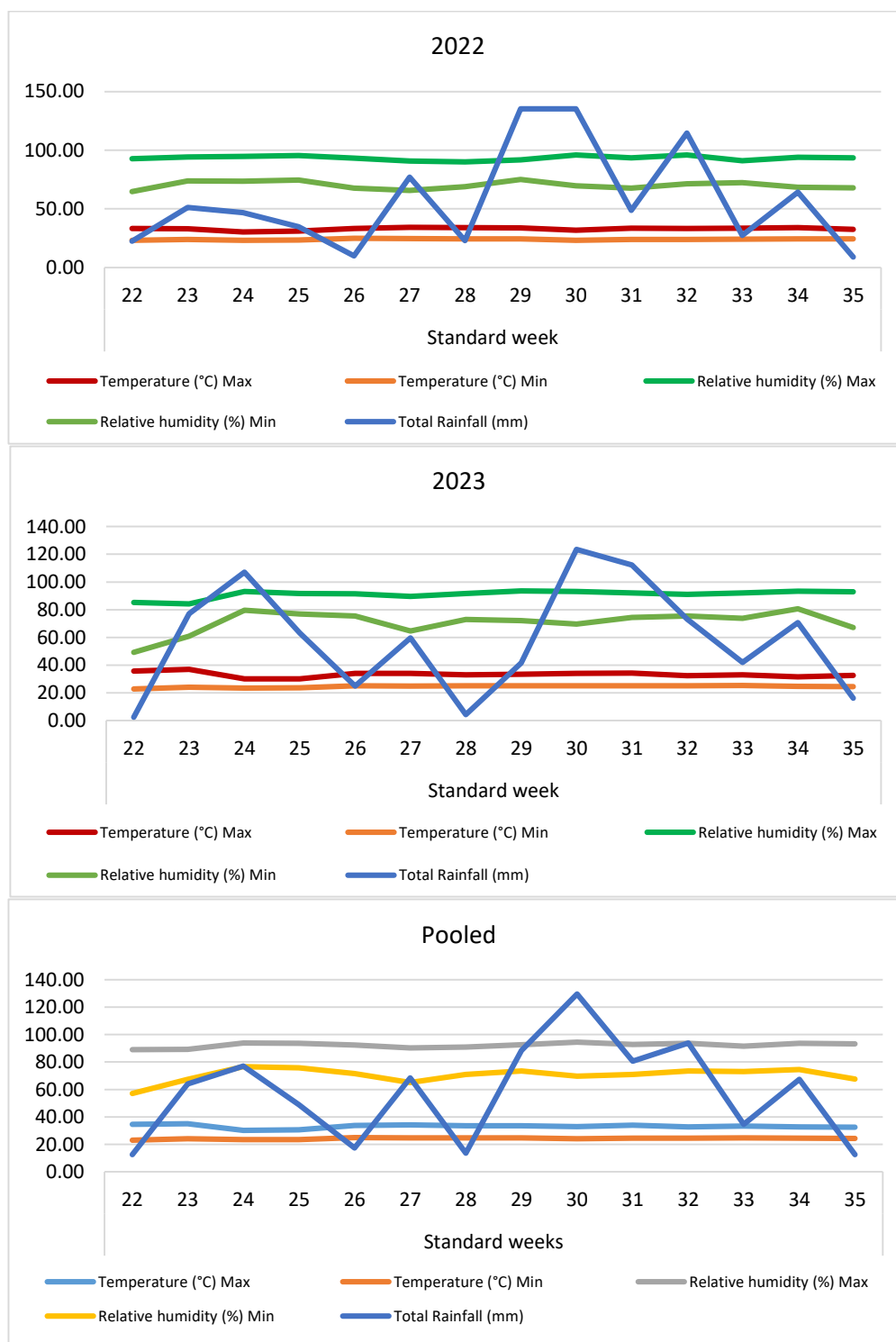


Fig. 1b Geographical representation of the meteorological data during the period of investigation, 2022 and 2023



Plate 1. A. Land preparation and B. experimental field

$$r = \frac{\sum xy - \frac{\sum x \cdot \sum y}{N}}{\sqrt{\left\{\sum x^2 - \frac{(\sum x)^2}{N}\right\}\left\{\sum y^2 - \frac{(\sum y)^2}{N}\right\}}}$$

Where,

r = Co- efficient of correlation

N = number of observation

x = mean number of pest infestation

y = independent variables

The correlation co- efficient was then tested for significance by “t” test with the following formula.

$$t = \frac{r}{\sqrt{1-r^2}} \times \sqrt{(n-2)}$$

3.8.2. Objective 2

3.8.2.1. Name of the experiment: To study the biology of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) using natural diet in Nagaland weather condition.

3.8.2.2. Location: The experiment was conducted at Entomological laboratory, Department of Entomology, SAS, NU, Medziphema campus under natural environment condition.

3.8.2.3. Methodology:

S. frugiperda larvae collected from the maize field was reared in plastic containers with aerated lids and was provided with maize leaves as food replacing daily. Parasitized larvae were excluded from the study and healthy ones were kept in a rearing room in natural environmental condition until pupation. Pupae were sorted out into male and female based on the distance between their genitalia and anal slots and kept in the same rearing room as the larvae. Pupae was monitored daily until moths emerged. After the emergence of moths, male–female pairs were confined to oviposition chamber in the same rearing room. Few plastic bottles (22 cm in height

and 10 cm in diameter) were cut open at the top and spare maize plants uprooted from the ecological plots were kept with the whorl intact in an upright position inside the bottle. Water was added up to level three-quarters of the height of the stones to provide humidity and to keep the plant parts fresh (Plessis *et al.*, 2020). The rearing plastic containers were covered with muslin clothes to prevent the moths from escaping whose lower surfaced were used as oviposition site by the female adults. Cotton swab on a petri plate was wetted with 10% honey solution as adult feed. When the adults started a new life cycle, the investigation on biological parameters was started.

3.8.2.4. Observations recorded:

Daily temperature and relative humidity of the rearing room was recorded during the insect life cycle using a digital thermometer cum hygrometer.

a. Larval observations:

- Larval duration: It was recorded from the hatching of eggs till pupation.
- Larval weight: Larval weight was measured starting from 2nd instar up to 6th instar.
- Larval morphology: Width of head capsules of instars was recorded under a stereo-microscope (10x resolution).

b. Pupal observations:

- Pupal duration: It was recorded from the starting of pupation till adult emergence.
- Pupal weight: It was recorded few days after pupation.

c. Adult longevity: Male and female adult longevity was recorded.

3.8.2.5. Statistical analysis:

Mean values of the readings were directly compared with the results of other researchers' work.

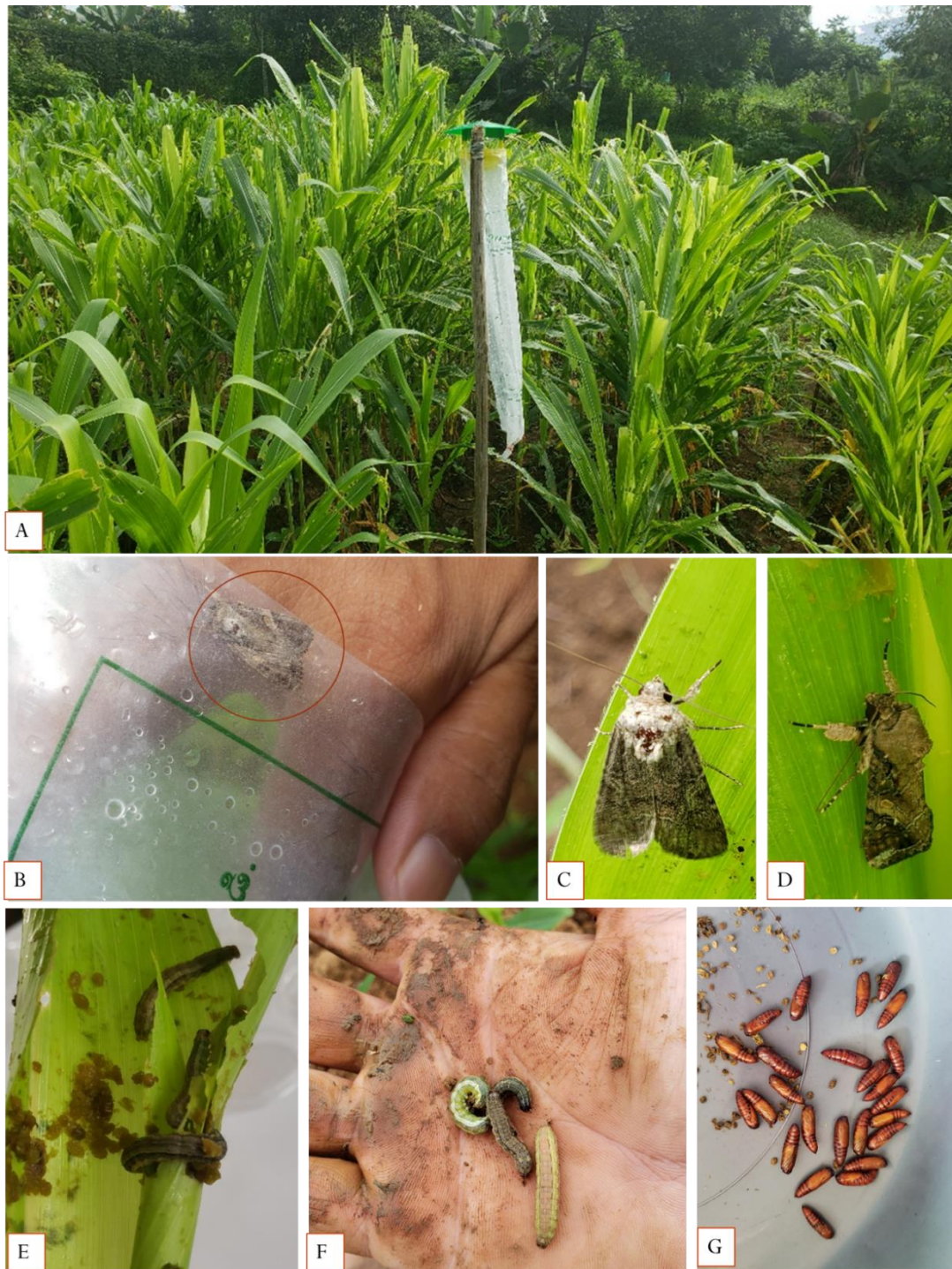


Plate 2. A. Pheromone trap installation B. adult caught, C. female moth D. male moth E. larval infestation F. larval instars and G. pupal stage

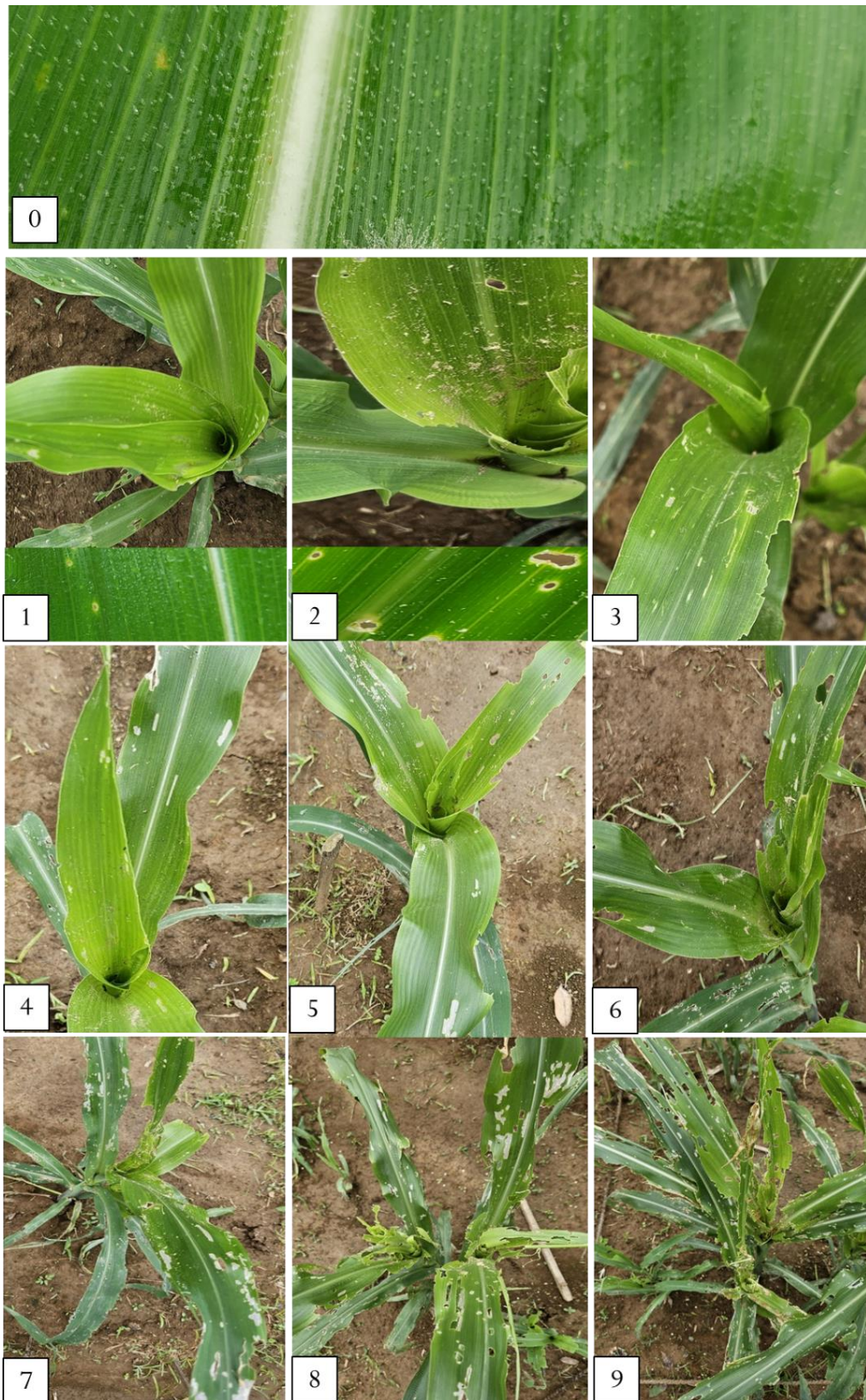


Plate 3. Leaf damage visual scoring in 0-9 scale in the field



Plate 4. A. Larval rearing B. Pupal maintenance

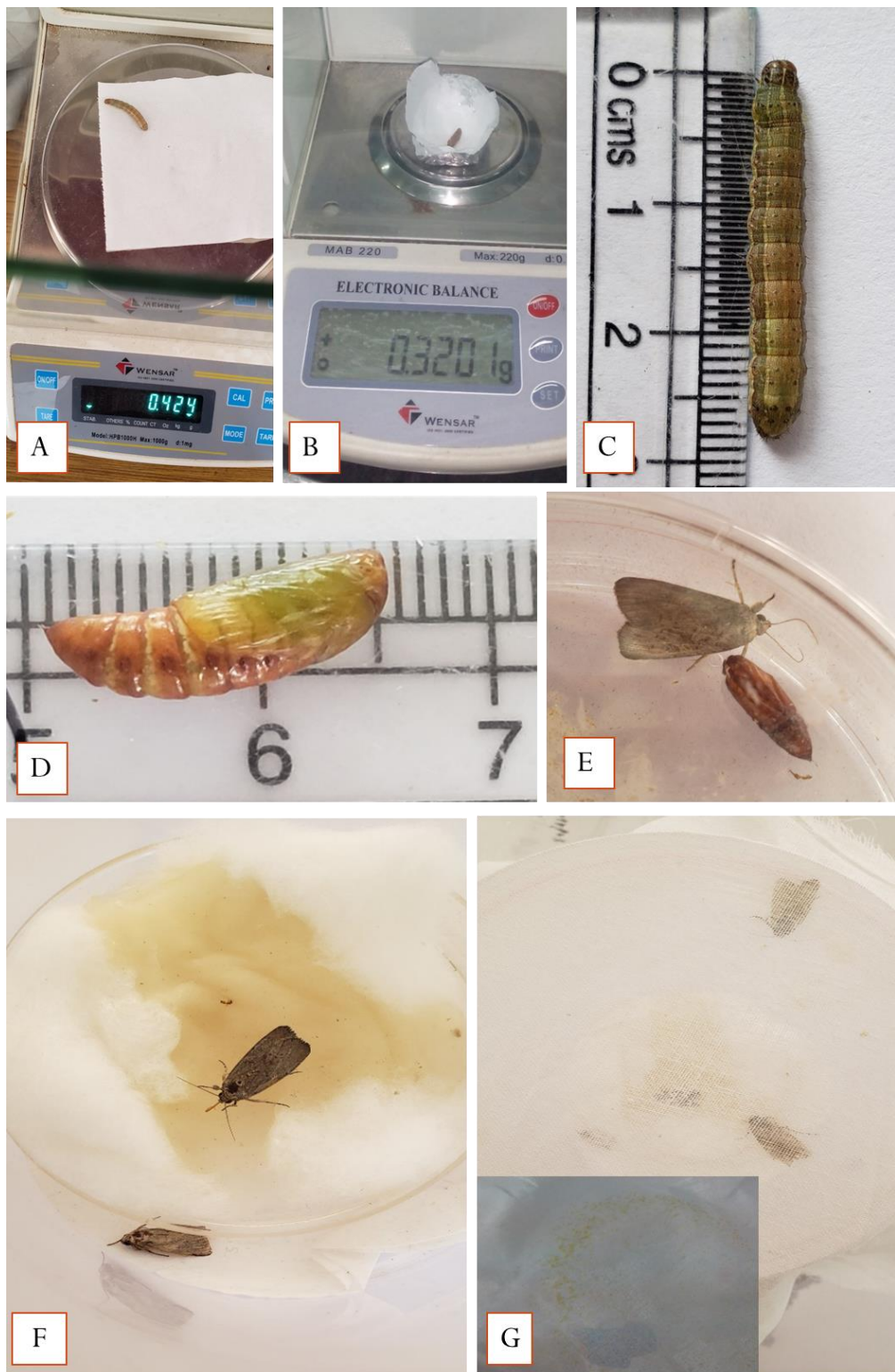


Plate 5. Measurement of **A.** larval weight, **B.** pupal weight, **C.** larval weight and **D.** pupal length, **E.** adult emergence, **F.** adults feeding on 10% honey solution **G.** eggs laid on the under surface of the muslin cloth covering the rearing jar

3.8.3. Objective 3

3.8.3.1. Name of the experiment: To study the combine effect of some insecticides on fall armyworm, *Spodoptera frugiperda* (J.E. Smith).

3.8.3.2. Location: The experiment was conducted at Entomological experimental farm at SAS, NU, Medziphema campus.

3.8.3.3. Methodology:

Four insecticides, including two entomopathogenic fungi (EPF), were employed as individual treatments at their recommended doses: Emamectin benzoate 5% SG, Chlorantraniliprole 18.5% SC, *Beauveria bassiana* and *Metarhizium anisopliae*. In order to maintain the recommended doses of chemical insecticides at half and the fungal formulation unchanged, they were combined to create five additional treatments for the experiment. The treatments employed in the investigation are detailed in Table 2d.

3.8.3.4. Laboratory bioassays

To test the effectiveness of the treatments, a leaf-dip bioassay method was conducted one time using fresh, uniform sized maize leaf. Leaves were immersed in aqueous insecticide solutions (treatments) for 10 seconds while agitating gently in distilled water for the control. Fourth instar larvae were placed in small petri plates and treated leaves were fed. The data was taken from four replications for each treatment. Mortality percentages was calculated after 24, 48, 72 and 96 hr post treatment and then percentages of mortality were corrected according to Abbott's formula (Abbott, 1925).

