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# Pest Complex and *In Vivo* Evaluation of the Synergistic Effect of Compatible Insecticides and *Metarhizium anisopliae* for Managing Fall Armyworm in Maize

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ABSTRACT

Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat and it is grown globally. It is also known as ‘queen of cereals’ because of its higher genetic yield potential among the cereals. Insect pest and diseases cause an economic loss to the tune of 13.2 %. Among the insect pests, Fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) due to its polyphagous nature accounts for 70 % yield reduction in maize. In the present investigation, the compatibility of chemical insecticides with entomopathogen *Metarhizium anisopliae* was evaluated in field conditions for managing fall armyworm (FAW). A total of twenty three arthropod species were observed in maize ecosystem, of which 8 species of insect pest, 13 natural enemies (10 predators and 3 spiders) and two species beneficial insects were identified from maize ecosystem. *In vivo* evaluation of synergistic effect of compatible insecticides with *M. anisopliae* sprayed in the whorl and soil for managing FAW revealed that per cent reduction in FAW population over control was highest in Emamectin benzoate (LD) @ 0.4 g/L (56.31 %) followed by Emamectin benzoate (SLD) @ 0.2 g/L + *M. anisopliae* (52.52 %). The corrected mortality percentage of FAW was recorded highest (46.42 %) in Emamectin benzoate (LD) @ 0.4 g/L followed by Emamectin benzoate (SLD) @ 0.2 g/L + *M. anisopliae* (39.21 %). This study concluded that the combined application of four different chemical insecticides with entomopathogen at sub-lethal doses in field conditions showed that *M. anisopliae* is compatible with Emamectin benzoate and was effective in controlling FAW.

## 1. Introduction

In maize, FAW mainly attacks on all the stages of the plant from seedling to tasseling and earing by causing defoliation and killing young plant, results in grain damage and subsequently reduce quantity and quality of yield. Neonate larvae mainly feed on leaf tissues whereas the second and third instars feed on the leaf making holes in leaves, typical damage symptoms of FAW.

During May-June 2018, FAW was first time reported in maize crop in Shivamogga district of Karnataka, India. In 2019, FAW was reported in 20 different states *viz*., Karnataka, Tamil Nadu, Telangana, Andhra Pradesh, Maharashtra, Gujarat, Madhya Pradesh, Rajasthan, Bihar, Jharkhand, Chhattisgarh, West Bengal, Uttar Pradesh, Sikkim, Meghalaya, Assam, Manipur, Tripura, Arunachal Pradesh and Mizoram. *S. furgiperda* is a serious notorious pestiferous insect of corn but it is also known for the attack of more than 100 different hosts. This pest could result in maize yield reduction up to 70 % (Ayala *et al*., 2013; Hruska, 2019).

For the management of the FAW, farmers are using different management practices *viz*., cultural, mechanical, biological and chemical. Application of insecticide in combination or separately with entomogenous fungi may effect on growth, sporulation and germination. Thus it is most important to test the compatibility of

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insecticides with entomogenous fungi, conidial survival can be effected by interaction with agrochemicals, environmental factors, biopesticides and chemical products used to protect plants. Use of several insecticides may cause environmental hazards, effects natural enemies, health risks and also develop resistance to the insect pests. Using entomopathogen and different chemical insecticides against FAW provides eco-friendly, safe and long-lasting insect control. FAW larvae are susceptible to entomopathogenic micro-organisms *viz*., fungi, bacteria, viruses, nematodes and protozoa (Molina-Ochoa *et al*., 2003; Rios-Velasco *et al*., 2010).

*Metarhizium anisopliae* is an entomopathogenic fungus. It was first named as *Entomphthora anisopliae* and used against insects in 1879, while Elie Metchnikoff used this microbial agent to control wheat grain beetle. Later on, it was renamed as *M. anisopliae* by Sorokin in 1883. It is also used as biological control agents of insects including gregarious insect pests. Using this entomopathogen against FAW leads to the mycelium formation inside the insect body and kills the insect after a few days and forms white mold in the body resulting into a green colour cadaver. It is also used as a biological control agent against insects including gregarious insect pests.