3.8.3.5. Field studies

First spray was initiated on 24th SMW when sufficient infestation is noticed followed by second spraying on 15th day after the first spray. During spraying, insecticides were directed specifically at the whorl region using a knapsack sprayer.

Table 2d. Insecticides and insecticide combinations used as treatments

Treatment No.	Treatments	Doses/ litre water
T ₁	<i>Beauveria bassiana</i>	10 ml*
T ₂	<i>Metarhizium anisopliae</i>	1 ml*
T ₃	Emamectin benzoate 5% SG	1 g*
T ₄	Chlorantraniliprole 18.5% SC	0.4 ml*
T ₅	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	10 ml* + 1 ml
T ₆	<i>Beauveria bassiana</i> + Emamectin benzoate 5% SG	10 ml* + 0.5 g
T ₇	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	1 ml* + 0.5 g
T ₈	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	10 ml* + 0.2 ml
T ₉	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	1 ml* + 0.2 ml
T ₁₀	Control	---

*RC= Recommended dose of the company's insecticide product

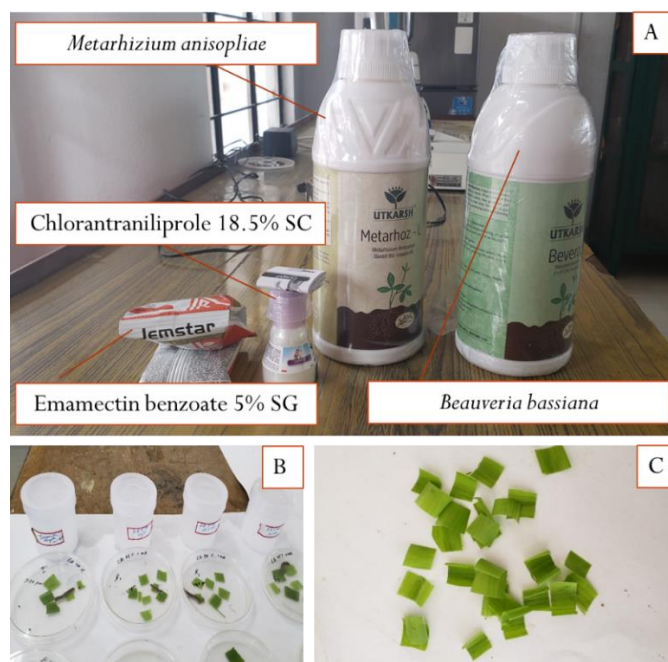


Plate 6. A. Composition of the treatments, B. Treatment preparation for bioassay and C. 1cm² size leaf cuts

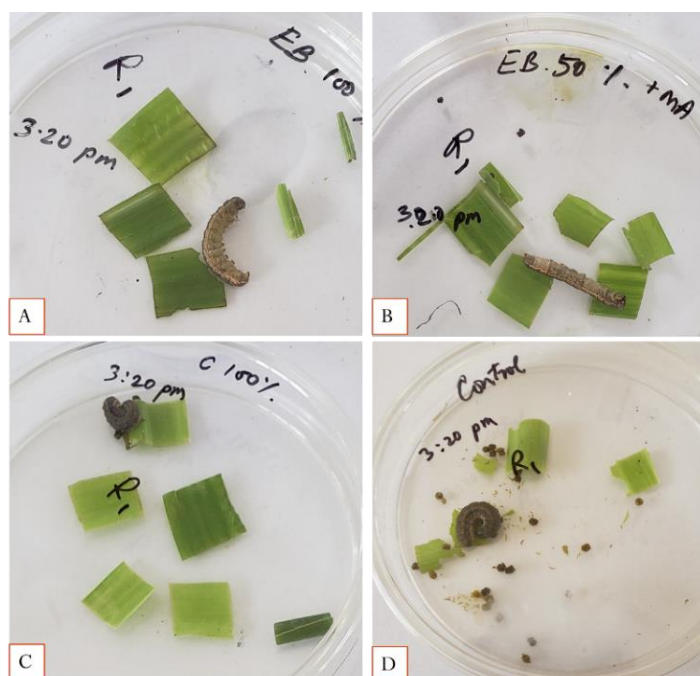


Plate 7. Larval mortality shown after 96 hrs post treatment by A. Emamectin benzoate 5% SG B. *Metarhizium anisopliae* + Emamectin benzoate 5% SG C. Chlorantraniliprole 18.5% SC and D. Control



Plate 8. A. Lab bioassay and B. field application

The larval counts and per cent leaf damage were estimated. Observations were recorded before imposing the treatments (pre-treatment counts) and post treatment observations at 7, 10 and 14 days after each application.

The extent of leaf damage (per cent leaf damage) caused by larvae of fall armyworm was estimated through visual scoring in 0-9 scale as described by Davis & Williams (1992) (Table 1).

The per cent reduction in pest population was calculated by a modification of Abbott's formula (Henderson & Tilton, 1955).

$$\% \text{ mortality} = 100 \left[1 - \frac{T_a \times C_b}{T_b \times C_a} \right]$$

Where, T_a = Post-treatment insect count

T_b = Pre-treatment insect count

C_b = Untreated insect count before treatment

C_a = Untreated insect count after treatment

3.8.3.6. Statistical analysis

The data on larval population was subjected to square root transformation and data on per cent leaf damage were subjected to arcsine transformation. Later, transformed values were analysed using ANOVA.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The findings of the present investigation on the “Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland” carried out during the kharif season, 2022 to 2023 are presented in this chapter. The weekly observations on larval population, per cent leaf infestation and adult counts were with weather parameters; maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity and rainfall were statistically analyzed, and the mean values were tabulated. The data recorded are presented in tables and illustrated as graphs.

4.1. To study the population dynamics of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) and its correlation with the weather parameter in maize.

The observation on the incidence of *Spodoptera frugiperda* as per cent leaf damage, number of larvae infested and adult occurrence on the maize variety BIO-9637 Maharaja are presented in Table 3, 4 and 5. The correlation coefficient (r) on the incidence of *S. frugiperda* in relation to these parameters with that of the abiotic factors was worked out by a simple correlation study and is presented in Table 6.

4.1.1. Incidence of fall armyworm as per cent leaf damage

The incidence of FAW as leaf damage started from 14-20 days after sowing (22nd SMW) on 24th standard meteorological week (SMW) in both the first and second years where 5.32% and 5.78% leaf damaged were recorded respectively (Table 3, Fig.2). The highest percentage of leaf damage per plant (83.86%) was seen in the 28th SMW of the first year (2022), during which the maximum and minimum temperatures were 34.13 °C and 24.49 °C, respectively, the maximum and minimum relative humidity levels were 90.00% and 68.86 %, and the rainfall was 22.90 mm. In the second year (2023), the highest percentage of leaf damage per plant (80.25%) was observed during the 27th SMW, with maximum and minimum temperatures of 33.01 °C and 25.13 °C, relative humidity levels of 91.71 % and 73.00%, and rainfall of 4.40 mm. Table 3 shows that the maximum number of per cent leaf damage attained peak

Table 3. Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022 and 2023

2022							2023							Pooled
SWM	Temperature		Relative humidity		Weekly Rainfall	% leaf damage	SWM	Temperature		Relative humidity		Weekly Rainfall	% leaf damage	
	Max.	Min.	Max.	Min.				Max.	Min.	Max.	Min.			
24	30.30	23.27	94.71	73.57	46.70	5.32	24	30.16	23.57	93.14	79.57	107.20	5.78	5.55
25	31.19	23.41	95.43	74.57	34.80	25.22	25	30.19	23.64	91.71	77.00	63.20	25.22	25.22
26	33.26	24.89	93.29	67.57	9.90	77.32	26	34.13	25.11	91.43	75.43	25.00	64.40	70.79
27	34.23	24.70	90.71	65.71	77.10	70.25	27	34.01	24.94	89.71	64.57	59.60	80.25	75.24
28	34.13	24.49	90.00	68.86	22.90	83.86	28	33.01	25.13	91.71	73.00	4.40	78.52	80.86
29	33.89	24.46	91.71	75.00	135.30	60.91	29	33.37	25.07	93.57	72.14	41.50	74.63	67.60
30	31.79	23.17	96.00	69.71	135.30	69.09	30	34.03	25.04	93.14	69.71	123.60	67.03	68.06
31	33.64	23.86	93.43	67.57	48.80	60.33	31	34.21	25.09	92.14	74.43	112.30	52.48	56.41
32	33.27	23.89	96.00	71.43	114.70	32.00	32	32.31	25.11	91.14	75.57	73.20	39.77	35.92
<i>SEm</i> ±						0.43	<i>SEm</i> ±						1.02	0.55
<i>CD</i> (<i>p</i> =0.05)						1.29	<i>CD</i> (<i>p</i> =0.05)						3.07	1.60

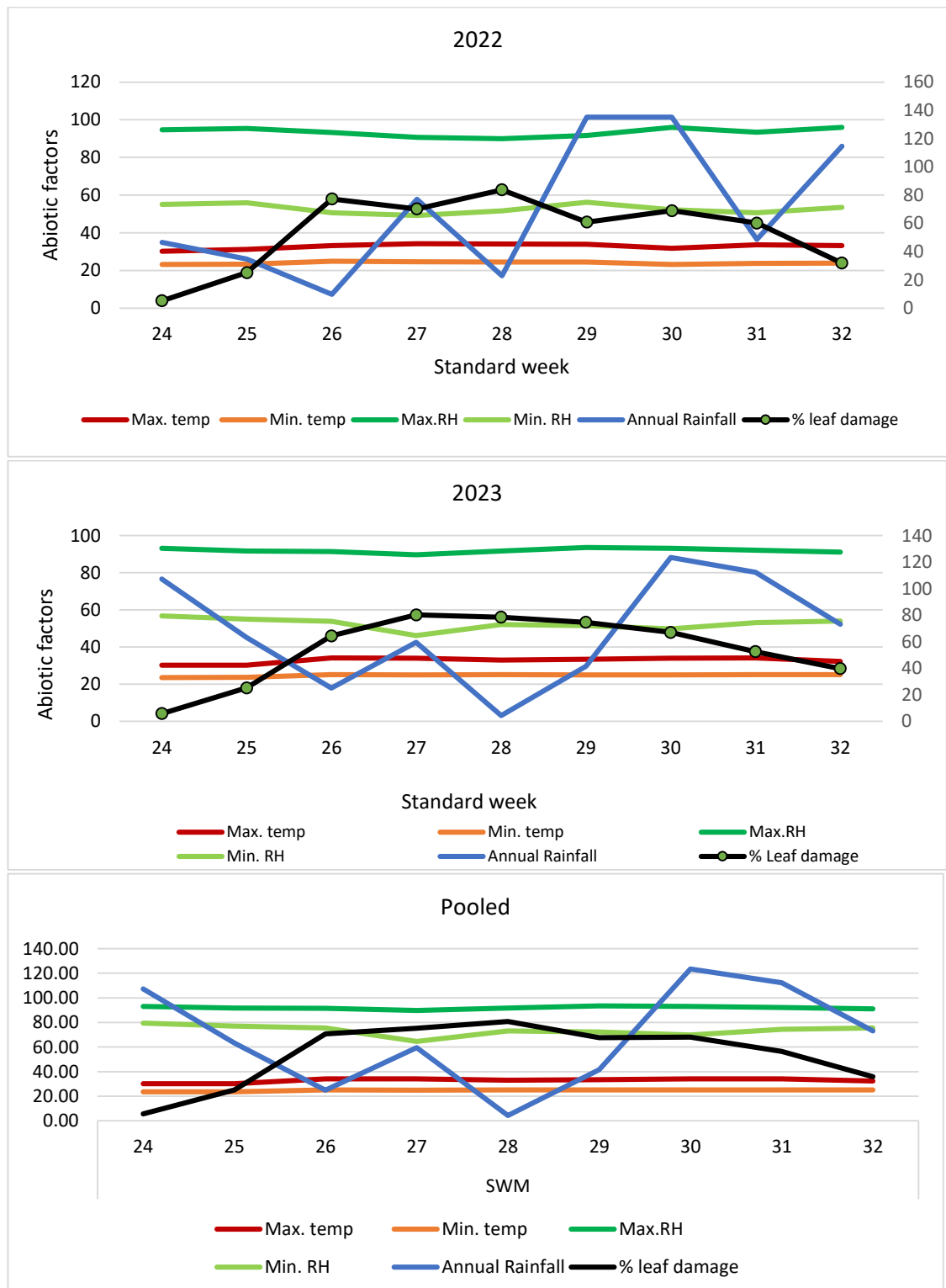


Fig. 2 Graphical representation on incidence of FAW as per cent leaf damage in 2022 and 2023

at 40-45 days after sowing in both first and second year. The current findings align with those of Vijayaakshaya *et al.* (2020) and Reddy *et al.* (2020), who indicated that the incidence of *S. frugiperda* peaked during the second half of July (30-45 days post-sowing). Furthermore, the findings are corroborated by Ratnam *et al.* (2023), who indicated that the maximum percentage of infestation reached 85.48% in mid-July i.e., 28th SMW.

The leaf damaged percentage were seen decreasing gradually as the plants got older till 32nd SMW in both first (32.00%) and second year (39.77%) when the maximum and minimum temperature (°C), maximum and minimum relative humidity (%) and rainfall (mm) were 33.27 °C, 23.89 °C, 96.00%, 71.43% and 114.70 mm in the first season (2022) and, 32.31 °C, 25.11 °C, 91.14%, 75.57% and 73.20 mm in the second season (2023), respectively.

The correlation coefficient (r) of FAW with that of the abiotic factors (Table 6) showed that, in the first year (2022), per cent leaf damage had positive significant correlation with maximum (r=0.759*) and minimum temperature (r=0.664*). However maximum relative humidity (r= -0.620), minimum relative humidity (r=-0.671*) and rainfall (r=-0.022) showed negative non-significant correlation. Similarly, it was observed in the second year (2023) that per cent leaf damage had positive significant correlation with maximum (r=0.850*) and minimum temperature (r=0.832*). Maximum relative humidity (r=-0.243) and rainfall (r=-0.467) showed negative non-significant correlation, while it was negatively significant with minimum relative humidity (r=-0.802*).

4.1.2. Incidence of fall armyworm as number of larvae

It is evident from the Table 4 and Figure 3 that the incidence of FAW as larvae was observed from 24th standard week and continued till 32nd standard week during both the first and second year. The number of larvae infesting per 10 plants on 24th standard week was recorded as 1.22 in the first year (2022) and 1.32 in the second year (2023). It gradually increased in the subsequent weeks and highest larval count per plant was recorded on 28th standard week (25.72) during first year when the maximum and minimum temperature (°C), maximum, minimum relative humidity (%) and

rainfall (mm) were 34.13 °C, 24.89 °C, 90.00%, 68.86% and 22.90 mm, respectively. Whereas it was found highest on 27th standard week (22.75) during the second year when the maximum and minimum temperature (°C), maximum, minimum relative humidity (%) and rainfall (mm) were 34.01 °C, 24.94 °C, 89.71%, 64.57 % and 59.60 mm, respectively. This is similar with the findings of Reddy *et al.* (2020) who reported that, in early sowing (June 15th), *S. frugiperda* incidence started at 27th standard week and continued till the 35th standard week with peak incidence between 27th to 28th standard week (0.54 larvae/plant).

The correlation coefficient (r) of FAW incidence as number of larvae infested per plant with that of the abiotic factors (Table 6) showed that in the first year (2022), number of larvae per plant had positive significant correlation with maximum (r=0.751*). Minimum temperature showed positive non-significant correlation (r=0.590). However maximum relative humidity (r=-0.743) had negative significant correlation with larval number while minimum relative humidity (r=-0.519) and rainfall (r=-0.011) showed negative non-significant correlation. Our findings are in line with that of the Kumar *et al.* (2020) who observed a significant positive correlation between the occurrence of *S. frugiperda*, specifically in terms of larval population, and maximum temperatures (r=0.7205). They also observed significant negative correlations with relative humidity (r=-0.6739) and rainfall (r=-0.8293) in Perambalur district of Tamil Nadu. The findings of Paul and Deole (2020) further corroborated this, revealing a significant positive connection (0.586) between *S. frugiperda* and maximum temperature and Silva *et al.* (2016) who indicated that the development rate of fall armyworm is heavily influenced by temperature, with faster rates observed at higher temperatures. Furthermore, Anandhi *et al.* (2020) indicated that the larval population of the fall armyworm exhibited a significant positive correlation with maximum temperature, while the correlation with the number of rainy days was predominantly negative and significant, implying that an increase in rainy days correlates with a decrease in insect pests. However, our findings are in contradictory to that of Reddy *et al.* (2020) who reported the onset and peak larval population during monsoon (August–September) on maize at Sabour, Bihar.