Entomopathogenic fungi are commonly perceived as having a slower impact, necessitating more time compared to traditional methods to achieve effective insect control. To tackle this concern, a potential solution could involve integrating these fungi (EPF) into a management plan alongside quicker-acting substances. The combination of mycoinsecticides with chemical insecticides has been observed to produce a synergistic effect, elevating insect mortality rates and hastening the time until death (Bitsadze et al., 2013; Shariffard et al., 2011). Additionally, the inclusion of synergists into insecticides has the potential to notably enhance cost-efficiency and environmental friendliness by reducing the necessary quantity of agents and prolonging their effectiveness. This strategy presents an alternate approach to combating resistance by targeting pests through a distinct mechanism.

Nonetheless, there exists a lack of comprehensive information concerning the harmonious interaction between EPF and insecticides, and the appraisal of amalgamations of synthetic insecticides with mycoinsecticides against fall armyworm is insufficient. As a result, the current investigation seeks to appraise the concordance between various insecticides and *M. anisopliae*, as well as to ascertain their lethal effects on fall armyworm.

## 2. Materials and methods

The present study was carried out under Department of Entomology, School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, CAU (Imphal), Umiam, Meghalaya during the year 2021-22 in an uniform sized plots of 2.0 m × 1.5 m in Randomized Block Design (RBD) with seven treatments and four replications. Maize variety "Megha maize -1" was grown in the prepared field with row to row and plant to plant spacing of 60 cm × 20 cm, respectively. The treatment combinations, *viz.* Control, Emamectin benzoate 5% SG + *Metarhizium anisopliae*, Chlorantraniliprole 18.5% SC + *M. anisopliae*, Deltamethrin 2.8% EC + *M. anisopliae*, Chlorpyriphos 20% EC + *M. anisopliae,* Emamectin benzoate 5% SG and *M. anisopliae* was taken against *S. frugiperda.*

Regular surveys were conducted on a weekly basis to document and collect information about the insect population throughout the growth stages of maize. The focus was on identifying insect pests based on the extent of damage and infestation, natural enemies through parasitism and predation, and observing and collecting pollinators concurrently. Insects were gathered using methods like manual collection, insect sweep nets, and aspirators. The identification of collected insects was performed using established taxonomic keys and relevant literature concerning the pest complex affecting maize crops.

UmMet is the liquid biopesticide procured from CPGS-AS biopesticide production unit having spore count of $4.7\times10^8$ cfu/gm. Compatibility of various insecticides with *M. anisopliae* was studied by using with standard food technique (Nene and Thapliyal, 1993). *Metarhizium* fungal broth is prepared by growing *M. anisopliae* species in a liquid medium, typically Sabouraud dextrose broth, under controlled conditions of temperature and agitation for a specified period (7-10 days). The resulting fungal broth is then harvested, filtered to remove mycelial fragments, and the concentration is adjusted as needed for application (St Leger *et al.,* 1999). The ratio of fungal broth and insecticide mixtures is 1:1. The first spray was applied at appearance of *S. frugiperda* and the two subsequent sprays were given at an interval of 30 days interval. The observations per cent plant infestation was recorded on 1 day before, 1, 7, 14, 21 and 28 days after each spray. Corrected mortality per cent was recorded at both sprays. The per cent plant infestation was worked out as:

$$\text{Per cent plant infestation}=\left(\frac{\text{No. of infested plants}}{\text{Total no. of plants in field}}\right) \times 100$$

Corrected mortality percentage was calculated by the formulae of Abbott, 1925

$$\text{Corrected mortality percentage (\%)} = [\frac{(\text{Po-Pc})}{(\text{100-Pc})} \times 100$$

Where, Po – Percentage mortality in treatment
Pc – Percentage mortality in control

The statistical analysis of the field experiments involved the utilization of a Two-way Analysis of Variance (ANOVA) with a Randomized Complete Block Design (RCBD). Dunken Multiple Range Test (DMRT) was applied to compare different treatments for their efficacy against fall armyworm. (Duncan, 1951) at a significance level of P < 0.05. The analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 22.0.