Table 4. Incidence of fall armyworm as number of larvae in relation to abiotic factors during kharif season, 2022 and 2023

2022							2023							Pooled
SWM	Temperature		Relative humidity		Weekly Rainfall	No. of larvae/10 plants	SWM	Temperature		Relative humidity		Weekly Rainfall	No. of larvae/10 plants	
	Max.	Min.	Max.	Min.				Max.	Min.	Max.	Min.			
24	30.30	23.27	94.71	73.57	46.70	1.22	24	30.16	23.57	93.14	79.57	107.20	1.32	1.46
25	31.19	23.41	95.43	74.57	34.80	6.40	25	30.19	23.64	91.71	77.00	63.20	6.40	6.40
26	33.26	24.89	93.29	67.57	9.90	14.65	26	34.13	25.11	91.43	75.43	25.00	14.46	14.52
27	34.23	24.70	90.71	65.71	77.10	16.99	27	34.01	24.94	89.71	64.57	59.60	22.75	19.51
28	34.13	24.49	90.00	68.86	22.90	25.72	28	33.01	25.13	91.71	73.00	4.40	17.91	21.81
29	33.89	24.46	91.71	75.00	135.30	17.30	29	33.37	25.07	93.57	72.14	41.50	17.63	17.61
30	31.79	23.17	96.00	69.71	135.30	16.20	30	34.03	25.04	93.14	69.71	123.60	14.75	15.31
31	33.64	23.86	93.43	67.57	48.80	15.27	31	34.21	25.09	92.14	74.43	112.30	12.07	13.67
32	33.27	23.89	96.00	71.43	114.70	6.00	32	32.31	25.11	91.14	75.57	73.20	9.94	8.14
<i>SEm</i> ±						0.19	<i>SEm</i> ±						0.20	0.14
<i>CD (p=0.05)</i>						0.57	<i>CD (p=0.05)</i>						0.59	0.39

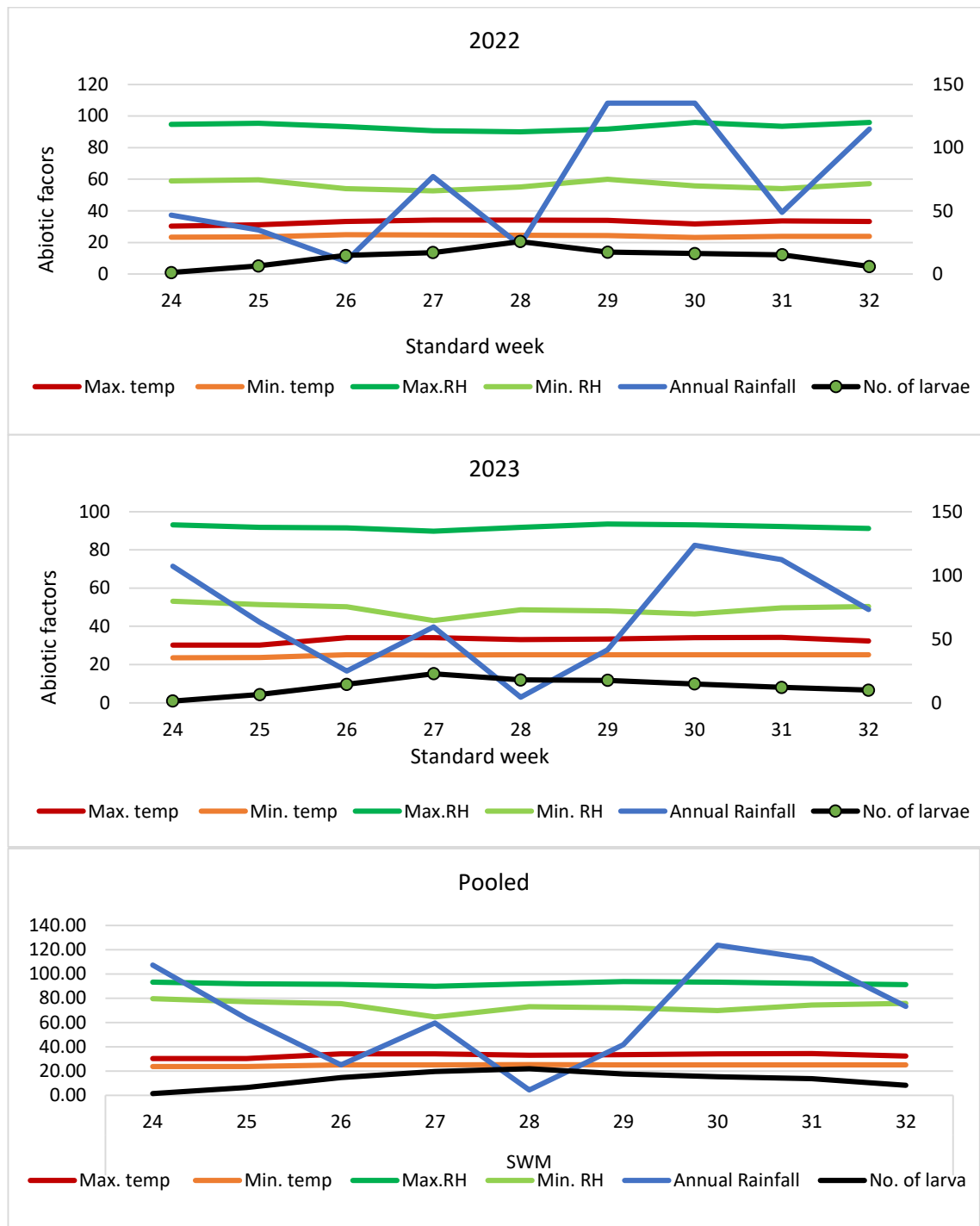


Fig. 3 Graphical representation on incidence of FAW as number of larvae per 10 plants in 2022 and 2023

4.1.3. Incidence of fall armyworm as number of adults

It is evident from the Table 4 and Figure 3 that the incidence of FAW in the whole plot as adults was less than expectation. During the first year (2022), the number of adults recorded from the single pheromone trap installed was 1.00 on 24th, 1.00 25th, 0.00 on 26th, 0.00 on 27th, 1.00 on 28th, 0.00 on 29th, 1.00 on 30th, 0.00 on 31st and 0.00 on 32nd SMW. Similarly, low number of adult count was observed as the number of adults caught was 1.00 on 24th, 0.00 25th, 1.00 on 26th, 1.00 on 27th, 0.00 on 28th, 1.00 on 29th, 0.00 on 30th, 0.00 on 31st and 1.00 on 32nd standard week in the second year (2023). The mean numbers of adult in first year and second year were 0.44 ± 0.53 and 0.56 ± 0.53 respectively. These data on adult count caught using pheromone trap placed at height of 1.5 m from the ground is against the findings of Nwanze *et al.* (2021) where he observed the daily mean numbers of adult for 35 days as 1.00 ± 0.48 in OBA Super 98, 0.20 ± 0.27 in White Maize and 1.00 ± 0.43 in Yellow Maize varieties. This contradiction might be due to known migratory behavior of the adult population to neighboring area after laying eggs which in turn hatched and caused plant damage. Sharath *et al.* (2022) also reported the highest trap catches during the July third week (29th standard week) as 16.32 moths/trap/week and the lowest number of moths during third week of September (37th standard week) as 0.18 moths/trap/week where each trap was installed at a distance of 30 m apart. Our findings though are in line with that of the observations by Ambia (2025) where it was reported that there is no point of intersection between moth catches and FAW infestation levels per trap density indicating that the two parameters do not have an inverse relationship in the experiment.

The correlation coefficient (r) of FAW adult incidence with that of the abiotic factors (Table 6) showed that in the first year (2022), maximum ($r = -0.674^*$) and minimum ($r = -0.632^*$) temperature had significant negative correlation with adult population of *S. frugiperda*. However, maximum ($r = 0.235$) and minimum relative humidity ($r = 0.348$) showed positive non-significant correlation while rainfall ($r = -0.188$) showed negative non-significant correlation.

Table 5. Incidence of fall armyworm as number of adults using one pheromone trap during kharif season, 2022 and 2023

2022							2023						
SWM	Temperature		Relative humidity		Weekly Rainfall	No. of adults	SWM	Temperature		Relative humidity		Weekly Rainfall	No. of adults
	Max.	Min.	Max.	Min.				Max.	Min.	Max.	Min.		
24	30.30	23.27	94.71	73.57	46.70	1.00	24	30.16	23.57	93.14	79.57	107.20	1.00
25	31.19	23.41	95.43	74.57	34.80	1.00	25	30.19	23.64	91.71	77.00	63.20	0.00
26	33.26	24.89	93.29	67.57	9.90	0.00	26	34.13	25.11	91.43	75.43	25.00	1.00
27	34.23	24.70	90.71	65.71	77.10	0.00	27	34.01	24.94	89.71	64.57	59.60	1.00
28	34.13	24.49	90.00	68.86	22.90	1.00	28	33.01	25.13	91.71	73.00	4.40	0.00
29	33.89	24.46	91.71	75.00	135.30	0.00	29	33.37	25.07	93.57	72.14	41.50	1.00
30	31.79	23.17	96.00	69.71	135.30	1.00	30	34.03	25.04	93.14	69.71	123.60	0.00
31	33.64	23.86	93.43	67.57	48.80	0.00	31	34.21	25.09	92.14	74.43	112.30	0.00
32	33.27	23.89	96.00	71.43	114.70	0.00	32	32.31	25.11	91.14	75.57	73.20	1.00
<i>Mean ± SD</i>						0.44 ± 0.53	<i>Mean ± SD</i>						0.56 ± 0.53

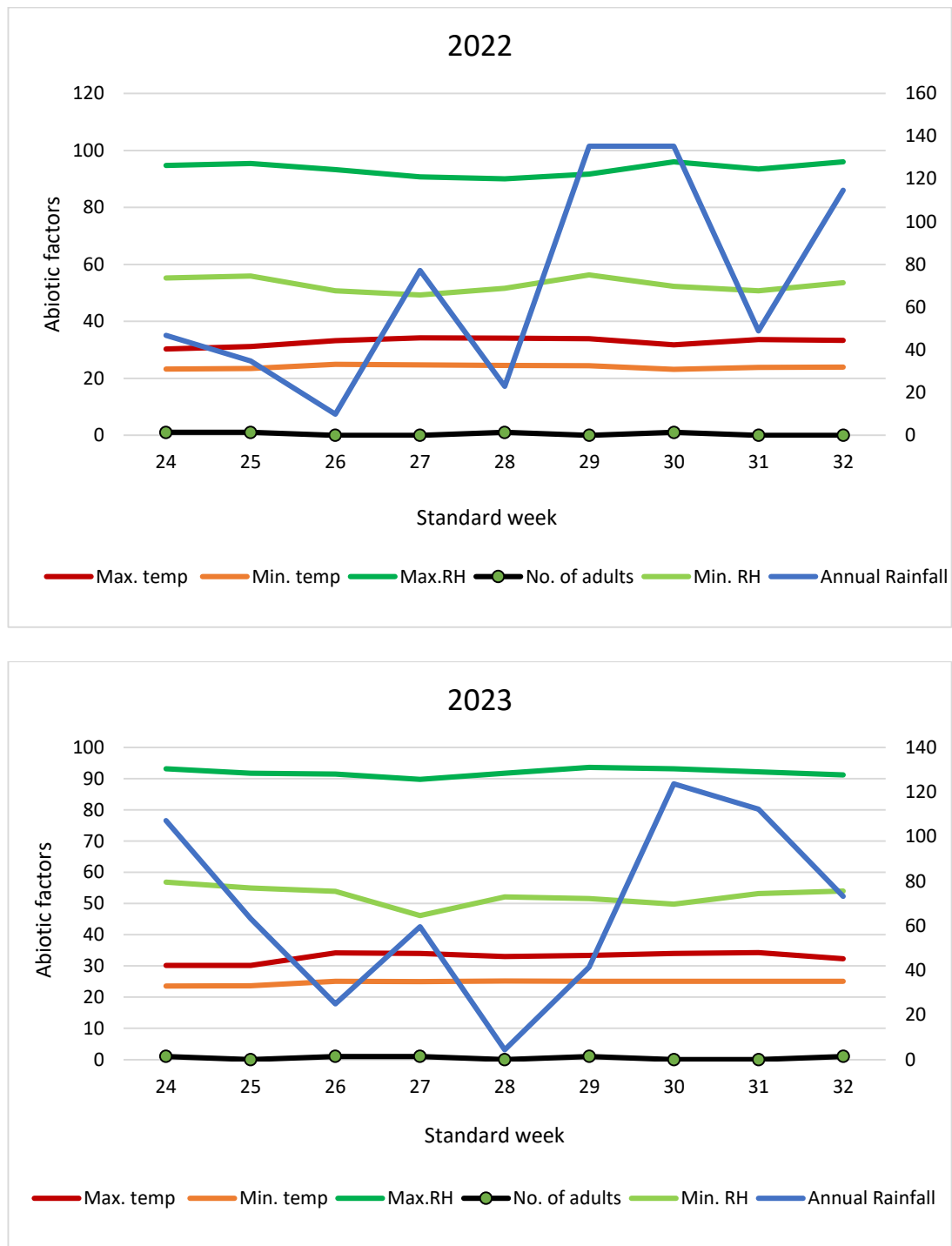


Fig. 4 Graphical representation on incidence of FAW as adult counts in 2022 and 2023

Table 6. Correlation coefficient (r) of FAW to weather parameters during kharif season, 2022 and 2023

Weathers parameters	2022			2023		
	% leaf damage	No. of larvae/ 10 plants	No. of adults	% leaf damage	No. of larvae/ 10 plants	No. of adults
Maximum Temperature (°C)	0.759*	0.751*	-0.674*	0.850*	0.805*	-0.021
Minimum Temperature (°C)	0.664*	0.590	-0.632*	0.832*	0.771*	0.031
Maximum RH (%)	-0.620	-0.743	0.235	-0.243	-0.389	-0.166
Minimum RH (%)	-0.671*	-0.519	0.348	-0.802*	-0.882*	-0.009
Rainfall (mm)	-0.022	-0.011	-0.188	-0.467	-0.457	-0.188

**Significant at 5% level*

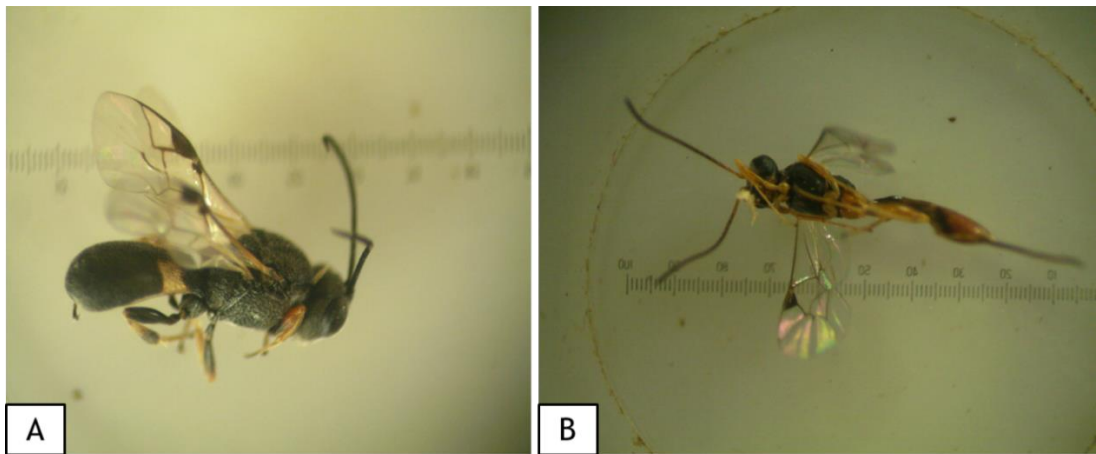


Plate 9. A. *Chelonus formosanus* (Braconidae) B. Unidentified parasitoid (Ichneumonidae)

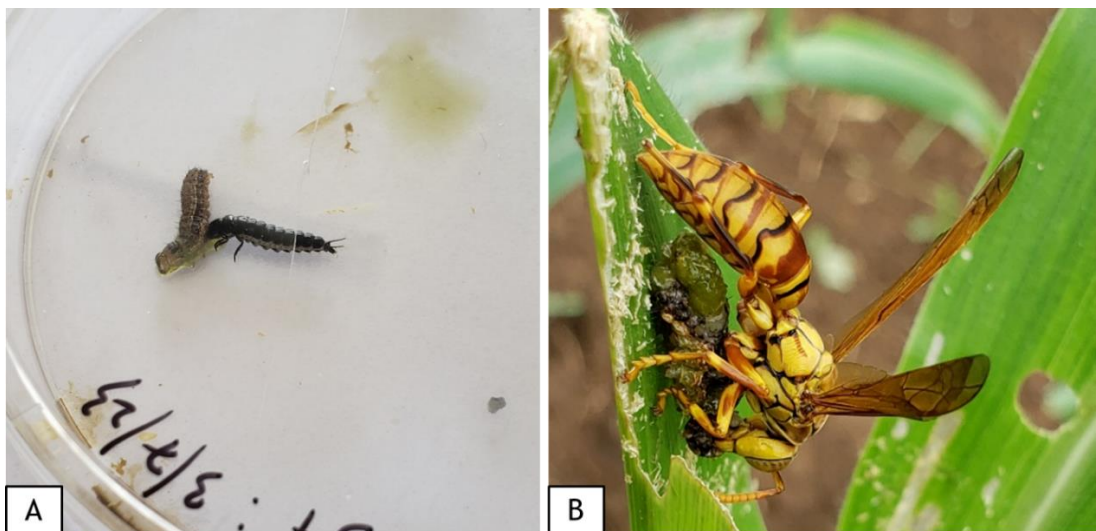


Plate 10. A. Predatory larva of a Carabid beetle B. Yellow oriental paper wasp (*Polistes* sp.)

4.1.4. Natural enemies of *Spodoptera frugiperda*

Plates 9 and 10 depict the most notable natural enemies of *Spodoptera frugiperda* that were found to be feeding on the larvae of this invasive pest in the region. The parasitoids observed were *Chelonus formosanus* (Sonan), an egg-larval parasitoid from the Braconidae family, and another unnamed Ichneumonoid. They deposited eggs inside host eggs and their larvae grew inside FAW larvae, killing the pest in the process. In addition, a predatory larva of a Carabid beetle and a hymenopteran adult wasp, Yellow oriental paper wasp (*Polistes sp.*), were seen to be actively feeding on the pest's larvae, operating as a natural control mechanism.

4.2. To study the biology of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) using natural diet in Nagaland weather condition

The observations on the biology of FAW were studied in terms of duration, length and weight of different life stages after the insect was fed with young maize leaves reared for two generations from the egg to the adult stage. Each adult male and female pair was nurtured in plastic jars and covered with muslin cloth. The observations are presented in Tables 7a, 7b, 7c and 8 represented by the mean values of 2 generations during months of June-July each year.

4.2.1. Egg stage

The female deposited egg masses in a single layer or in two stacked layers on the underside of the muslin cloth covering the rearing jar. The eggs were dome-shaped and adorned with greyish-white body scales of females. During oviposition, the eggs appeared creamy or pale yellow (Plate 11); nevertheless, they transformed from brown to black in the days leading up to hatching. The incubation period of the eggs under laboratory conditions ranged between 1-3 days with an average of 1.89 ± 0.14 days in the first year and 1.93 ± 0.15 days in the second year (Table 7a). The mean duration of egg stage during these two years was 1.91 ± 0.14 days (Table 8). The present findings are in line with the earlier research work of Dubale *et al.* (2022) who observed “the incubation period of 2-4 days”. Incubation period of 2-3 days on maize was reported by Vishwakarma *et al.* (2020) and Dileep and Murali (2022) which corroborate the present findings. Our findings are in contrast to Sparks (1979), who indicated that

hatching often occurs after 3-5 days. The discrepancies might be from variations in temperature that can influence oviposition.

4.2.2. Larval stage

The larval stage of FAW consists of six instar phases. The immature larvae had a greenish hue with a black cephalic region, while the mature larvae displayed a brownish coloration characterized by a distinctive inverted 'Y' shape on the head capsule and four dark spots arranged in a square on the penultimate segment (Plate 12). The total larval duration varied from 17-18 days (Table 7a) with a mean duration of 17.42 ± 0.32 days (Table 8).

The result showed similarity with the previous findings of Dubale *et al.* (2022) who observed the total larval period ranged from 14-18 days with mean of 16.07 days. Similar finding was reported by Sharma *et al.* (2022) who reported that the total larval period was 16.31 days. Our finding contradicts with that of Hong *et al.* (2022) who reported that the larval duration of *S. frugiperda* ranged between 10.83 and 11.28 days and also differ from that of Silva *et al.* (2017) who studied FAW reared on maize and oat, and Plessis *et al.* (2020), who studied this insect reared on sweet maize stems and leaves. The variability in larval development may result from inappropriate host plants and their biological adaptability across diverse geographic regions, leading to prolonged development periods.

The width of head capsule of each instar was 0.345 ± 0.011 , 0.471 ± 0.012 , 0.780 ± 0.009 , 1.501 ± 0.104 , 2.157 ± 0.058 and 2.700 ± 0.096 mm respectively (Table 8). Montezano *et al.* (2019) suggested width of head capsule of FAW varies according to the instars and our finding also suggested same results saying head capsules are smaller in early instars which is increased with the increasing instars. The results for average cephalic capsule width in this study are similar to those observed by Bailey and Chada (1968) for *S. frugiperda*, fed with sorghum grain, in five instars: 0.27, 0.45, 0.85, 1.44, and 2.15, respectively. These results are also similar to those found by Machado *et al.* (1985) working with *S. frugiperda* fed with kale. The authors recorded average values for the first, second, third, fourth, fifth, and sixth instars as 0.28, 0.47, 0.80, 1.29, 1.91,

Table 7a. Duration of different life stages of *Spodoptera frugiperda* (J. E. Smith) on maize during 2022 and 2023

Sl. No.	Parameters	2022			2023			Pooled		
		Mean (days)	± SEM	Range (days)	Mean (days)	± SEM	Range (days)	Mean (days)	± SEM	Range (days)
1	Incubation period	1.89	± 0.14	1 to 3	1.93	± 0.14	1 to 3	1.91	± 0.14	1 to 3
2	Larval period	17.42	± 0.32	17 to 18	17.49	± 0.33	17 to 18	17.46	± 0.33	17 to 18
	1 st instar	2.75	± 0.15	2 to 3	2.80	± 0.15	2 to 3	2.78	± 0.15	2 to 3
	2 nd instar	2.70	± 0.10	2 to 3	2.75	± 0.09	1 to 3	2.73	± 0.10	2 to 3
	3 rd instar	2.62	± 0.13	2 to 3	2.65	± 0.13	2 to 3	2.64	± 0.13	2 to 3
	4 th instar	2.31	± 0.17	2 to 3	2.33	± 0.18	2 to 3	2.32	± 0.18	2 to 3
	5 th instar	2.90	± 0.08	2 to 3	2.93	± 0.09	2 to 3	2.92	± 0.09	2 to 3
	6 th instar	4.20	± 0.23	3 to 5	4.13	± 0.24	3 to 5	4.17	± 0.24	3 to 5
3	Pupal period	7.43	± 0.14	7 to 8	7.45	± 0.13	7 to 8	7.44	± 0.14	7 to 8
	Male pupa	7.58	± 0.14	7 to 8	7.60	± 0.15	7 to 8	7.59	± 0.15	7 to 8
	Female Pupa	7.30	± 0.25	7 to 8	7.35	± 0.26	6 to 8	7.33	± 0.26	7 to 8
4	Oviposition period	4.15	± 0.54	4 to 5	4.20	± 0.51	3 to 5	4.18	± 0.53	3 to 5
5	Male adult longevity	8.85	± 0.64	8 to 10	8.90	± 0.62	8 to 9	8.88	± 0.63	8 to 9
6	Female adult longevity	9.15	± 0.82	8 to 10	9.20	± 0.83	8 to 10	9.18	± 0.83	8 to 10
7	Total male life cycle	35.29	± 0.90	34 to 37	35.38	± 0.91	34 to 36	35.34	± 0.91	34 to 36
8	Total female life cycle	36.30	± 1.22	36 to 38	36.68	± 1.14	35 to 37	36.49	± 1.18	35 to 37

*SEM= Standard error of mean

Table 7b. Measurement of larval body length, head width and pupal length of *S. frugiperda* (J. E. Smith) during 2022 and 2023

Stage	Length (mm)				Pooled	Head capsule width (mm)		Pooled
	2022		2023			2022	2023	
	Mean ±SEm	Range	Mean ±SEm	Range		Mean ±SEm	Mean ±SEm	
1 st instar	1.62 (± 0.073)	1.5 - 1.7	1.63 (± 0.073)	1.6 – 1.7	1.63 (± 0.073)	0.334 (± 0.008)	0.356 (± 0.013)	0.345 (± 0.011)
2 nd instar	3.14 (± 0.144)	3.0 - 3.3	3.17 (± 0.150)	3.0 - 3.3	3.16 (± 0.147)	0.472 (± 0.012)	0.485 (± 0.012)	0.479 (± 0.012)
3 rd instar	6.48 (± 0.205)	6.3 -6.7	6.52 (± 0.215)	6.3 -6.7	6.50 (± 0.21)	0.79 (± 0.005)	0.781 (± 0.007)	0.786 (± 0.006)
4 th instar	9.43 (± 0.214)	9.2 -9.6	9.47 (± 0.215)	9.3 -9.7	9.45 (± 0.215)	1.461 (± 0.098)	1.541 (± 0.110)	1.501 (± 0.104)
5 th instar	16.10 (± 0.538)	15.6 -16.6	15.89 (± 0.512)	15.4 -16.4	16.00 (± 0.525)	2.102 (± 0.006)	2.211 (± 0.110)	2.157 (± 0.058)
6 th instar	31.25 (± 1.050)	30.2 -32.3	31.52 (± 1.061)	30.5 -32.6	31.39 (± 1.056)	2.59 (± 0.06)	2.810 (± 0.132)	2.700 (± 0.096)
Male pupa	14.803 (± 0.107)	14.70 -14.91	14.743 (± 0.191)	14.45 -14.93	14.77 (± 0.149)	---	---	---
Female Pupa	15.056 (± 0.161)	14.90 -15.22	15.0395 (± 0.161)	14.88 -15.20	15.05 (± 0.161)	---	---	---

*SEm= Standard error of mean

Table 7c. Measurement of weight of larval and pupal stages of *S. frugiperda* (J. E. Smith) during 2022 and 2023

Stage	Weight (gm)				Pooled
	2022		2023		
	Mean ± SEM	Range	Mean ± SEM	Range	
1 st instar	---	---	---	---	---
2 nd instar	0.0405 (± 0.0031)	0.0374 - 0.0436	0.0395 (±0.0035)	0.036 - 0.043	0.0400 (±0.0033)
3 rd instar	0.0452 (± 0.0012)	0.044 - 0.0464	0.0470 (±0.0012)	0.0458 - 0.0482	0.0461 (±0.0012)
4 th instar	0.0515 (± 0.0014)	0.0501 - 0.0529	0.0533 (±0.0022)	0.0511 - 0.0555	0.0524 (±0.0018)
5 th instar	0.0552 (± 0.0007)	0.0545 - 0.0559	0.0585 (±0.0026)	0.0559 -0.0611	0.0569 (±0.0017)
6 th instar	0.0581 (± 0.0014)	0.175 - 0.187	0.0606 (±0.0024)	0.0582 -0.063	0.0594 (±0.0019)
Male pupa	0.181 (± 0.006)	0.176 - 0.190	0.186 (±0.0073)	0.1787 - 0.1933	0.1835 (±0.0067)
Female Pupa	0.183 (± 0.007)	0.0374 - 0.0436	0.1945 (±0.0111)	0.1834 - 0.2056	0.1888 (±0.0091)

*SEM= Standard error of mean

Table 8. Duration and morphometric parameters in terms of length, width and weight of different life stages of *S. frugiperda* (J. E. Smith)

Stage	Duration (days)	Length (mm)	Weight (gm)	Head capsule width (mm)
	Mean ±SEm	Mean ±SEm	Mean ±SEm	Mean ±SEm
Incubation period	1.91 (± 0.14)	---	---	---
Larval period	17.46 (± 0.33)	---	---	---
1 st instar	2.78 (± 0.15)	1.63 (± 0.073)	---	0.345 (± 0.011)
2 nd instar	2.73 (± 0.10)	3.16 (± 0.147)	0.0400 (±0.0033)	0.479 (± 0.012)
3 rd instar	2.64 (± 0.13)	6.50 (± 0.21)	0.0461 (±0.0012)	0.786 (± 0.006)
4 th instar	2.32 (± 0.18)	9.45 (± 0.215)	0.0524 (±0.0018)	1.501 (± 0.104)
5 th instar	2.92 (± 0.09)	16.00 (± 0.525)	0.0569 (±0.0017)	2.157 (± 0.058)
6 th instar	4.17 (± 0.24)	31.39 (± 1.056)	0.0594 (±0.0019)	2.700 (± 0.096)
Pupal period	7.44 (± 0.14)	---	---	---
Male pupa	7.59 (± 0.15)	14.77 (± 0.149)	0.1835 (±0.0067)	---
Female Pupa	7.33 (± 0.26)	15.05 (± 0.161)	0.1888 (±0.0091)	---
Oviposition period	4.18 (± 0.53)	---	---	---
Male adult longevity	8.88 (± 0.63)	---	---	---
Female adult longevity	9.18 (± 0.83)	---	---	---
Total male life cycle	35.34 (± 0.91)	---	---	---
Total female life cycle	36.49 (± 1.18)	---	---	---

*SEm= Standard error of mean

and 2.82 mm, respectively. However, Rezende *et al.* (1994) recorded values similar to those of this study for *S. frugiperda* fed on corn leaves, but only for the first and second instars; for the others, the average values were lesser. This could be due to the different feeding intensity of the larvae in their experiment.

4.2.2.1. First instar

Table 7a shows that the duration of first instar larvae varied from 2 to 3 days, with a mean of 2.75 ± 0.15 days and 2.80 ± 0.15 days in 2022 and 2023 respectively. The initial instar larvae were minuscule and entirely consumed the eggshells from which they emerged. The larvae have a somewhat extensive, flattened, round black cephalic region and a pallid torso adorned with tiny hairs. They were observed consuming young, tender leaves and shoots, exhibiting no harmful behavior towards one another, since there were no indications of cannibalism. The mean duration of neonate larvae in the pooled data (Table 8) for two 2022 and 2023 was 2.77 ± 0.15 days. Sharanabassapa *et al.* (2018) and Reddy *et al.* (2020) reported the average first instar larval duration of *S. frugiperda* was 2.6 ± 0.49 and 2.6 ± 0.51 days, respectively which support the present findings.

The mean length (Table 8) of the first instar larvae was 1.63 ± 0.073 mm which ranged (Table 7b) from 1.5-1.7 mm. Similarly, Reddy *et al.* (2021) observed the average length of 1.42 ± 0.28 . However, Marri *et al.* (2023) reported the average length of first instar larvae as 4.63 mm which contradicts the present findings. The difference may be due to variation in climatic conditions of two different locations.

4.2.2.2. Second instar

The second instar larvae had an amber coloration, distinguished by a pale white to yellowish body with a brown tinge on the dorsal surface. At this juncture, subtle white dorsal and sub dorsal lines began to develop on the body. The larvae were observed vying for food, although cannibalism among them was lacking. The duration of second instar larvae varied (Table 7a) from 2-3 days, with a mean of 2.70 ± 0.10 days in the 2022 and 2.75 ± 0.09 days in the second year which ranged from 1-3 days (Table 7a). The mean duration from the pooled data (Table 8) for two seasons was 2.73 ± 0.09



Plate 11. *Spodoptera frugiperda* eggs on the muslin cloth vs on leaf



Plate 12. A distinctive inverted 'Y' shape on the head capsule and four dark spots arranged in a square on the second last segment

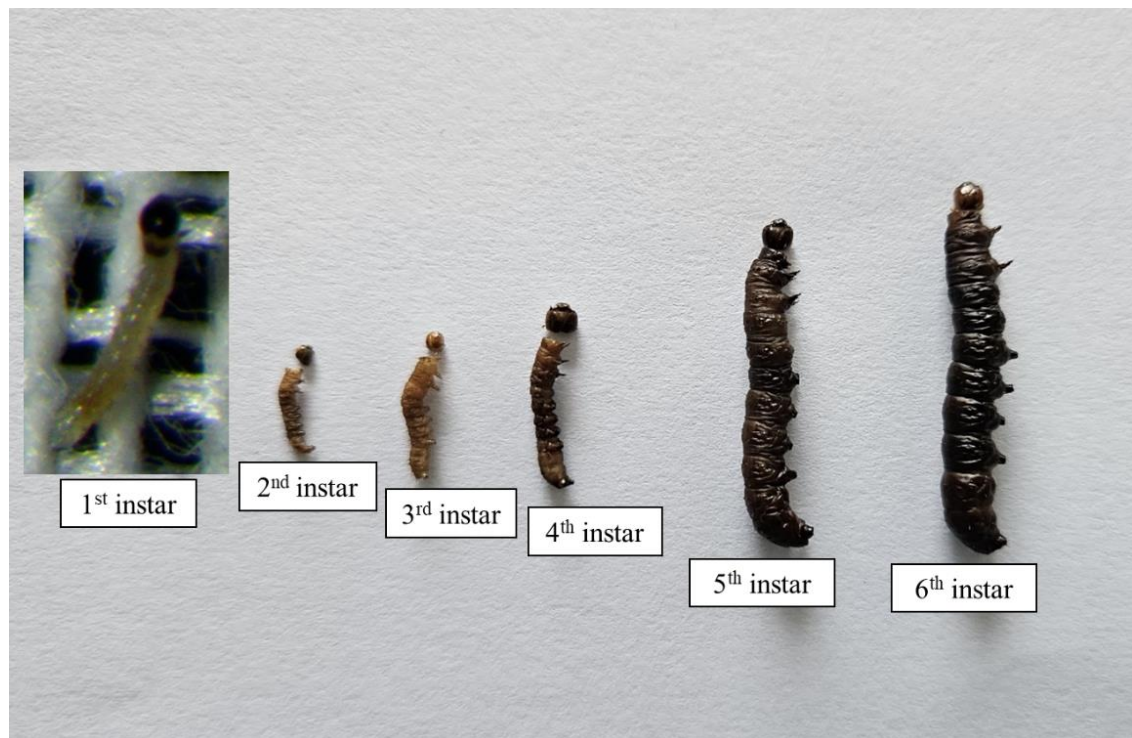


Plate 13. Six larval instars of *Spodoptera frugiperda* (alcohol preserved)

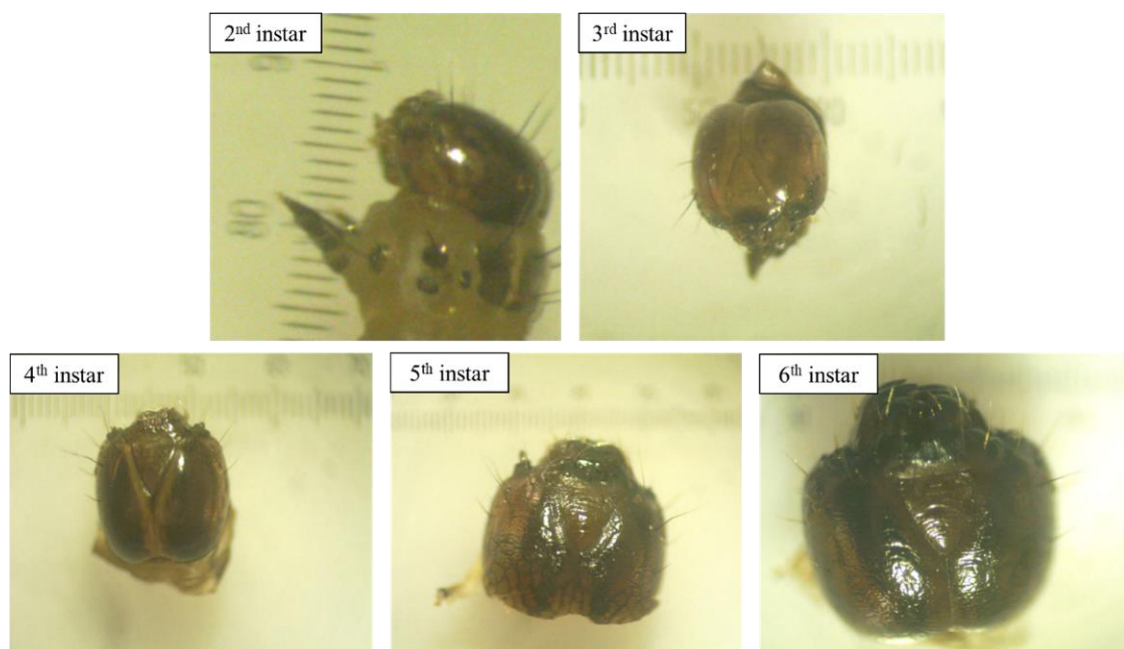


Plate 14. Measurement of head capsules of the larva (*Spodoptera frugiperda*)

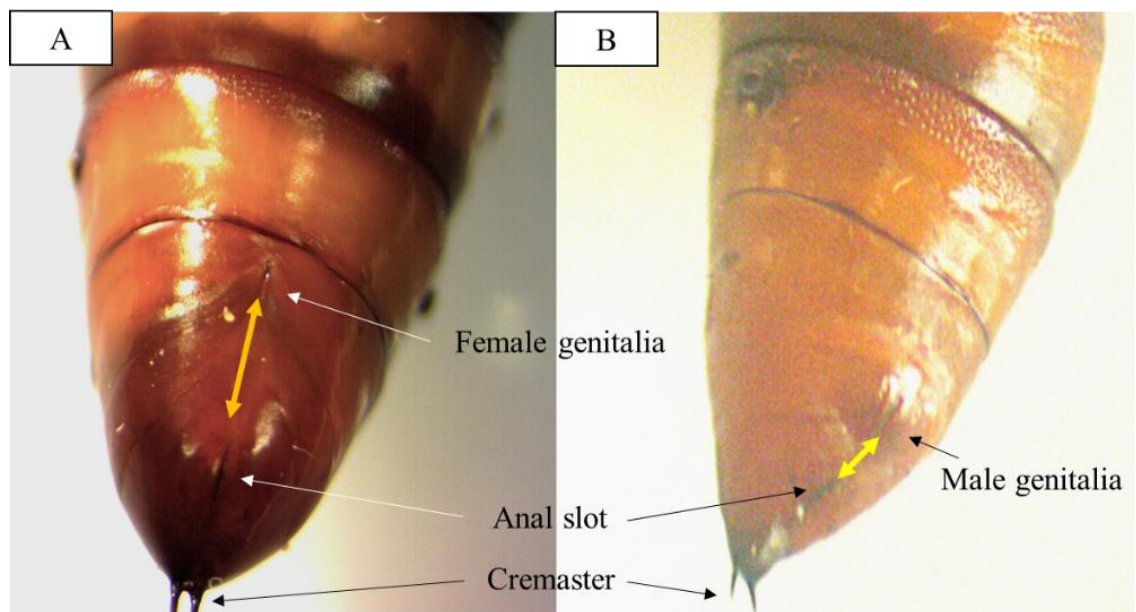


Plate 15. Difference in the (A) female and (B) male pupa (*Spodoptera frugiperda*)



Plate 16. Female and male adult moths of *Spodoptera frugiperda*

days. The results are in accordance with the findings of Kalyan *et al.* (2020) and Reddy *et al.* (2021) who observed the duration of second instar larvae was 2.5 and 2.7 ± 0.48 days, respectively. Table 8 shows the mean length of the larva as 3.16 ± 0.147 mm which ranged (Table 7b) from 3.0 to 3.3 mm. The present findings are more or less similar with Kalyan *et al.* (2020) who reported the mean length of 3.5 ± 0.45 mm. Our findings show the mean weight (Table 8) of larvae as 0.0405 ± 0.0033 gm and ranged (Table 7c) from 0.0360-0.0436 gm. The result is more or less similar to Marri *et al.* (2023) who reported that the average weight of second instar larvae was 0.019 gm.

4.2.2.3. Third instar

It is evident from the Table 7a that the duration of third instar larvae varied from 2 to 3 days, with a mean 2.62 ± 0.13 days in 2022 and 2.65 ± 0.13 days in 2023. The third instar larvae exhibited a significant alteration in body coloration. The larval body color transitioned from pale white to an olive-brown tint. The larvae had a light brown coloration on the dorsal aspect and a greenish hue on the ventral aspect. The white lines were distinctly observable on the dorsal and sub-dorsal surfaces, whereas the black dots became increasingly pronounced. The mean duration of the larva was 2.63 ± 0.13 days which supports the previous findings of Dubale *et al.* (2022) who reported the average duration of 3rd instar larvae were 2.10 ± 0.31 days with a range of 2-3 days.

Table 8 shows the mean length of larvae of 6.50 ± 0.210 mm which ranged from 6.3 -6.7 mm (Table 7b). This is in par with Reddy *et al.* (2021) who reported an average length of 5.78 ± 0.56 mm in 3rd instar larvae. The mean larval weight was 0.0461 ± 0.0012 gm.