## 3. Results

### 3.1 Diversity of insect fauna, non insects and observed in maize ecosystem

Twenty-three arthropod species were observed in maize ecosystem, 8 species of insect pest, 13 natural enemies (in that 10 are predators and 3 are spiders) and two species beneficial insects were identified from maize ecosystem (table 1,2,3,4 and 5). Insect species *viz.,* Aphid (*Rhopalosiphum maidis*), White grub (*Leucopholis sumatrensis*), Termites (*Odontotermes obesus*), Flea beetle (*Monolepta signata*), Gypsy moth (*Lymantria dispar*), Pale striped flea beetle (*Systena blanda*) and Long legged Katydids (*Mecopoda nipponensis*) were recorded.

Predators *viz.*, *Coelophora inaequalis*, *Oenopia kirbyi*, *Epilachna* sp, *Harmonia axyridis*, *Coccinella transversalis*, *Oenopia sexareata, Zelus luridus*, *Anisolabis maritime*, *Crocothemis servilia* and *Blattella asahinai* were recorded.

Natural enemies (spiders) *viz*., Striped lynx spider (*Oxyopes salticus*), Orb-weaver spiders (*Lariniodes cornutus*) and Black ant mimic jumping spider (*Mymarachne* spp) were also recorded.

Among the insect pest species, Fall armyworm *S.frugiperda*, was observed as the most destructive pest in maize crop. Larval stage was recorded as the most damaging stage. Larval instars were found on leaf, leaf sheath, whorl, tassels, cobs *i.e*., from seedling stage to till maturity stage. Incidence range of FAW was up to 47 %, therefore highest infestation was recorded due to high relative humidity (91.69 %) and minimum temperature (19.07 °C).

### 3.2 Synergistic effect of UmMet and compatible insecticides on fall armyworm of maize

The efficacy of UmMet and compatible insecticides on the population of fall armyworm (*Spodoptera frugiperda*) was recorded at 1st, 7th, 14th, 21st and 28th day after sprayings. The pre-treatment FAW population were non-significant and ranged from 0.61 to 0.94 FAW/plant and 0.42 to 0.9 in both the spraying, respectively (table 8).

**First spray**

At 1st day the treatments were significant; the least count of fall armyworm population was found in Emamectin benzoate @ 0.4 g/L (0.54±0.28), followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.59±0.24). The highest population of FAW was found in control (0.93±0.03). At 7th DAS, Emamectin benzoate @ 0.4 g/L (0.42±0.26) reduced the number of pest population and was significantly superior over control, followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.46±0.17). At 14th DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.35±0.18) and followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.37±0.12). At 21th DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.40±0.12) and followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.48±0.07). At 28th DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.47±0.11) and followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.52±0.06).

**Second spray**

At 1st DAS, the least count of FAW population was found in Emamectin benzoate @ 0.4 g/L (0.42±0.10), followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.51±0.08). At 7th DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.32±0.09) followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.39±0.09). At 14th DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.26±0.05) and followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.3±0.03). At 21st DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.38±0.02) and followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.34±0.09). At 28th DAS, Emamectin benzoate @ 0.4 g/L reduced the number of pest population (0.41±0.02) and followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (0.42±0.09).

The treatments with only chemical insecticides and UmMet combination with chemical insecticides were successful in substantial reduction of FAW population as superior over control.

### 3.3 Corrected per cent mortality of FAW on maize

Corrected per cent mortality of FAW on maize was calculated by Abbott's formula and represented in table 6. After first spray, the highest corrected mortality (32.54 %) for FAW was recorded from Emamectin benzoate @ 0.4 g/L followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (24.47 %) and Chlorantraniliprole @ 0.2 ml/L with *M. anisopliae* (22.1 %). After second spray, the highest corrected mortality (46.42 %) was observed in Emamectin benzoate @ 0.4 g/L, followed by Emamectin benzoate @ 0.2

g/L with *M. anisopliae* (39.21 %) and Chlorantraniliprole @ 0.2 ml/L with *M. anisopliae* (35.25 %).