4.2.2.4. Fourth instar

The larval morphology experienced substantial change from the third to the fourth instar. Their body colors ranged from olive to dark brown. The dorsal and subdorsal white lines, along with the inverted "Y" shape on the head capsule, became more apparent. The duration of the fourth instar larvae varied from 2 to 3 days, with a mean of 2.31 ± 0.17 days 2.33 ± 0.18 days (Table 7a). The mean duration from the pooled data was 2.32 ± 0.17 days which is similar with that of Sharanabasappa *et al.* (2018) who reported the average duration of fourth instar larvae as 2.00 days. Table 8 shows the mean length of the larva

as 9.45 ± 0.215 mm which ranged from 9.2-9.7 mm (Table 7b). More or less similar observations were recorded by Kalyan *et al.* (2020) who reported an average length of 9.7 ± 0.55 mm. The mean weight was 0.0524 ± 0.0018 gm and ranged from 0.0501 to 0.0555 (Table 7c). Marri *et al.* (2023) observed an average weight of 0.050 gm which supports the present findings.

4.2.2.5. Fifth instar

The fifth instar larvae were observed to be similar to their earlier instars, albeit greater in size. The larvae had a greyish-brown coloration on the dorsal aspect and a greenish tinge on the ventral and sub-ventral surfaces. A unique arrangement of four "dots" was noted on the eighth abdominal segment of larvae, organized in a square formation, whereas the other abdominal segments had a trapezoidal configuration. The fifth instar larvae were observed to be similar to their earlier instars, albeit greater in size. The larvae developed a greyish-brown hue on the dorsal side and a verdant hue on the ventral and sub-ventral surfaces. A unique arrangement of four "dots" was noted on the eighth abdominal segment of larvae, organized in a square formation, whereas the other abdominal segments had a trapezoidal configuration. The duration of fifth instar larvae varied (Table 7a) from 2-3 days, with a mean of 2.90 ± 0.08 days in the first year and 2.93 ± 0.09 days in the second year. The mean duration from the pooled data (Table 8) for two seasons was 2.90 ± 0.08 days. The results showed similarity with the past findings of Sharanabassapa *et al.* (2018), Kalyan *et al.* (2020) who reported an average duration of 2.8 days.

Table 8 shows the mean length of the larva as 15.9 ± 0.525 mm which ranged (Table 7b) from 15.4 to 16.4 mm which is in line with the findings of Reddy *et al.* (2021) who observed an average length of 16.5 ± 0.99 mm. Table 8 shows the mean weight of 0.0568 ± 0.0017 gm and ranged (Table 7c) from 0.0545 to 0.0611 gm. Marri *et al.* (2023) observed an average weight of 0.060 gm which supports our findings.

4.2.2.6. Sixth instar

During this stage, the larvae were stout, thicker, more bulged and slightly cylindrical in shape. The head of the larva was black and bilobed in morphology, while

the larval body was smooth with distinct segmentation. On the dorsum, the body exhibited a greyish-brown hue, and on the ventral and sub-ventral sides, it was greenish spots with reddish brown colour. The duration of sixth instar larvae varied (Table 7a) from 3 to 5 days, with a mean of 4.20 ± 0.23 days in the 2022 and 4.13 ± 0.24 days in 2023. The mean duration from the pooled data (Table 8) for two seasons was 4.20 ± 0.23 days. The current findings closely align with the previous research conducted by Maharani *et al.* (2021), which reported an average length of 4.31 ± 0.21 days.

Table 8 shows the mean length of the larva as 31.38 ± 1.056 mm which ranged (Table 7b) from 30.2 to 32.6 mm which supports the works of Deole and Paul (2018) who reported the length of sixth instar larva as 32-35 mm. Our data on the mean weight (Table 8) was 0.0594 ± 0.0019 gm and ranged (Table 7c) from 0.0582 to 0.187 gm which is in line with Marri *et al.* (2023) who reported the larval weight of 0.067 gm.

4.2.3. Pupal stage

During the pre-pupal stage, the fully developed larva ceased feeding, transitioned to a greenish hue, and exhibited a vibrant brown coloration. The pupae were initially ochre in colour and later turned to dark reddish brown. Male and female pupae were distinguished by measuring the distance from the genital entrance to the anal slot. The distance was more in female pupa when compared to the male (Plate 4.4). The pupal period (Table 8) ranged from 7 to 8 days with a mean of 7.43 ± 0.14 days. The male pupal period varied between 7 to 8 days with a mean of 7.58 ± 0.14 days whereas the female pupal period also ranged from 7 to 8 days with an average of 7.30 ± 0.25 days. The present findings are in close agreement with Ramya and Maheswari (2019) having 8-9 days of pupal period. Similarly, Ashok *et al.* (2020) reported the pupal period of 8.24 days on maize.

Table 8 shows our findings on mean female and male pupal length as 14.77 ± 0.149 and 15.05 ± 0.161 mm respectively. These are in line with Kalyan *et al.* (2020) who reported the mean pupal length of *S. frugiperda* as 15.7 ± 1.55 mm.

4.2.4. Adult stage

Plate 4.6 shows that the adult is a small to medium-sized moth with pronounced sexual dimorphism. Female forewings exhibited less pronounced markings, varying from

a uniform greyish-brown to a subtle mottling of grey and brown, while male forewings were mostly tinted in grey and brown, featuring triangular white dots at the apex and at the center. Both genders possessed iridescent silver-white hind wings adorned with a slender dark border. The oviposition duration varied from 4 to 5 days, with an average of 4.15 ± 0.54 days. (Table 8). The present results are in line with Reddy *et al.* (2021) who recorded an average oviposition period of 3.02 ± 0.78 days ranging from 3 to 4 days. Similarly, Hong *et al.* (2022) reported that the oviposition period ranged from 3.00 to 4.00 days. Whereas, in the study conducted by Murúa and Virla (2004), the oviposition period was 8.5 to 11 days. The brief duration of oviposition was likely attributable to elevated reproductive output during the early life stage.

Table 7a shows that the total life cycle of male and female ranged from 34 to 37 days with a mean of (Table 8) 35.29 ± 0.90 days and 36 to 38 days with a mean of (Table 8) 36.30 ± 1.22 days, respectively. The results are in close conformity with the earlier findings of Kalyan *et al.* (2020) who reported an average life cycle of male and female was 36.15 and 40.11 days, respectively. Similarly, Jena *et al.* (2024) observed an average life cycle of male and female ranged from 32-37 and 34-39 days, respectively. Siddhapara *et al.* (2021) also reported the total life cycle of male and female was 34.50 ± 1.80 and 37.20 ± 2.52 days, respectively.

The longevity of adult males and females varied from 8 to 10 days, with mean durations of 8.85 ± 0.64 days and 9.15 ± 0.82 days, respectively. This is in conformity with Reddy *et al.* (2021) who reported an average male longevity of 9.10 days and female longevity of 11.52 days. Similarly, Vishwakarma *et al.* (2020) reported an average male longevity of 8.0 days and female longevity of 10.5 days.

4.3. To study the combine effect of some insecticides on fall armyworm, *Spodoptera frugiperda* (J.E. Smith)

The experiment on the combine effect of some insecticides on FAW was executed as one time probit analysis in the laboratory in 2022 to test the effectiveness of the treatments. Thirty larvae in their fourth instars were collected from the rearing culture population and the effect of the treatments are presented as larval mortality in Table 9.

Table 9. Cumulative mortality of 4th instar larva of *S. frugiperda* at different hour intervals after treatment application

Treatment No.	Treatments	Mortality percentage of fall armyworm larvae (%)				
		No. of larva pre-treatment	24 hrs	48 hrs	72 hrs	96 hrs
T1	<i>Beauveria bassiana</i>	12	16.67 (24.09)	24.09 (31.48)	36.36 (37.09)	62.50 (52.24)
T2	<i>Metarhizium anisopliae</i>	12	25.00 (30.00)	30.00 (37.09)	36.36 (37.09)	75.00 (60.00)
T3	Emamectin benzoate 5% SG	12	83.33 (65.91)	65.91 (72.45)	100.00 (90.00)	100.00 (90.00)
T4	Chlorantraniliprole 18.5% SC	12	75.00 (60.00)	60.00 (64.76)	100.00 (90.00)	100.00 (90.00)
T5	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	12	33.33 (35.26)	35.26 (37.09)	45.45 (42.39)	50.00 (45.00)
T6	<i>Beauveria bassiana</i> + Emamectin benzoate 5% SG	12	58.33 (49.80)	49.80 (52.91)	90.91 (72.45)	100.00 (90.00)
T7	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	12	66.67 (54.74)	54.74 (58.52)	81.82 (64.76)	100.00 (90.00)
T8	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	12	41.67 (40.20)	40.20 (42.39)	54.55 (47.61)	62.50 (52.24)
T9	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	12	50.00 (45.00)	45.00 (47.61)	63.64 (52.91)	87.50 (69.30)
T10	Control	12	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
SEm±		0.00	8.44	8.70	10.33	10.11
CD (5%)		NS	0.59	0.54	0.54	0.43

*Parenthesis values are angular transformed

Whereas, field application of the treatment was conducted during 2022 and 2023 on 24th SMW which consisted of two sprays with an interval of 15 days between the first and the second sprays. Data on leaf damage percentage and larval count before and after the treatments and the mean reduction by the treatments after each spray are formulated in Table 10a, 10b, 11, 12a, 12b and 13.

4.3.1. Mortality test in laboratory

Table 9 shows there was a significant difference among the treatments used in the larval mortality of FAW. When the larvae were fed with maize leaves treated with pesticides, the highest percentage of larval mortality after 24 hours was given by Emamectin benzoate 5% SG (83.33%) followed by Chlorantraniliprole 18.5% SC (75.00%), *Metarhizium anisopliae* + Emamectin benzoate 5% SG (66.67%), *Beauveria bassiana* + Emamectin benzoate 5% SG (75.22%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (50.00%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (41.67%), *Beauveria bassiana* + *Metarhizium anisopliae* (33.33%), *Metarhizium anisopliae* (25.00%) and *Beauveria bassiana* (16.67%). After 48 hours post treatment, the treatment showed the similar trend. However, after 72 hours, only Emamectin benzoate 5% SG and Chlorantraniliprole 18.5% SC caused 100% mortality rate. Ninety-six hours post treatment, *Beauveria bassiana* + Emamectin benzoate 5% SG (75.22%) and *Metarhizium anisopliae* + Emamectin benzoate 5% SG also induced 100% mortality on larvae of *S. frugiperda*. The results showed that all treatments significantly reduced the larval population. This similar pattern of higher mortality of FAW larvae within a very short time was also reported by Sharma *et al.* (2022) who found out that Chlorantraniliprole caused mortality of 30% in the first twelve hours and more than 90% within twenty-four hours in their experiment. Similar findings were reported by Sisay *et al.* (2019), Thrash *et al.* (2013) and Hardke *et al.* (2011). *M. anisopliae* and *B. bassiana* induced 36.36 per cent larval mortality at 96 hours post-treatment. However, Kumar and Mohan (2021) reported *Metarhizium anisopliae* caused 100.00 per cent mortality and *Beauveria bassiana* (95% mortality) at 96 hrs after treatment application.

4.3.2. Bioefficacy of the treatments in the field

4.3.2.1 On leaf per cent damage

Reduction of leaf damage percentage over control (ROC) post treatment on 7th, 10th and 15th days after first and second spraying during 2022 and 2023 and pooled data are shown in Table 10a, 10b and 11, respectively.

4.3.2.1.1. First year field application

Spray during 2022 was conducted one day after documenting the incidence of *S. frugiperda* about leaf percentage damage which ranged from 11% to 15% (Table 10a) with no significant difference among the plots. Seven days after spraying, the highest percent reduction in leaf per cent damage over control was observed in the plots treated with Emamectin benzoate 5% SG (87.58%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (81.29%) and Chlorantraniliprole 18.5% SC (76.36%). This was followed by *Beauveria bassiana* + Emamectin benzoate 5% SG (75.22%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (73.79%), *Beauveria bassiana* + *Metarhizium anisopliae* (63.10%) and *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (62.10%). The lowest percent reduction was recorded in *Metarhizium anisopliae* (59.66%) and *Beauveria bassiana* (58.28%).

After ten days of spraying, the plots treated with Emamectin benzoate 5% SG had the highest percentage reduction in leaf per cent damage compared to the control group (89.82%), followed by 83.75% *Metarhizium anisopliae* + Emamectin benzoate 5% SG and 78.31% Chlorantraniliprole. The *Beauveria bassiana* + Emamectin benzoate 5% SG combination came in at 77.32%, followed by the *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (75.99%), *Beauveria bassiana* + *Metarhizium anisopliae* (65.54%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (64.86%) and finally, *Metarhizium anisopliae* (62.19%). *Beauveria bassiana* had the lowest percentage reduction with 60.07%.

Following fifteen days of application, the most significant reduction in leaf damage percentage compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (92.43%), succeeded by *Metarhizium anisopliae* +

Emamectin benzoate 5% SG (87.74%) and Chlorantraniliprole 18.5% SC (84.01%). Subsequently, *Beauveria bassiana* combined with Emamectin benzoate 5% SG yielded an efficacy of 83.61%, whereas *Metarhizium anisopliae* combined with Chlorantraniliprole at 18.5% achieved 82.34%, and *Beauveria bassiana* combined with *Metarhizium anisopliae* (74.59%) and *Metarhizium anisopliae* alone demonstrated 73.59% efficacy. *Beauveria bassiana* combined with Chlorantraniliprole 18.5% SC (73.53%). The minimal percentage drop was observed in *Beauveria bassiana* (70.48%).

Second spray was followed after taking the initial reading on one day ahead. The leaf damage percentage infested by *S. frugiperda* found to be varied among the plots due to the effect of the first spraying (Table 10a). After seven days of spraying, the highest percent reduction in leaf per cent damage over control was observed in the plots treated with Emamectin benzoate 5% SG (75.26%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (51.24%) and Chlorantraniliprole 18.5% SC (36.74%). This was followed by *Beauveria bassiana* + Emamectin benzoate (33.49%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (31.82%), *Beauveria bassiana* + *Metarhizium anisopliae* (30.15%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (29.61%) and *Beauveria bassiana* (22.81%). The lowest percent reduction was recorded in *Metarhizium anisopliae* (16.93%).

Following ten days of application, the greatest percentage reduction in leaf damage compared to the control was noted in plots treated with Emamectin benzoate 5% SG (70.68%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (59.85%) and Chlorantraniliprole 18.5% SC (41.08%). The subsequent results were *Beauveria bassiana* + Emamectin benzoate (36.29%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (35.13%), *Beauveria bassiana* + *Metarhizium anisopliae* (33.94%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (32.19%), and *Beauveria bassiana* alone (26.60%). The minimal percentage reduction was observed in *Metarhizium anisopliae* (21.30%).

After fifteen days of spraying, the highest percent reduction in leaf per cent damage over control was observed in the plots treated with Emamectin benzoate 5%

SG (79.22%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (59.19%) and Chlorantraniliprole 18.5% SC (41.14%). This was followed by *Beauveria bassiana* + Emamectin benzoate 5% SG (37.39%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (33.74%), *Beauveria bassiana* + *Metarhizium anisopliae* (33.53%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (32.89%) and *Beauveria bassiana* (24.19%). The lowest percent reduction was recorded in *Metarhizium anisopliae* (18.77%).

Table 10a shows that after the first and second sprayings, the plots treated with a mixture of *Metarhizium anisopliae* and Emamectin benzoate 5% SG had the highest mean reduction on the percentage of leaf damage caused by *Spodoptera frugiperda* compared to the control plots in 2022, at 82.50%. The next highest treatments were Chlorantraniliprole 18.5% SC at 59.51%. After that came the following combinations: *Beauveria bassiana* + Emamectin benzoate 5% SG (57.24%), *Metarhizium anisopliae* + Chlorantraniliprole (18.5%, 54.47%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (50.20%), *Beauveria bassiana* + *Metarhizium anisopliae* (50.14%), and *Metarhizium anisopliae* (44.50%). In plots treated with *Beauveria bassiana*, the percentage reduction was the lowest at 43.74%.

4.3.2.1.2. Second year field application

First spray during 2023 was executed after recording the preliminary mean leaf damage percentage caused by *S. frugiperda* one day ahead which varied between 10% and 15% (Table 10b), with no significant differences among the plots. Following seven days of application, the highest percentage reduction in leaf damage compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (86.58%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (84.59%) and *Beauveria bassiana* + Emamectin benzoate 5% SG (81.14%). The subsequent results were as follows: Chlorantraniliprole 18.5% SC (73.90%), *Metarhizium anisopliae* combined with Chlorantraniliprole 18.5% (71.04%), *Beauveria bassiana* combined with Chlorantraniliprole 18.5% SC (70.15%), *Beauveria bassiana* combined with *Metarhizium anisopliae* (69.14%), and *Beauveria bassiana* (62.12%). The minimal percentage drop was observed in plots treated with *Metarhizium anisopliae* (59.66%).

After ten days of spraying, the highest percent reduction in leaf per cent damage over control was observed in the plots treated with Emamectin benzoate 5% SG (88.61%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (86.15%) and *Beauveria bassiana* + Emamectin benzoate 5% SG (83.68%). This was followed by Chlorantraniliprole 18.5% SC (76.41%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (73.37%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (72.75 %), *Beauveria bassiana* + *Metarhizium anisopliae* (69.14%) and *Beauveria bassiana* (64.70%). The lowest percent reduction was recorded in *Metarhizium anisopliae* (62.19%).

Following fifteen days of application, the greatest percentage decrease in leaf damage relative to the control was seen in plots treated with Emamectin benzoate 5% SG (92.73%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (90.57%) and *Beauveria bassiana* + Emamectin benzoate 5% SG (87.65%). The subsequent results were as follows: Chlorantraniliprole 18.5% SC (83.95%), *Metarhizium anisopliae* combined with Chlorantraniliprole 18.5% (81.46%), *Beauveria bassiana* combined with Chlorantraniliprole 18.5% SC (81.17%), *Beauveria bassiana* combined with *Metarhizium anisopliae* (80.50%), and *Beauveria bassiana* alone (75.91%). The minimal percentage drop was observed in *Metarhizium anisopliae* (73.59%).

Second spray was carried out after noting down the mean leaf damage percentage a day ahead. The was differences among the plots due to the effect of the first spraying (Table 10b). After 7 days of spraying, the highest percent reduction in leaf per cent damage over control was observed in the plots treated with Emamectin benzoate 5% SG (64.53%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (44.79%), Chlorantraniliprole 18.5% SC (38.97%) and *Beauveria bassiana* + Emamectin benzoate 5% SG (23.05%). Succeeding the trend were *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (28.09%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (27.94%), *Beauveria bassiana* + *Metarhizium anisopliae* (21.05%) and *Metarhizium anisopliae* (20.09%) The lowest percent reduction was recorded in plots treated with *Beauveria bassiana* (17.71%).