### 3.4 Reduction of FAW population over control

After first spray, the highest FAW population reduction (45 %) was recorded from Emamectin benzoate @ 0.4 g/L which was followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (41.01 %) and Chlorantraniliprole @ 0.2 ml/L). with *M. anisopliae* (37.31 %). After second spray, the highest FAW population reduction (56.31 %) was observed in Emamectin benzoate @ 0.4 g/L, followed by Emamectin benzoate @ 0.2 g/L with *M. anisopliae* (52.52 %) and Chlorantraniliprole @ 0.2 ml/L with *M. anisopliae* (47.89 %), respectively (table. 7

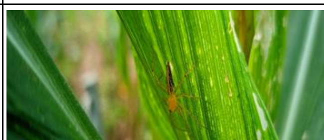
**Table 1.** Insect pests recorded in maize crop during experimentation

| Sl. No. | Commonname | Scientific name | Order:Family | Feedingsite | Images ofadult insects |
|---|---|---|---|---|---|
| 1. | Fall armyworm | *Spodoptera frugiperda* (J. E. Smith) | Lepidoptera: Noctuidae | Leaf, leaf sheath, whorl, foliage, silking and cob |  |
| 2. | Aphid | *Rhopalosiphum maidis* (Fitch) | Homoptera:Aphididae | Stem, tassel, leaf |  |
| 3. | White grub | *Leucopholis sumatrensis* (Blanchard) | Coleoptera: Melolonthidae | Corn root |  |
| 4. | Termites | *Odontotermes obesus* (Rambur) | Isoptera: Termitidae | Root, stem |  |
| 5. | Flea beetle | *Monolepta signata* (Motschulsky) | Coleoptera: Chrysomelidae | Leaf |  |
| 6. | Gypsy moth | *Lymantria dispar* (Linnaeus) | Lepidoptera: Noctuidae | Leaf |  |
| 7. | Pale striped flea beetle | *Systena blanda* (Melsheimer) | Coleoptera: Chrysomelidae | Leaf |  |
| 8. | Long legged katydids | *Mecopoda nipponensis* (Haan) | Orthoptera: Mecopodinae | Leaf, Flower |  |

**Table 2.** Natural enemies (Predators) recorded in maize crop during experimentation

| Sl. No. | Common name | ScientificName | Order:Family | Prey | Prey stage | Images of adult predator |
|---|---|---|---|---|---|---|
| 1. | Lady bird beetle | *Coelophora inaequalis* (Fabricius) | Coleoptera: Coccinellidae | *A. gossypii* | Nymph and adult |  |
| 2. | Lady bird beetle | *Oenopia kirbyi* (Mulsant) | Coleoptera: Coccinellidae | *A. gossypii* | Nymph and adult |  |
| 3. | Lady bird beetle | *Epilachna* sp | Coleoptera: Coccinellidae | *A. gossypii* | Nymph and adult |  |
| 4. | Lady bird beetle | *Harmonia axyridis* (Pallas) | Coleoptera: Coccinellidae | *A. gossypii* | Nymph and adult |  |
| 5. | Lady bird beetle | *Coccinella transversalis* (Fabricus) | Coleoptera: Coccinellidae | *A. gossypii* | Nymph and adult |  |
| 6. | Lady bird beetle | *Oenopia sexareata* (Mulsant) | Coleoptera: Coccinellidae | *A. gossypii* | Nymph and adult |  |
| 7. | Assassin bug | *Zelus luridus* (Stal) | Hemiptera: Reduviidae | Small flies, wasps or sawflies | Nymph and adult |  |
| 8. | Earwig | *Anisolabis maritima* (Bonelli) | Dermaptera: Anisolabididae | *S. frugiperda* | Egg |  |
| 9. | Dragonfly | *Crocothemis servilia* (Drury) | Odonata: Chrysomelidae | Mosquito larvae | Larvae |  |
| 10. | Asian cockroach | *Blattella asahinai* (Mizukubo) | Blattodae: Ectobiidae | *Helicoverpa armigera, S. litura* | Larvae |  |

**Table 3.** Natural enemies (Spiders) recorded in maize crop during experimentation

| Sl. No. | Commonname | ScientificName | Order:Family | Status of spiders | Images of Spiders |
|---|---|---|---|---|---|
| 1. | Striped lynxspider | *Oxyopes salticus* (Hentz) | Araneae: Oxyopidae | Major |  |
| 2. | Orb-weaver spiders | *Lariniodes cornutus* (Clerck) | Araneae: Araneoidae | Major |  |

| | | | | | |
|---|---|---|---|---|---|
| 3. | Black ant mimic jumping spider | *Mymarachne* spp | Araneae: Salticidae | Minor |  |

**Table 4.** Major beneficial insects recorded in maize crop during experimentation

| Sl. No. | Common name | Scientific Name | Order: Family | Status | Adult image |
|---|---|---|---|---|---|
| 1. | Honey bee | *Apis mellifera* (Linnaeus) | Hymenoptera:Apidae | Major |  |
| 2. | Hover fly | *Allograpta obliqua* (Say) | Diptera: Syrphidae | Minor |  |

**Table 5.** Diseases recorded in maize crop during experimentation

| Sl. No. | Common name | Causal organism | Status | Disease image |
|---|---|---|---|---|
| 1. | Anthracnose leaf blight | *Colletotrichum graminicola* | Major |  |
| 2. | Banded leaf and sheath blight | *Rhizoctonia solani* | Minor |  |
| 3. | Corn rust | *Puccinia sorghi* | Major |  |

**Table 6.** Observed and corrected per cent mortality recorded on FAW after first and second spray

| Treatments | | First spray | | Second spray | |
|---|---|---|---|---|---|
| | | Observed mortality (%) | Corrected mortality (%) | Observed mortality (%) | Corrected mortality (%) |
| $T_1$ | Control | 5.01 | 0 | 12.29 | 0 |
| $T_2$ | Emamectin benzoate @ 0.2 g/L (SLD) + *M. anisopliae* @ 10 ml/L | 28.26 | 24.47 | 46.68 | 39.21 |
| $T_3$ | Chlorantraniliprole @ 0.2 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | 26.01 | 22.10 | 43.21 | 35.25 |
| $T_4$ | Deltamethrin @ 0.5 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | 20.91 | 16.73 | 42.83 | 34.81 |
| $T_5$ | Chlorpyriphos @ 1.5 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | 20.12 | 15.90 | 42.35 | 34.05 |
| $T_6$ | Recommended insecticide (Emamectin benzoate @ 0.4 g/L) | 35.92 | 32.54 | 53.01 | 46.42 |
| $T_7$ | *M. anisopliae* @ 10 ml/L | 18.53 | 14.23 | 36.27 | 27.34 |

**Table 7.** Reduction of FAW population (%) over control after first and second spray

| Treatments | | Reduction over control (%) | |
|---|---|---|---|
| | | First spray | Second spray |
| $T_1$ | Control | 0 | 0 |
| $T_2$ | Emamectin benzoate @ 0.2 g/L (SLD) + *M. anisopliae* @ 10 ml/L | 41.01 | 52.52 |
| $T_3$ | Chlorantraniliprole @ 0.2 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | 37.31 | 47.89 |
| $T_4$ | Deltamethrin @ 0.5 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | 30.13 | 45.30 |
| $T_5$ | Chlorpyriphos @ 1.5 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | 28.33 | 43.98 |
| $T_6$ | Recommended insecticide (Emamectin benzoate @ 0.4 g/L) | 45 | 56.31 |
| $T_7$ | *M. anisopliae* @ 10 ml/L | 27.12 | 34.06 |