Table 10a. Efficacy of different treatments against per cent leaf damage caused by *S. frugiperda* during Kharif season (2022)

Treatment No.	Treatments	1 st spray				2 nd spray				Mean per cent reduction
		Pre-treatment %	Day 7	Day 10	Day 15	Pre-treatment %	Day 7	Day 10	Day 15	
			Per cent reduction				Per cent reduction			
T1	<i>Beauveria bassiana</i>	12.70	58.28 (49.77)	60.07 (50.81)	70.48 (57.09)	19.84	22.81 (28.53)	26.60 (31.05)	24.19 (29.46)	43.74
T2	<i>Metarhizium anisopliae</i>	13.49	64.24 (53.27)	69.09 (56.22)	76.64 (61.10)	16.59	16.93 (24.30)	21.30 (27.49)	18.77 (25.67)	44.50
T3	Emamectin benzoate 5% SG	12.70	87.58 (69.37)	89.82 (71.40)	92.43 (74.03)	5.29	75.26 (60.17)	70.68 (57.22)	79.22 (62.88)	82.50
T4	Chlorantraniliprole 18.5% SC	13.49	76.36 (60.91)	78.31 (62.24)	84.01 (66.43)	11.52	36.74 (37.31)	41.08 (39.86)	41.14 (39.90)	59.61
T5	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	11.11	63.10 (52.59)	65.54 (54.05)	74.59 (59.73)	13.89	30.15 (33.31)	33.94 (35.63)	33.53 (35.38)	50.14
T6	<i>Beauveria bassiana</i> + Emamectin benzoate	14.29	75.22 (60.15)	77.42 (61.63)	83.61 (66.12)	12.36	33.49 (35.36)	36.29 (37.04)	37.39 (37.70)	57.24
T7	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	12.70	81.29 (64.37)	83.75 (66.23)	87.74 (69.51)	7.76	51.24 (45.71)	59.85 (50.68)	59.19 (50.30)	70.51
T8	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	12.70	62.10 (52.00)	64.86 (53.64)	73.53 (59.04)	17.99	31.82 (34.34)	35.13 (36.35)	33.74 (35.51)	50.20
T9	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	14.29	73.79 (59.20)	75.99 (60.66)	82.34 (65.15)	13.81	29.61 (32.96)	32.19 (34.56)	32.89 (34.99)	54.47
T10	Control	14.29	0.00	0.00	0.00	78.77	0.00	0.00	0.00	0.00
<i>SEm</i> ±		1.76	7.72	7.93	8.34	1.93	9.30	9.07	10.26	
<i>CD</i> (<i>p</i> =0.05)		NS	3.46	3.38	5.74		3.02	3.08	3.02	

*Parenthesis values are angular transformed

Table 10b. Efficacy of different treatments against per cent leaf damage caused by *S. frugiperda* during Kharif season (2023)

Treatment No.	Treatments	1 st spray				2 nd spray				Mean per cent reduction
		Pre-treatment %	Day 7	Day 10	Day 15	Pre-treatment %	Day 7	Day 10	Day 15	
			Per cent reduction				Per cent reduction			
T1	<i>Beauveria bassiana</i>	10.32	62.12 (52.01)	64.70 (53.55)	75.91 (60.61)	15.35	17.71 (24.89)	17.44 (24.68)	17.34 (24.61)	42.54
T2	<i>Metarhizium anisopliae</i>	11.90	59.66 (50.57)	62.19 (52.06)	73.59 (59.07)	19.08	20.09 (26.63)	20.85 (27.17)	19.41 (26.14)	42.64
T3	Emamectin benzoate 5% SG	11.90	86.58 (68.51)	88.61 (70.27)	92.73 (74.36)	5.03	64.53 (53.45)	66.98 (54.93)	72.58 (58.42)	78.67
T4	Chlorantraniliprole 18.5% SC	11.90	73.90 (59.28)	76.41 (60.94)	83.95 (66.38)	11.54	38.97 (38.63)	38.33 (38.25)	40.61 (39.59)	58.69
T5	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	11.90	69.14 (56.25)	71.95 (58.02)	80.50 (63.80)	14.08	21.05 (27.31)	23.90 (29.27)	23.99 (29.33)	48.42
T6	<i>Beauveria bassiana</i> + Emamectin benzoate % SG	15.08	81.14 (64.26)	83.68 (66.17)	87.65 (69.42)	10.51	23.05 (28.69)	26.26 (30.83)	23.96 (29.31)	54.29
T7	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	12.70	84.59 (66.89)	86.15 (68.15)	90.57 (72.12)	7.41	44.79 (42.01)	44.87 (42.05)	47.99 (43.85)	66.49
T8	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	12.70	70.15 (56.89)	72.75 (58.53)	81.17 (64.28)	14.71	27.94 (31.91)	27.53 (31.65)	28.06 (31.99)	51.27
T9	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	14.29	71.04 (57.44)	73.37 (58.93)	81.46 (64.49)	16.30	28.09 (32.00)	27.63 (31.71)	31.69 (34.26)	52.22
T10	Control	12.70	0.00	0.00	0.00	78.57	0.00	0.00	0.00	42.54
<i>SEm</i> ±		1.13	7.83	8.03	8.52	0.87	9.50	9.86	10.73	
<i>CD</i> (<i>p</i> =0.05)		NS	1.61	1.56	2.59	1.68	3.14	3.03	3.14	

*Parenthesis values are angular transformed

Table 11. Efficacy of different treatments against per cent leaf damage caused by *S. frugiperda* during Kharif season 2022 and 2023 (pooled)

Treatment No.	Treatments	Pooled mean of per cent leaf damage (2022-2023)								
		1st spray				2nd spray				
		Pre-treatment %	7 days	10 days	15 days	Pre-treatment %	7 days	10 days	15 days	Mean per cent reduction
			Per cent reduction				Per cent reduction			
T ₁	<i>Beauveria bassiana</i>	12.30	58.97 (50.17)	61.13 (51.43)	72.03 (58.07)	19.46	21.45 (27.59)	23.73 (29.15)	21.80 (27.83)	43.19
T ₂	<i>Metarhizium anisopliae</i>	11.90	63.18 (52.64)	66.89 (54.87)	76.28 (60.85)	15.97	17.32 (24.59)	19.37 (26.11)	18.05 (25.14)	43.52
T ₃	Emamectin benzoate 5% SG	12.30	87.08 (68.93)	89.21 (70.83)	92.58 (74.20)	5.16	69.90 (56.72)	68.83 (56.06)	75.90 (60.60)	80.59
T ₄	Chlorantraniliprole 18.5% SC	12.70	75.13 (60.09)	77.36 (61.59)	83.98 (66.40)	11.53	37.85 (37.97)	39.71 (39.06)	40.87 (39.74)	59.15
T ₅	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	13.49	66.57 (54.68)	69.11 (56.24)	77.49 (61.68)	17.15	29.95 (33.18)	31.38 (34.07)	32.72 (34.89)	51.21
T ₆	<i>Beauveria bassiana</i> + Emamectin benzoate 5% SG	14.68	78.18 (62.15)	80.55 (63.83)	85.63 (67.72)	11.43	28.27 (32.12)	31.28 (34.01)	30.68 (33.63)	55.76
T ₇	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	12.70	82.94 (65.60)	84.95 (67.17)	89.16 (70.78)	7.58	48.01 (43.86)	52.36 (46.35)	53.59 (47.06)	68.50
T ₈	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	11.90	66.63 (54.71)	69.15 (56.26)	77.88 (61.95)	14.30	29.04 (32.61)	30.73 (33.67)	30.79 (33.70)	50.71
T ₉	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	13.10	71.46 (57.71)	73.97 (59.33)	81.42 (64.47)	13.94	25.33 (30.22)	28.04 (31.98)	28.44 (32.23)	51.45
T ₁₀	Control	13.49	0.00	0.00	0.00	78.67	0.00	0.00	0.00	
SEm±		1.04	7.95	8.42	8.02	1.06	9.44	10.48	9.76	
CD (p=0.05)		NS	1.84	1.80	3.04	1.68	2.11	3.03	2.11	

*Parenthesis values are angular transformed

Following 10 days of application, the highest percentage reduction in leaf damage compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (66.98%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (44.87%) and *Beauveria bassiana* + Emamectin benzoate 5% SG (26.26 %). The subsequent results were Chlorantraniliprole 18.5% SC (38.33%), *Metarhizium anisopliae* combined with Chlorantraniliprole 18.5% (27.63%), *Beauveria bassiana* combined with Chlorantraniliprole 18.5% SC (27.53%), *Beauveria bassiana* combined with *Metarhizium anisopliae* (23.90%), and *Metarhizium anisopliae* (20.85%). The minimal percentage reduction was observed in *Beauveria bassiana* (17.44%) treated plots.

After 15 days of spraying, the highest percent decrease in leaf per cent damage over control was observed in the plots treated with Emamectin benzoate 5% SG (72.58%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (47.99%) and Chlorantraniliprole 18.5% SC (40.61%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (31.69%), This was followed by *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (28.06%), *Beauveria bassiana* + *Metarhizium anisopliae* (23.99%), *Beauveria bassiana* + Emamectin benzoate 5% SG (23.96%) and *Metarhizium anisopliae* (19.41%). The lowest percent reduction was recorded in *Beauveria bassiana* (17.34%).

Table 10b shows that after first and second sprayings, the mean reduction on leaf damage percentage infested by *Spodoptera frugiperda* over control plots 2023 was found highest in the plots treated with Emamectin benzoate 5% SG (78.67%). These results contrast with the findings of Naram *et al.* (2022), who showed a reduction of 19.20 percent by Emamectin benzoate 5% SG after 10 days of treatment. This may be attributed to the variation in the developmental stages of larval instars present in the field at the time of treatment. *Metarhizium anisopliae* combined with Emamectin benzoate 5% SG demonstrated a 66.49% reduction, whereas Chlorantraniliprole 18.5% SC shown a 58.69% reduction. Next were *Beauveria bassiana* + Emamectin benzoate 5% SG (54.29%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5%

(52.22%), SC (51.27%), and *Beauveria bassiana* + *Metarhizium* (48.42%). The minimal percentage drop was observed in *Beauveria bassiana* (42.54%).

4.3.2.3. Mean of two sprays of insecticides (pooled)

It is evident from the pooled table of 2022 and 2023 (Table 11) that among the treatments applied, the cumulative mean reduction on the leaf damage percentage was found highest in the plots treated with Emamectin benzoate 5% SG (80.59%). Similarly, Dileep (2020) also reported that maize fields infested with fall armyworm, when sprayed with Emamectin benzoate 5% SG resulted 78.89 per cent reduction in leaf infestation. Per cent reduction given by *Metarhizium anisopliae* + Emamectin benzoate 5% SG was 68.50 per cent followed by Chlorantraniliprole 18.5% SC (59.15%). Our findings support the consistent reports by many authors about Emamectin benzoate 5% SG and Chlorantraniliprole 18.5% SC being highly effective in management of FAW. Kumar *et al.* (2020) reported that Emamectin benzoate 5% SG was the most effective treatment, with Chlorantraniliprole 18.5% SC next best among their treatments. Deshmukh *et al.* (2021) reported in their field efficacy experiment that the effective insecticides were Chlorantraniliprole 18.5 SC, followed by Emamectin benzoate 5% SG on FAW over control. This corroborates that Emamectin benzoate and Chlorantraniliprole cluster at the top of chemical options. However, Rizvi and Deole (2022) reported about Chlorantraniliprole 18.5% SC being recorded 71.67% and 82.30% reduction in larval population after first and second sprays, respectively. The lower reduction percentage in our findings could be due to environmental factors or stage of instars infesting the crop.

Table 11 indicates that *Beauveria bassiana* + Emamectin benzoate (55.76%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (51.45%), *Beauveria bassiana* + *Metarhizium anisopliae* (51.21%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (50.71%) perform better when mixing with a chemical insecticide than their individual fungal treatment.

The lowest percent reduction was recorded almost similar in *Metarhizium anisopliae* (43.52%) and *Beauveria bassiana* (43.19%). This is in line with Ramos *et al.* (2020) who reported that there were no discrepancies in the mortality rates induced

by *B. bassiana* and *M. anisopliae* on *S. frugiperda* larvae. Our findings also support Ramanujam *et al.* (2020) who reported that Indian isolates of *Beauveria bassiana* and *Metarhizium anisopliae* caused significant FAW mortality and reduced field damage, though biologicals generally act slower than Emamectin benzoate 5% SG and Chlorantraniliprole 18.5% SC.

Similar studies were conducted by Hardke *et al.* (2011) who evaluated field efficacy of some newer compounds insecticides which were recommended against fall armyworm and reported that Chlorantraniliprole among others reduced fall armyworm infestations by 2.5-fold below that in the non-treated control.

4.3.2.2 On larval population

Reduction of larval population over control (ROC) post treatment on 7th, 10th and 15th days after first and second spraying during 2022 and 2023 as well as pooled data are shown in Table 12a, 12b and 13, respectively.

4.3.2.2.1. First year field application

First spray in 2022 was performed after documenting the initial mean larval population per 10 which ranged from 6 to 7 (Table 12a) with no significant difference among the plots. After 7 days of spraying, the highest percent reduction in larval population over control was observed in the plots treated with Emamectin benzoate 5% SG (54.52%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (49.50%) and Chlorantraniliprole 18.5% SC (48.25%). This was followed by *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (45.37%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (42.30%), *Beauveria bassiana* + Emamectin benzoate 5% SG (33.51%), *Beauveria bassiana* + *Metarhizium anisopliae* (35.15%) and *Metarhizium anisopliae* (29.04%). The lowest percent reduction was recorded in *Beauveria bassiana* (14.99%).

Table 12a. Efficacy of different treatments against larval stage of *S. frugiperda* during Kharif season (2022)

Treatment No.	Treatments	1 st spray				2 nd spray				Mean per cent reduction
		Pre count	Day 7	Day 10	Day 15	Pre count	Day 7	Day 10	Day 15	
			Reduction percentage				Reduction percentage			
T1	<i>Beauveria bassiana</i>	6.23	14.99 (22.78)	39.86 (39.15)	53.38 (46.94)	2.78	27.38 (31.55)	34.33 (35.87)	45.60 (42.47)	35.93
T2	<i>Metarhizium anisopliae</i>	6.17	29.04 (32.60)	56.37 (48.66)	56.40 (48.68)	2.40	28.75 (32.43)	35.71 (36.70)	46.75 (43.13)	42.17
T3	Emamectin benzoate 5% SG	6.21	54.52 (47.59)	74.20 (59.47)	86.71 (68.62)	0.53	64.57 (53.47)	71.95 (58.02)	76.71 (61.15)	71.45
T4	Chlorantraniliprole 18.5% SC	6.17	48.25 (44.00)	64.84 (53.63)	68.81 (56.05)	0.91	45.57 (42.46)	52.72 (46.56)	60.81 (51.24)	56.83
T5	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	6.19	35.15 (36.36)	55.17 (47.97)	60.30 (50.95)	2.07	30.40 (33.46)	37.35 (37.68)	48.13 (43.93)	44.42
T6	<i>Beauveria bassiana</i> + Emamectin benzoate 5% SG	6.11	33.51 (35.37)	53.04 (46.75)	57.96 (49.58)	1.77	56.51 (48.74)	61.68 (51.76)	69.32 (56.36)	55.34
T7	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	6.24	49.50 (44.72)	66.14 (54.41)	70.12 (56.87)	0.38	82.61 (65.35)	43.95 (41.53)	61.32 (51.54)	62.28
T8	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	6.14	42.30 (40.57)	66.92 (54.89)	61.05 (51.38)	1.73	32.72 (34.89)	39.72 (39.07)	50.06 (45.04)	48.80
T9	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	6.23	45.37 (42.35)	66.84 (54.84)	66.48 (54.62)	1.09	41.07 (39.85)	48.17 (43.95)	57.05 (49.05)	54.17
T10	Control	6.22	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	14.65	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	
<i>SEm</i> ±		0.04	5.36	6.77	7.12	0.40	5.45	7.00	6.76	
<i>CD</i> (<i>p</i> =0.05)		NS	0.48	0.39	0.39	1.18	0.42	0.52	0.41	

*Parenthesis values are angular transformed

Table 12b. Efficacy of different treatments against larval stage of *S. frugiperda* during Kharif season (2023)

Treatment No.	Treatments	1 st spray				2 nd spray				
		Pre count	Day 7	Day 10	Day 15	Pre count	Day 7	Day 10	Day 15	Mean per cent reduction
			Reduction percentage				Reduction percentage			
T1	<i>Beauveria bassiana</i>	6.54	33.83 (35.57)	61.71 (51.77)	61.08 (51.40)	1.62	17.04 (24.38)	21.50 (27.63)	36.19 (36.98)	38.56
T2	<i>Metarhizium anisopliae</i>	6.63	21.07 (27.32)	49.02 (44.44)	51.04 (45.60)	2.81	31.95 (34.42)	36.07 (36.91)	47.96 (43.83)	39.52
T3	Emamectin benzoate 5% SG	6.61	59.78 (50.64)	75.61 (60.40)	85.15 (67.34)	0.46	75.90 (60.60)	82.34 (65.15)	85.57 (67.67)	77.39
T4	Chlorantraniliprole 18.5% SC	6.53	48.76 (44.29)	67.51 (55.25)	67.66 (55.34)	1.04	48.23 (43.99)	53.16 (46.81)	61.88 (51.87)	57.87
T5	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	6.58	32.95 (35.03)	57.63 (49.39)	58.16 (49.70)	1.90	35.89 (36.80)	40.23 (39.37)	51.34 (45.77)	46.03
T6	<i>Beauveria bassiana</i> + Emamectin benzoate 5% SG	6.56	47.83 (43.75)	65.66 (54.13)	63.92 (53.08)	1.30	42.86 (40.90)	47.49 (43.56)	57.27 (49.18)	54.17
T7	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	6.71	46.19 (42.81)	70.74 (57.26)	68.74 (56.00)	0.83	51.71 (45.98)	56.79 (48.90)	64.84 (53.63)	59.84
T8	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	6.58	33.89 (35.60)	59.19 (50.29)	58.08 (49.65)	1.97	35.31 (36.46)	39.60 (39.00)	50.84 (45.48)	46.15
T9	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	6.53	38.46 (38.33)	58.64 (49.97)	56.68 (48.84)	1.87	36.82 (37.36)	41.21 (39.94)	52.14 (46.23)	47.33
T10	Control	6.32	0.00	0.00	0.00	13.46	0.00	0.00	0.00	
<i>SEm</i> ±		0.11	5.29	6.72	6.99	0.41	5.96	7.33	6.99	
<i>CD (p=0.05)</i>		NS	0.46	0.38	0.39	1.22	0.50	0.55	0.43	

*Parenthesis values are angular transformed

Table 13. Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (pooled)

Treatment No.	Treatments	Pre-treatment	Pooled mean of no. of larvae/10 plants							
			1st spray			Pre-treatment	2nd spray			
			7 days	10 days	15 days		7 days	10 days	15 days	Mean % reduction
			Reduction percentage over control (ROC)				Reduction percentage over control (ROC)			
T1	<i>Beauveria bassiana</i>	6.43	21.07 (25.13)	49.02 (41.81)	51.04 (46.27)	2.79	31.95 (33.00)	36.07 (36.39)	47.96 (43.15)	39.52
T2	<i>Metarhizium anisopliae</i>	6.38	32.95 (33.83)	57.63 (49.02)	58.16 (49.19)	2.15	35.89 (34.65)	40.23 (38.04)	51.34 (44.45)	46.03
T3	Emamectin benzoate 5% SG	6.41	59.78 (49.11)	75.61 (59.94)	85.15 (67.97)	0.50	75.90 (56.94)	82.34 (61.44)	85.57 (64.26)	77.39
T4	Chlorantraniliprole 18.5% SC	6.35	48.76 (44.14)	67.51 (54.44)	67.66 (55.69)	0.97	48.23 (43.22)	53.16 (46.69)	61.88 (51.56)	57.87
T5	<i>Beauveria bassiana</i> + <i>Metarhizium anisopliae</i>	6.38	33.89 (35.98)	59.19 (49.13)	58.08 (50.30)	2.02	35.31 (34.97)	39.60 (38.34)	50.84 (44.70)	46.15
T6	<i>Beauveria bassiana</i> + Emamectin benzoate 5% SG	6.32	38.46 (36.86)	58.64 (48.35)	56.68 (49.21)	1.82	36.82 (43.09)	41.21 (45.83)	52.14 (51.19)	47.33
T7	<i>Metarhizium anisopliae</i> + Emamectin benzoate 5% SG	6.48	46.19 (43.77)	70.74 (55.82)	68.74 (56.43)	0.61	51.71 (55.03)	56.79 (45.21)	64.84 (52.58)	59.84
T8	<i>Beauveria bassiana</i> + Chlorantraniliprole 18.5% SC	6.34	33.83 (38.10)	61.71 (53.32)	61.08 (51.39)	1.68	17.04 (29.92)	21.50 (33.59)	36.19 (41.05)	38.56
T9	<i>Metarhizium anisopliae</i> + Chlorantraniliprole 18.5% SC	6.39	47.83 (43.05)	65.66 (54.48)	63.92 (53.85)	1.20	42.86 (40.38)	47.49 (43.76)	57.27 (49.12)	54.17
T10	Control	6.27	0.00	0.00	0.00	14.05	0.00	0.00	0.00	
<i>SEm</i> ±		0.02	5.28	6.72	7.05	1.27	5.64	7.14	6.85	
<i>CD (p=0.05)</i>		NS	0.47	0.38	0.39	1.45	0.45	0.53	0.42	

*Parenthesis values are angular transformed

After 10 days of spraying, the highest percent reduction in larval population over control was observed in the plots treated with Emamectin benzoate 5% SG (74.20%) followed by *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (66.92%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5 SC % (66.84%), *Metarhizium anisopliae* + Emamectin benzoate 5% SG (66.14%) and Chlorantraniliprole 18.5% SC (64.84%). This was followed by *Metarhizium anisopliae* (56.37%), *Beauveria bassiana* + *Metarhizium anisopliae* (55.17%), *Beauveria bassiana* + Emamectin benzoate 5% SG (53.04%) and the lowest percent reduction was recorded in *Beauveria bassiana* (39.86%).