**Table 8.** Per cent incidence of FAW at first and second spray

| Treatments | | Per cent incidence of FAW (First spray) | | | | | | | Per cent incidence of FAW (Second spray) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 DBS | 1 DAS | 7 DAS | 14 DAS | 21 DAS | 28 DAS | Mean | 1 DBS | 7 DAS | 14 DAS | 21 DAS | 28 DAS | Mean |
| $T_1$ | Control | $0.94^{b}\pm0.04$ (5.58) | $0.93^{b}\pm0.03$ (5.55) | $0.91^{b}\pm0.04$ (5.48) | $0.88^{c}\pm0.04$ (5.39) | $0.82^{c}\pm0.02$ (5.21) | $0.89^{d}\pm0.04$ (5.42) | 0.9 | $0.9^{b}\pm0.07$ (5.44) | $0.86^{b}\pm0.06$ (5.32) | $0.81^{b}\pm0.01$ (5.17) | $0.79^{c}\pm0.01$ (5.11) | $0.78^{c}\pm0.11$ (5.08) | 0.83 |
| $T_2$ | Emamectin benzoate @ 0.2 g/L (SLD) + *M. anisopliae* @ 10 ml/L | $0.74^{a}\pm0.12$ (4.93) | $0.59^{a}\pm0.23$ (4.40) | $0.46^{a}\pm0.17$ (3.91) | $0.37^{ab}\pm0.12$ (3.52) | $0.48^{ab}\pm0.07$ (3.99) | $0.52^{ab}\pm0.06$ (4.16) | 0.53 | $0.51^{a}\pm0.08$ (4.09) | $0.39^{a}\pm0.09$ (3.59) | $0.3^{a}\pm0.03$ (3.13) | $0.34^{a}\pm0.09$ (3.37) | $0.42^{a}\pm0.09$ (3.72) | 0.39 |
| $T_3$ | Chlorantraniliprole @ 0.2 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | $0.76^{a}\pm0.15$ (5.00) | $0.60^{a}\pm0.07$ (4.45) | $0.50^{a}\pm0.17$ (4.06) | $0.44^{ab}\pm0.15$ (3.82) | $0.5^{ab}\pm0.14$ (4.05) | $0.57^{ab}\pm0.15$ (4.33) | 0.56 | $0.57^{a}\pm0.08$ (4.32) | $0.40^{a}\pm0.07$ (3.64) | $0.29^{a}\pm0.11$ (3.12) | $0.42^{ab}\pm0.08$ (3.74) | $0.46^{ab}\pm0.06$ (3.91) | 0.43 |
| $T_4$ | Deltamethrin @ 0.5 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | $0.79^{ab}\pm0.08$ (5.11) | $0.63^{a}\pm0.09$ (4.56) | $0.50^{a}\pm0.09$ (4.08) | $0.56^{ab}\pm0.03$ (4.31) | $0.61^{b}\pm0.10$ (4.47) | $0.66^{bc}\pm0.11$ (4.66) | 0.63 | $0.56^{a}\pm0.12$ (4.29) | $0.49^{a}\pm0.10$ (4.03) | $0.32^{a}\pm0.09$ (3.25) | $0.42^{ab}\pm0.15$ (3.72) | $0.47^{ab}\pm0.1$ (3.94) | 0.45 |
| $T_5$ | Chlorpyriphos @ 1.5 ml/L (SLD) + *M. anisopliae* @ 10 ml/L | $0.80^{ab}\pm0.11$ (5.15) | $0.66^{ab}\pm0.19$ (4.68) | $0.54^{a}\pm0.20$ (4.23) | $0.57^{b}\pm0.09$ (4.35) | $0.61^{b}\pm0.05$ (4.48) | $0.66^{bc}\pm0.06$ (4.65) | 0.64 | $0.60^{a}\pm0.06$ (4.47) | $0.5^{a}\pm0.05$ (4.05) | $0.35^{a}\pm0.1$ (3.39) | $0.40^{ab}\pm0.005$ (3.63) | $0.46^{ab}\pm0.01$ (3.92) | 0.46 |
| $T_6$ | Recommended insecticide (Emamectin benzoate @ 0.4 g/L) | $0.77^{ab}\pm0.14$ (5.04) | $0.54^{a}\pm0.28$ (4.23) | $0.42^{a}\pm0.26$ (3.72) | $0.35^{ab}\pm0.18$ (3.42) | $0.40^{a}\pm0.12$ (3.63) | $0.47^{a}\pm0.10$ (3.93) | 0.49 | $0.42^{a}\pm0.10$ (3.73) | $0.32^{a}\pm0.09$ (3.28) | $0.26^{a}\pm0.05$ (2.93) | $0.38^{ab}\pm0.02$ (3.56) | $0.41^{a}\pm0.02$ (3.68) | 0.36 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_7$ | *M. anisopliae* @ 10 ml/L | $0.80^{ab}\pm0.06$ (5.14) | $0.61^{a}\pm0.22$ (4.47) | $0.48^{a}\pm0.22$ (3.97) | $0.46^{ab}\pm0.18$ (3.91) | $0.64^{b}\pm0.17$ (4.58) | $0.7^{cd}\pm0.11$ (5.09) | 0.61 | $0.57^{a}\pm0.25$ (4.34) | $0.50^{a}\pm0.24$ (4.07) | $0.40^{a}\pm0.14$ (3.66) | $0.49^{b}\pm0.06$ (4.03) | $0.58^{b}\pm0.08$ (4.37) | 0.51 |
| | CD (p=0.05) | 0.06 | 0.12 | 0.12 | 0.09 | 0.06 | 0.05 | | 0.07 | 0.08 | 0.06 | 0.06 | 0.06 | |
| | SEm (±) | 0.02 | 0.04 | 0.04 | 0.03 | 0.02 | 0.019 | | 0.026 | 0.027 | 0.02 | 0.02 | 0.02 | |