After 15 days of spraying, the highest percent reduction in larval population over control was observed in the plots treated with Emamectin benzoate 5% SG (86.71%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (70.12%) and Chlorantraniliprole 18.5% SC (68.81%). This was followed by *Metarhizium anisopliae* + Chlorantraniliprole 18.5% 66.48%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (61.05%), *Beauveria bassiana* + *Metarhizium anisopliae* (60.30%), *Beauveria bassiana* + Emamectin benzoate 5% SG (57.96%) and *Metarhizium anisopliae* (56.40%). The lowest percent reduction was recorded in *Beauveria bassiana* (53.38%).

The preliminary mean larval population of *S. frugiperda* per 10 plants, recorded one day prior to the second spraying in 2022, exhibited variability across the plots as a result of the first spraying, ranging from 0 to 3 larvae per 10 plants, whereas control plots displayed a mean larval count of 14.65 per 10 plants (Table 12a). Following 7 days of application, the most significant reduction in larval population compared to the control was recorded in plots treated with *Metarhizium anisopliae* + Emamectin benzoate 5% SG (82.61%), succeeded by Emamectin benzoate 5% SG (64.57%), *Beauveria bassiana* + Emamectin benzoate 5% SG (56.51%), and Chlorantraniliprole 18.5% SC (45.57%). This was succeeded by *Metarhizium anisopliae* combined with Chlorantraniliprole at 18.5% (41.07%), *Beauveria bassiana* with Chlorantraniliprole at 18.5% SC (32.72%), and *Beauveria bassiana* combined with *Metarhizium anisopliae* (30.40%). The minimal percentage drop was observed in *Metarhizium anisopliae* (28.75%) and *Beauveria bassiana* (27.38%).

Following a 10-day spraying period (Table 12a), the most significant reduction in larval population compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (71.95%), succeeded by *Beauveria bassiana* + Emamectin benzoate 5% SG (61.68%) and Chlorantraniliprole 18.5% SC (52.72%). Subsequently, the combinations included *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (48.17%), *Metarhizium anisopliae* + Emamectin benzoate 5% SG (43.95%) and *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (39.72%). Subsequently, *Metarhizium anisopliae* (35.71%) and the combination of *Beauveria bassiana* with *Metarhizium anisopliae* (37.35%) showed superior performance in comparison. The minimal percentage drop was observed in *Beauveria bassiana* (34.33%).

Following 15 days of application, the most significant reduction in larval population compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (76.71%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (61.32%) and Chlorantraniliprole 18.5% SC (60.81%). This was succeeded by *Beauveria bassiana* combined with Emamectin benzoate 5% SG (69.32%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (57.05%), *Metarhizium anisopliae* (46.75%), *Beauveria bassiana* + *Metarhizium anisopliae* (48.13%), and *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (50.06%). The minimal percentage reduction was observed in *Beauveria bassiana* (45.60%).

Table 12a shows that after first and second sprayings, the mean reduction on larval population of *Spodoptera frugiperda* over control plots during 2022 was found highest in the plots treated with Emamectin benzoate 5% SG (71.45%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (62.28%) and Chlorantraniliprole 18.5% SC (56.83%). This was followed by *Beauveria bassiana* + Emamectin benzoate 5% SG (35.93%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (54.17%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (48.80%), *Beauveria bassiana* + *Metarhizium anisopliae* (44.42%) and *Metarhizium anisopliae* (42.17%) The lowest percent reduction was recorded in *Beauveria bassiana* (35.93%). Sangle *et al.* (2020) who reported field sprays of Emamectin benzoate 5% SG

delivered the lowest larval counts while Chlorantraniliprole 18.5% SC was statistically next best.

4.3.2.1.2. Second year field application

First spray during 2023 was executed after recording the initial mean larval population per 10 plants which ranged from 6 to 7 (Table 12b) with no significant difference among the plots. After seven days of application, the greatest percentage reduction in larval population compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (59.78%), followed by Chlorantraniliprole 18.5% SC (48.76%), *Beauveria bassiana* + Emamectin benzoate 5% SG (47.83%), *Metarhizium anisopliae* + Emamectin benzoate 5% SG (46.19%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (38.46%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (33.89%), *Beauveria bassiana* (33.83%), and *Beauveria bassiana* + *Metarhizium anisopliae* (32.95%). *Metarhizium anisopliae* had the minimal percent reduction at 21.07 per cent.

Following 10 days of application (Table 12b), the greatest percentage reduction in larval population compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (75.61%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (70.74%) and Chlorantraniliprole 18.5% SC (67.51%). The subsequent results followed *Beauveria bassiana* combined with Emamectin benzoate 5% SG (65.66%), *Beauveria bassiana* alone (61.71%), and *Beauveria bassiana* combined with Chlorantraniliprole 18.5% SC (59.19%). *Metarhizium anisopliae* combined with Chlorantraniliprole at 18.5% yields an efficacy of 58.64%, whereas the combination of *Beauveria bassiana* and *Metarhizium anisopliae* achieved an efficacy of 57.63%. The minimal percentage drop was observed in *Metarhizium anisopliae* (49.02%).

After 15 days of first spraying (Table 12b), the highest percent reduction in larval population over control was observed in the plots treated with Emamectin benzoate 5% SG (85.15%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (68.74%) and Chlorantraniliprole 18.5% SC (67.66 %). This was followed by *Beauveria bassiana* + Emamectin benzoate 5% SG (63.92%), *Beauveria*

bassiana (61.08%), *Beauveria bassiana* + *Metarhizium anisopliae* (58.16%), *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (58.08%) and *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (56.68%). The lowest percent reduction was recorded in *Metarhizium anisopliae* (51.04%).

Before second spray during 2023 the initial mean larval population of *S. frugiperda* per 10 plants was found to be uneven among the plots due to the effect of the first spraying and ranged between 0 to 3 larva per 10 plants while in control plots, the mean number of larvae was 14.65 per 10 plants (Table 12b). After 7 days of spraying, the highest percent reduction in larval population over control was observed in the plots treated with Emamectin benzoate 5% SG (75.90%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (51.71%) and Chlorantraniliprole 18.5% SC (48.23%). This was followed by *Beauveria bassiana* + Emamectin benzoate 5% SG (42.86%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (36.82%), *Metarhizium anisopliae* (51.71%), *Beauveria bassiana* + *Metarhizium anisopliae* (35.89%) and *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (35.31%). The lowest percent reduction was recorded in *Beauveria bassiana* (17.04%).

After 10 days of second spraying (Table 12b), the highest percent reduction in larval population over control was observed in the plots treated with Emamectin benzoate 5% SG (82.34%) followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (56.79%) and Chlorantraniliprole 18.5% SC (53.16%). This was followed by *Beauveria bassiana* + Emamectin benzoate 5% SG (47.49%), *Metarhizium anisopliae* + Chlorantraniliprole 18.5% (41.21%), *Metarhizium anisopliae* (36.07%), *Beauveria bassiana* + *Metarhizium anisopliae* (40.23%) and *Beauveria bassiana* + Chlorantraniliprole 18.5% SC (39.60%). The lowest percent reduction was recorded in *Beauveria bassiana* (21.50%).

Fifteen days post-second application, the greatest percentage reduction in larval population compared to the control was recorded in plots treated with Emamectin benzoate 5% SG (85.57%), followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (64.84%) and Chlorantraniliprole 18.5% SC (61.88%).

The subsequent results included *Beauveria bassiana* combined with Emamectin benzoate 5% SG (57.27%), *Metarhizium anisopliae* combined with Chlorantraniliprole 18.5% (52.14%), *Beauveria bassiana* combined with *Metarhizium anisopliae* (51.34%), *Beauveria bassiana* combined with Chlorantraniliprole 18.5% SC (50.84%) and *Metarhizium anisopliae* (47.96%). The minimal percentage drop was observed in *Beauveria bassiana* (36.19%).

Table 12b indicates that following the first and second applications, the mean reduction in the larval population of *Spodoptera frugiperda* compared to control plots in 2023 was greatest in the plots treated with Emamectin benzoate 5% SG (77.39%), succeeded by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (59.84%) and Chlorantraniliprole 18.5% SC (57.87%). The subsequent combinations included *Beauveria bassiana* with Emamectin benzoate (54.18%), *Metarhizium anisopliae* with Chlorantraniliprole 18.5% (47.33%), *Beauveria bassiana* with Chlorantraniliprole 18.5% SC (46.16%), *Beauveria bassiana* with *Metarhizium anisopliae* (46.04%), and *Metarhizium anisopliae* alone (39.52%). The least percentage decline was noted in *Beauveria bassiana* (38.56%).

4.3.2.1.3. Mean of two sprays of insecticides (pooled)

The aggregated data from 2022 and 2023 (Table 13) clearly indicates that the highest cumulative mean reduction in larvae per plant occurred in plots treated with Emamectin benzoate 5% SG (71.45%), followed by *Metarhizium anisopliae* + Emamectin benzoate 5% SG (62.28%) and Chlorantraniliprole 18.5% SC (56.83%). Subsequently, the results indicated *Beauveria bassiana* combined with Emamectin benzoate 5% SG (55.34%). *Metarhizium anisopliae* combined with Chlorantraniliprole at 18.5% (54.17%) showed comparable efficacy and the combination of *Beauveria bassiana* with Chlorantraniliprole 18.5% SC (48.80%), the combination of *Beauveria bassiana* and *Metarhizium anisopliae* (44.42%), *Metarhizium anisopliae* (42.17%) and *Beauveria bassiana* (35.93%).

Table 13 indicates that Emamectin benzoate 5% SG decreased the average larval population by 77.39 percent. Our findings align with Dileep *et al.* (2020), who indicated that maize fields infested with autumn armyworm, when treated with

Emamectin benzoate 5% SG, achieved an 82.37 percent reduction in larval population. The current findings align with those of Bird *et al.* (2020), who indicated that Emamectin benzoate was the most effective insecticide, succeeded by Chlorantraniliprole.

Metarhizium anisopliae caused 46.03 per cent larval reduction (Table 13) which is slightly similar with the findings of Patel *et al.* (2020) who reported that the AAU strain of *M. anisopliae* caused the highest larval mortality rates up to 50.63 per cent. However, Kiruthiga *et al.* (2022) observed mortality *Metarhizium anisopliae* against *S. frugiperda* reaching up to 86.67 percent. This might be due of the difference in fungal strains.

CHAPTER V
SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The study was undertaken in the experimental farm, Department of Entomology, SAS, Nagaland University, Medziphema campus, Nagaland from June 2022 to October during 2022 and 2023. The experiment entitled “Bio-ecological studies and management of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize, *Zea mays* L. in Nagaland” was conducted to study the incidence and biology of *S. frugiperda*, and to examine the effectiveness of some common pesticides and their combined application. The maize variety (BIO-9637 Maharaja) used in the experiment was procured from College of Agriculture, Central Agricultural University, Imphal. The field trial was conducted in a Randomized Block Design with three replications and 10 treatments including a control. The data obtained were subjected to suitable statistical analysis as per the requirements of the experimental design. The findings of these experiments are summarized below:

- ❖ Incidence of FAW as Leaf Damage (%): FAW infestation commenced between 14 to 20 days after sowing, corresponding to the 24th Standard Meteorological Week (SMW) in the both years, 2022 and 2023. Initial leaf damage was documented at 5.32% in 2022 and 5.78% in 2023. The infestation escalated consistently, peaking at 83.86% on the 28th SMW (2022) and 80.25% on the 27th SMW (2023).
- ❖ Correlation analysis revealed that during 2022, the leaf damage (%) showed positive significant correlation with maximum temperature ($r=0.759^*$) and minimum temperature ($r=0.664^*$) while negative significant correlation with minimum RH ($r=-0.671^*$) and non-significant with maximum RH ($r=-0.620$) and rainfall ($r=-0.022$). Whereas, during 2023, it also showed positive significant correlation with maximum temp ($r=0.850^*$), minimum temp and ($r=0.832^*$) but negative significant with minimum RH ($r=-0.802^*$) and non-significant with maximum RH ($r=-0.243$) and rainfall ($r=-0.467$).
- ❖ Incidence of FAW as Number of Larvae: Larval incidence was first observed in 24th SMW at 1.22 larvae/10 plants during 2022 and 1.32 larvae/10 plants during 2023. Counts increased to peaks of 25.72 larvae/10 plants and 22.75

larvae/10 plants on 28th SMW and on 27th SMW during 2022 and 2023, respectively. Conditions during these peaks were similar to those for peak leaf damage.

- ❖ During 2022, larval population correlated positively significant with maximum temperature ($r=0.751^*$), positive non-significant with minimum temperature ($r=0.590$) but negative significant with maximum RH ($r=-0.743$) while it was negative non-significant with minimum RH ($r=-0.519$) and rainfall ($r=-0.011$).
- ❖ During 2023, there was positive significant with maximum temp ($r=0.805^*$) and minimum temp ($r=0.771^*$) but negative significant with minimum RH ($r=-0.882^*$). Whereas, correlation was negative non-significant with maximum RH ($r=-0.389$) and rainfall ($r=-0.457$).
- ❖ Incidence of FAW as number of adults: Pheromone trap catches were consistently low. In 2022, adults captured per week ranged from 0–1, with a mean of 0.44 ± 0.53 . In 2023, the mean was slightly higher at 0.56 ± 0.53 . The highest weekly captures never exceeded 1.00 adult/trap/week in either year. No clear alignment was observed between adult trap catches and peaks in larval numbers or leaf damage, likely due to FAW's migratory behavior post-oviposition.
- ❖ Detailed weekly monitoring showed the rapid population build-up between 26th-28th SMW in both years. Declining incidence from 29th SMW onwards as maize matured and weather conditions changed. High temperatures in late July favored pest proliferation; higher humidity in August likely contributed to declines. Weekly temperature variation was narrower in 2023, which may explain slightly lower peaks in leaf damage and larval counts compared to 2022.
- ❖ The study used young maize leaves (BIO-9637 Maharaja) as a natural diet and examined all life stages, recording durations, morphometrics and weights, with statistical comparisons.
- ❖ Eggs were laid in clusters of 1–2 layers, dome-shaped, and covered with greyish-white body scales. Initially creamy-yellow, they darkened to brown and finally black prior to hatching. Mean incubation periods during 2022 was 1.89 ± 0.14 days (2022) and 1.93 ± 0.15 days (range 1–3) during 2023.

- ❖ The larval period consisted of six distinct instars, with a pooled mean total duration of 17.42 ± 0.32 days (17.38 ± 0.31 in 2022; 17.46 ± 0.34 in 2023).
- ❖ First Instars had Duration of 2.75 ± 0.15 days (2022) and 2.80 ± 0.15 days (2023). Length was 1.63 mm and head capsule width was 0.345 mm.
- ❖ Second Instars had Duration of 2.73 ± 0.09 days during 2022 and 2023. Length was 3.16 mm and weight was 0.0400 g.
- ❖ Third instars lasted around 2.63 ± 0.13 days (2022) and 2.64 ± 0.12 days (2023). Length was 6.50 mm and weight was 0.0461 g.
- ❖ The pooled data showed the fourth, fifth, sixth instars and pupal stage of *S. frugiperda* were 2.32 ± 0.17 , 2.9 ± 0.08 , 4.20 ± 0.23 and 7.43 ± 0.14 days, respectively. The length of fourth, fifth and sixth instar and pupal stages were 4.95, 15.99, 31.38 and 14.77 mm, respectively.
- ❖ Adults emerged with distinct sexual dimorphism where males had brownish-grey forewings with triangular white spot near center, hindwings were white with dark border. Females had duller forewing markings. Oviposition period lasted for 4.15 ± 0.54 days).
- ❖ Adult males lasted around 8.85 days and females about 9.15 days. Total life cycle duration (egg to adult death) of males were 35.29 days and 36.30 days for females.
- ❖ In controlled laboratory conditions, significant differences were observed among treatments. After 24 hours, the highest mortality was achieved with Emamectin benzoate 5% SG (83.33%), followed by Chlorantraniliprole (75.00%) and combinations involving these insecticides with entomopathogenic fungi. Mortality steadily increased with time, and by 72 hours both Emamectin benzoate 5% SG and Chlorantraniliprole achieved 100% mortality. By 96 hours, combinations such as *B. bassiana* + Emamectin benzoate and *M. anisopliae* + Emamectin benzoate 5% SG also caused complete larval mortality. Single fungal applications were less effective, though combinations generally outperformed fungi alone.
- ❖ Field experiments in both years revealed that Emamectin benzoate 5% SG consistently achieved the greatest reduction in leaf damage with 82.50% during 2022 and 78.67% during 2023, followed by *Metarhizium anisopliae* +

Emamectin benzoate 5% SG and Chlorantraniliprole. Fungal treatments alone provided the least reduction. Pooled analysis confirmed Emamectin benzoate 5% SG (80.59 %) as most effective overall, with *M. anisopliae* + Emamectin benzoate 5% SG (68.50 %) and Chlorantraniliprole (59.15 %) as strong alternatives.

- ❖ Regarding larval population, Emamectin benzoate again outperformed other treatments, reducing larval numbers by 71.45 per cent in 2022 and 77.39 per cent in 2023. Fungal combinations ranked moderately, while individual fungi were the least effective. The pooled analysis supported Emamectin benzoate 5% SG as the dominant treatment (77.39 % reduction).
- ❖ It can be concluded that that Emamectin benzoate 5% SG is the most effective insecticide against fall armyworm, achieving the highest mortality, greatest leaf protection, and largest larval population reductions. Chlorantraniliprole 18.5% SC performed reliably but slightly less effectively. Biological agents, while weaker on their own, enhanced control when combined with chemicals, particularly *M. anisopliae* + Emamectin benzoate 5% SG, which consistently ranked just below Emamectin benzoate 5% SG.

Conclusions:

Based on the present studies, the following conclusions have been drawn from the findings given above

1. FAW infestation began early (14-20 DAS), peaking around the 27th –28th SMW with more than 80 per cent leaf damage, confirming its destructive potential in maize. Both leaf damage and larval population were positively correlated with maximum and minimum temperatures, highlighting the pest's preference for warmer conditions. Pest incidence declined after 29th SMW as maize matured and weather conditions shifted, suggesting crop stage and environmental factors jointly regulate pest dynamics.
2. Minimum relative humidity showed a significant negative correlation with FAW incidence, suggesting dry air conditions favor infestation. FAW incidence in maize is strongly temperature-dependent, with humidity exerting

a significant negative effect, and rainfall having minimal influence. Management strategies should be proactive during periods of high temperature and low humidity, with interventions timed within the short window between pest establishment and peak damage.

3. The complete life cycle of FAW (egg to adult death) lasted about 35–36 days, showing it can complete multiple generations within one cropping season. Eggs were laid in protective clusters, ensuring high survival, while six distinct larval instars were observed with clear morphological markers. The larval stage was the longest and most destructive, averaging 17.4 days, confirming its role as the major damaging phase. Pupal duration was relatively short (7.4 days), with distinct sexual dimorphism evident in adult moths. Adult longevity averaged 8–9 days, with females surviving slightly longer, supporting their ability to oviposit extensively.
4. The length of first, second, third, fourth, fifth and sixth instar were 1.63, 3.16, 6.50, 9.45, 15.99 and 31.38 mm, respectively. Male and female pupae were 14.77 and 15.05 long, respectively. Width of the head capsule of first, second, third, fourth, fifth and sixth instar were 0.345, 0.471, 0.780, 1.501, 2.157 and 2.70 mm.
5. Emamectin benzoate 5% SG was the most effective treatment, achieving 100% mortality under lab conditions and more than 80% field reduction in leaf damage. Chlorantraniliprole 18.5% SC was the next best, though slightly less effective than Emamectin benzoate. Over two seasons, Emamectin benzoate 5% SG consistently provided the highest FAW control. Fungal bio-agents (*Beauveria bassiana*, *Metarhizium anisopliae*) alone were less effective but contributed significantly when combined with chemical insecticides. In field condition, the combination of *M. anisopliae* + Emamectin benzoate 5% SG consistently ranked second to Emamectin benzoate alone, proving synergistic effects. Hence, integrated approaches using both entomopathogenic fungi and selective insecticides offer a sustainable management option for FAW.

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APPENDICES

APPENDICES

ANOVA I(A)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022 and 2023

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.36	0.18	0.33	3.63	NS
Treatment	8	16927.62	2115.95	3825.24	2.59	Significant
Error	16	8.85	0.55			
Total	26	16936.83				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	7.48	3.74	1.19	3.63	NS
Treatment	8	16052.36	2006.54	639.43	2.59	Significant
Error	16	50.21	3.14			
Total	26	16110.05				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	3.88	3.88	2.10	4.15	NS
Replication	4	7.84	1.96	1.06	2.67	NS
Treatment	16	32979.98	2061.25	1116.85	1.97	Significant
Error	32	59.06	1.85			
Total	53	33050.76				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	3.88	3.88	2.10	4.15	NS
Replication	4	7.84	1.96	1.06	2.67	NS
Treatment	8	32071.85	4008.98	2172.19	2.24	Significant
Years x Treatment	8	908.13	113.52	61.51	2.24	Significant
Error	32	59.06	1.85			
Total	53	33050.76				

ANOVA I(B)

Incidence of fall armyworm as number of larvae in relation to abiotic factors during kharif season, 2022 and 2023

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.16	0.08	0.73	3.63	NS
Treatment	8	1319.33	164.92	1528.64	2.59	Significant
Error	16	1.73	0.11			
Total	26	1321.21				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.11	0.06	0.49	3.63	NS
Treatment	8	950.13	118.77	1020.42	2.59	Significant
Error	16	1.86	0.12			
Total	26	952.10				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	1.29	1.29	11.49	4.15	Significant
Replication	4	0.27	0.07	0.60	2.67	NS
Treatment	16	2269.45	141.84	1264.89	1.97	Significant
Error	32	3.59	0.11			
Total	53	2274.60				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	1.29	1.29	11.49	4.15	Significant
Replication	4	0.27	0.07	0.60	2.67	NS
Treatment	8	2096.30	262.04	2336.76	2.24	Significant
Years x Treatment	8	173.16	21.64	193.02	2.24	Significant
Error	32	3.59	0.11			
Total	53	2274.60				

ANOVA II (A)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (Pre infestation)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	7.18	3.59	0.39	3.55	NS
Treatment	9	27.21	3.02	0.33	2.46	NS
Error	18	166.67	9.26			
Total	29	201.06				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	18.52	9.26	2.44	3.55	NS
Treatment	9	48.37	5.37	1.41	2.46	NS
Error	18	68.41	3.80			
Total	29	135.30				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	6.05	6.05	0.93	4.11	NS
Replication	4	25.70	6.42	0.98	2.63	NS
Treatment	18	75.59	4.20	0.64	1.90	NS
Error	36	235.07	6.53			
Total	59	342.40				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	6.05	6.05	0.93	4.11	NS
Replication	4	25.70	6.42	0.98	2.63	NS
Treatment	9	57.07	6.34	0.97	2.15	NS
Years x Treatment	9	18.52	2.06	0.32	2.15	NS
Error	36	235.07	6.53			
Total	59	342.40				

ANOVA II (B)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (7 days after 1st spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	25.37	12.68	3.11	3.55	NS
Treatment	9	2678.58	297.62	73.02	2.46	Significant
Error	18	73.37	4.08			
Total	29	2777.31				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	3.34	1.67	1.89	3.55	NS
Treatment	9	2568.45	285.38	322.99	2.46	Significant
Error	18	15.90	0.88			
Total	29	2587.70				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.58	0.58	0.23	4.11	NS
Replication	4	28.71	7.18	2.89	2.63	Significant
Treatment	18	5247.03	291.50	117.55	1.90	Significant
Error	36	89.27	2.48			
Total	59	5365.59				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.58	0.58	0.23	4.11	NS
Replication	4	28.71	7.18	2.89	2.63	Significant
Treatment	9	5237.43	581.94	234.67	2.15	Significant
Years x Treatment	9	9.60	1.07	0.43	2.15	NS
Error	36	89.27	2.48			
Total	59	5365.59				

ANOVA II (C)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (10 days after 1st spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	34.84	17.42	4.48	3.55	Significant
Treatment	9	2696.68	299.63	77.07	2.46	Significant
Error	18	69.98	3.89			
Total	29	2801.50				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	4.79	2.39	2.91	3.55	NS
Treatment	9	2576.85	286.32	347.52	2.46	Significant
Error	18	14.83	0.82			
Total	29	2596.47				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.28	0.28	0.12	4.11	NS
Replication	4	39.62	9.91	4.20	2.63	Significant
Treatment	18	5273.53	292.97	124.36	1.90	Significant
Error	36	84.81	2.36			
Total	59	5398.25				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.28	0.28	0.12	4.11	NS
Replication	4	39.62	9.91	4.20	2.63	Significant
Treatment	9	5263.46	584.83	248.24	2.15	Significant
Years x Treatment	9	10.07	1.12	0.48	2.15	NS
Error	36	84.81	2.36			
Total	59	5398.25				

ANOVA II (D)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (15 days after 1st spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	2.43	1.21	0.11	3.55	NS
Treatment	9	2292.16	254.68	22.74	2.46	Significant
Error	18	201.58	11.20			
Total	29	2496.16				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	4.47	2.24	0.98	3.55	NS
Treatment	9	2153.07	239.23	104.85	2.46	Significant
Error	18	41.07	2.28			
Total	29	2198.61				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.22	2.22	0.33	4.11	NS
Replication	4	6.90	1.72	0.26	2.63	NS
Treatment	18	4445.23	246.96	36.64	1.90	Significant
Error	36	242.65	6.74			
Total	59	4696.99				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.22	2.22	0.33	4.11	NS
Replication	4	6.90	1.72	0.26	2.63	NS
Treatment	9	4437.38	493.04	73.15	2.15	Significant
Years x Treatment	9	7.85	0.87	0.13	2.15	NS
Error	36	242.65	6.74			
Total	59	4696.99				

ANOVA III (A)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (Pre infestation)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	17.49	8.75	4.81	3.55	Significant
Treatment	9	2262.06	251.34	138.22	2.46	Significant
Error	18	32.73	1.82			
Total	29	2312.29				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	4.47	2.24	0.98	3.55	NS
Treatment	9	2153.07	239.23	104.85	2.46	Significant
Error	18	41.07	2.28			
Total	29	2198.61				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.36	2.36	1.15	4.11	NS
Replication	4	21.97	5.49	2.68	2.63	Significant
Treatment	18	4415.13	245.29	119.65	1.90	Significant
Error	36	73.80	2.05			
Total	59	4513.26				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.36	2.36	1.15	4.11	NS
Replication	4	21.97	5.49	2.68	2.63	Significant
Treatment	9	4407.55	489.73	238.89	2.15	Significant
Years x Treatment	9	7.58	0.84	0.41	2.15	NS
Error	36	73.80	2.05			
Total	59	4513.26				

ANOVA III (B)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (7 days after 2nd spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	9.37	4.68	1.51	3.55	NS
Treatment	9	3662.63	406.96	130.87	2.46	Significant
Error	18	55.98	3.11			
Total	29	3727.97				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.28	0.14	0.04	3.55	NS
Treatment	9	3532.85	392.54	117.02	2.46	Significant
Error	18	60.38	3.35			
Total	29	3593.51				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.36	2.36	0.73	4.11	NS
Replication	4	9.64	2.41	0.75	2.63	NS
Treatment	18	7195.48	399.75	123.68	1.90	Significant
Error	36	116.36	3.23			
Total	59	7323.84				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.36	2.36	0.73	4.11	NS
Replication	4	9.64	2.41	0.75	2.63	NS
Treatment	9	7187.90	798.66	247.10	2.15	Significant
Years x Treatment	9	7.58	0.84	0.26	2.15	NS
Error	36	116.36	3.23			
Total	59	7323.84				

ANOVA III (C)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (10 days after 2nd spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	12.57	6.28	1.95	3.55	NS
Treatment	9	3721.58	413.51	128.12	2.46	Significant
Error	18	58.09	3.23			
Total	29	3792.25				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.39	0.20	0.06	3.55	NS
Treatment	9	3578.41	397.60	127.50	2.46	Significant
Error	18	56.13	3.12			
Total	29	3634.93				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	3.85	3.85	1.21	4.11	NS
Replication	4	12.96	3.24	1.02	2.63	NS
Treatment	18	7299.99	405.55	127.82	1.90	Significant
Error	36	114.22	3.17			
Total	59	7431.02				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	3.85	3.85	1.21	4.11	NS
Replication	4	12.96	3.24	1.02	2.63	NS
Treatment	9	7293.61	810.40	255.41	2.15	Significant
Years x Treatment	9	6.38	0.71	0.22	2.15	NS
Error	36	114.22	3.17			
Total	59	7431.02				

ANOVA III (D)

Incidence of fall armyworm as per cent leaf damage in relation to abiotic factors during kharif season, 2022-2023 (15 days after 2nd spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	9.37	4.68	1.51	3.55	NS
Treatment	9	3662.63	406.96	130.87	2.46	Significant
Error	18	55.98	3.11			
Total	29	3727.97				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.28	0.14	0.04	3.55	NS
Treatment	9	3532.85	392.54	117.02	2.46	Significant
Error	18	60.38	3.35			
Total	29	3593.51				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.36	2.36	0.73	4.11	NS
Replication	4	9.64	2.41	0.75	2.63	NS
Treatment	18	7195.48	399.75	123.68	1.90	Significant
Error	36	116.36	3.23			
Total	59	7323.84				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.36	2.36	0.73	4.11	NS
Replication	4	9.64	2.41	0.75	2.63	NS
Treatment	9	7187.90	798.66	247.10	2.15	Significant
Years x Treatment	9	7.58	0.84	0.26	2.15	NS
Error	36	116.36	3.23			
Total	59	7323.84				

ANOVA IV (A)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (Pre count)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.01	0.00	0.54	3.55	NS
Treatment	9	0.05	0.01	1.10	2.46	NS
Error	18	0.09	0.01			
Total	29	0.15				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.23	0.11	3.00	3.55	NS
Treatment	9	0.27	0.03	0.80	2.46	NS
Error	18	0.69	0.04			
Total	29	1.19				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.05	2.05	94.48	4.11	Significant
Replication	4	0.23	0.06	2.71	2.63	Significant
Treatment	18	0.33	0.02	0.84	1.90	NS
Error	36	0.78	0.02			
Total	59	3.39				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.05	2.05	94.48	4.11	Significant
Replication	4	0.23	0.06	2.71	2.63	Significant
Treatment	9	0.19	0.02	0.98	2.15	NS
Years x Treatment	9	0.14	0.02	0.69	2.15	NS
Error	36	0.78	0.02			
Total	59	3.39				

ANOVA IV (B)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (7 days after 1st spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.21	0.10	1.14	3.55	NS
Treatment	9	21.10	2.34	25.94	2.46	Significant
Error	18	1.63	0.09			
Total	29	22.93				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.03	0.02	0.07	3.55	NS
Treatment	9	19.11	2.12	9.68	2.46	Significant
Error	18	3.95	0.22			
Total	29	23.09				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.01	0.01	0.05	4.11	NS
Replication	4	0.24	0.06	0.38	2.63	NS
Treatment	18	40.21	2.23	14.42	1.90	Significant
Error	36	5.58	0.15			
Total	59	46.03				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.01	0.01	0.05	4.11	NS
Replication	4	0.24	0.06	0.38	2.63	NS
Treatment	9	39.12	4.35	28.07	2.15	Significant
Years x Treatment	9	1.08	0.12	0.78	2.15	NS
Error	36	5.58	0.15			
Total	59	46.03				

ANOVA IV (C)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (10 days after 1st spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.29	0.15	0.73	3.55	NS
Treatment	9	19.89	2.21	11.06	2.46	Significant
Error	18	3.60	0.20			
Total	29	23.78				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.57	0.29	2.35	3.55	NS
Treatment	9	17.03	1.89	15.57	2.46	Significant
Error	18	2.19	0.12			
Total	29	19.79				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.00	0.00	0.00	4.11	NS
Replication	4	0.87	0.22	1.35	2.63	NS
Treatment	18	36.92	2.05	12.77	1.90	Significant
Error	36	5.78	0.16			
Total	59	43.57				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.00	0.00	0.00	4.11	NS
Replication	4	0.87	0.22	1.35	2.63	NS
Treatment	9	35.89	3.99	24.82	2.15	Significant
Years x Treatment	9	1.03	0.11	0.71	2.15	NS
Error	36	5.78	0.16			
Total	59	43.57				

ANOVA IV (D)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (15 days after 1st spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.67	0.33	0.71	3.55	NS
Treatment	9	84.58	9.40	20.00	2.46	Significant
Error	18	8.46	0.47			
Total	29	93.71				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	2.07	1.04	2.06	3.55	NS
Treatment	9	62.21	6.91	13.75	2.46	Significant
Error	18	9.05	0.50			
Total	29	73.34				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.44	0.44	0.90	4.11	NS
Replication	4	2.74	0.69	1.41	2.63	NS
Treatment	18	146.79	8.16	16.77	1.90	Significant
Error	36	17.51	0.49			
Total	59	167.48				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.44	0.44	0.90	4.11	NS
Replication	4	2.74	0.69	1.41	2.63	NS
Treatment	9	144.62	16.07	33.04	2.15	Significant
Years x Treatment	9	2.18	0.24	0.50	2.15	NS
Error	36	17.51	0.49			
Total	59	167.48				

ANOVA V (A)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (Pre count)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.67	0.33	0.71	3.55	NS
Treatment	9	84.58	9.40	20.00	2.46	Significant
Error	18	8.46	0.47			
Total	29	93.71				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.36	0.18	0.39	3.55	NS
Treatment	9	82.51	9.17	19.41	2.46	Significant
Error	18	8.50	0.47			
Total	29	91.37				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.03	0.03	0.06	4.11	NS
Replication	4	1.03	0.26	0.55	2.63	NS
Treatment	18	167.09	9.28	19.70	1.90	Significant
Error	36	16.96	0.47			
Total	59	185.11				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	0.03	0.03	0.06	4.11	NS
Replication	4	1.03	0.26	0.55	2.63	NS
Treatment	9	166.98	18.55	39.38	2.15	Significant
Years x Treatment	9	0.10	0.01	0.02	2.15	NS
Error	36	16.96	0.47			
Total	59	185.11				

ANOVA V (B)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (7 days after 2nd spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.54	0.27	0.31	3.55	NS
Treatment	9	206.73	22.97	26.35	2.46	Significant
Error	18	15.69	0.87			
Total	29	222.96				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.27	0.14	0.15	3.55	NS
Treatment	9	220.09	24.45	27.04	2.46	Significant
Error	18	16.28	0.90			
Total	29	236.64				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.03	2.03	2.28	4.11	NS
Replication	4	0.81	0.20	0.23	2.63	NS
Treatment	18	426.82	23.71	26.70	1.90	Significant
Error	36	31.97	0.89			
Total	59	461.63				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.03	2.03	2.28	4.11	NS
Replication	4	0.81	0.20	0.23	2.63	NS
Treatment	9	426.60	47.40	53.37	2.15	Significant
Years x Treatment	9	0.22	0.02	0.03	2.15	NS
Error	36	31.97	0.89			
Total	59	461.63				

ANOVA V (C)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (10 days after 2nd spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	3.33	1.66	1.56	3.55	NS
Treatment	9	188.13	20.90	19.59	2.46	Significant
Error	18	19.21	1.07			
Total	29	210.66				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.15	0.08	0.06	3.55	NS
Treatment	9	225.35	25.04	21.15	2.46	Significant
Error	18	21.31	1.18			
Total	29	246.82				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	8.52	8.52	7.57	4.11	Significant
Replication	4	3.48	0.87	0.77	2.63	NS
Treatment	18	413.48	22.97	20.41	1.90	Significant
Error	36	40.52	1.13			
Total	59	466.00				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	8.52	8.52	7.57	4.11	Significant
Replication	4	3.48	0.87	0.77	2.63	NS
Treatment	9	410.56	45.62	40.53	2.15	Significant
Years x Treatment	9	2.93	0.33	0.29	2.15	NS
Error	36	40.52	1.13			
Total	59	466.00				

ANOVA V (D)

Efficacy of different treatments against larval stage of *S. frugiperda* during *Kharif* season, 2022 and 2023 (15 days after 2nd spray)

<i>ANOVA Table of first year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	0.74	0.37	0.22	3.55	NS
Treatment	9	373.17	41.46	25.02	2.46	Significant
Error	18	29.83	1.66			
Total	29	403.73				

<i>ANOVA Table of second year</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Replication	2	3.79	1.89	26.83	3.55	Significant
Treatment	9	413.26	45.92	650.88	2.46	Significant
Error	18	1.27	0.07			
Total	29	418.31				

<i>ANOVA Table of Pooled</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.82	2.82	3.27	4.11	NS
Replication	4	4.53	1.13	1.31	2.63	NS
Treatment	18	786.42	43.69	50.58	1.90	Significant
Error	36	31.10	0.86			
Total	59	824.87				

<i>ANOVA Table of Pooled Final</i>						
<i>Source of Variance</i>	<i>Degree of Freedom</i>	<i>Sum of Square</i>	<i>Mean Sum of Square</i>	<i>F Cal</i>	<i>F Tab at 5%</i>	<i>S/NS</i>
Years	1	2.82	2.82	3.27	4.11	NS
Replication	4	4.53	1.13	1.31	2.63	NS
Treatment	9	780.03	86.67	100.33	2.15	Significant
Years x Treatment	9	6.39	0.71	0.82	2.15	NS
Error	36	31.10	0.86			
Total	59	824.87				