Note: Data represented by alphabet are calculated by DMRT
Data followed by same alphabets are statistically at par
DBS- Days before spraying DAS- Days after spraying
Data in parenthesis are arc sin transformed values

## 4. Discussion

### 4.1 Diversity of insect fauna, non-insects and observed in maize ecosystem

Twenty-three arthropod species were observed in maize ecosystem, 8 species of insect pest, 13 natural enemies (in that 10 are predators and 3 are spiders) and two species beneficial insects were identified from maize ecosystem. These findings are in confirmity with the findings of Kuotsu and Lalrinfeli (2019) who reported 23 insects pest on rice and maize, the most common of which were *R. maidis*, *L. lepidophora* and *M. quadriguttata* as minor pest on maize. The results are also supported with earlier findings of Rajagopal and Channabasavanna (1975) , Naz *et al*. (2003), Boupha *et al*. (2006), Biradar *et al*. (2011), Ahad *et al*. (2012), Bereś (2015), Arifie *et al*. (2019) and Kumar *et al*. (2016) who reported *R. maidis* as a minor pest infesting maize crop. These results are supported by Dhillon *et al*. (2014) who reported about different insect pest species on maize, the common pests being *R. maidis* and *Odontotermes* spp. as minor pests.

Deole *et* al. (2019) reported 19 natural enemies on maize, among which the most common predator is *Coccinella transversalis*. These are in conformity with the earlier results of Koch *et al*. (2006) who reported that *Harmonia axyridis* coccinellide beetle preys on a wide variety of homopteran insects *i.e.,* aphids, psyllids, coccids and other insects.

Deole *et al.* (2019) reported 19 natural enemies on maize, in that the most common spider is *Oxyopes salticus*. Major beneficial insects observed from maize ecosystem were Honeybee (*Apis mellifera*) and Hoverfly (*Allograpta obliqua*). Diseases were observed from maize ecosystem *viz*., Anthracnose leaf blight (*Colletotrichum graminicola*), Banded leaf and sheath blight (*Rhizoctonia solani*) and Corn rust (*Puccinia sorghi*) were recorded. Similarly, Navik *et al*. (2021) reported that damage incidence of fall armyworm was between 22.13 – 46.83 %.

### 4.2 Synergistic effect of UmMet and compatible insecticides on fall armyworm of maize

In the field studies highest bio efficacy was recorded with the sole treatment of Emamectin benzoate followed by the combination of Emamectin benzoate and *M. anisopliae*. These findings are similar with the work of Rivero-Borja *et al*., (2018) who studied Interaction of *Beauveria bassiana* and *Metarhizium anisopliae* with chlorpyrifos ethyl and spinosad in Spodoptera frugiperda larvae and found that synergistic mortality was observed when Bb88 (*B. bassiana*) and spinosad were applied simultaneously, which resulted in 34% more dead larvae than the spinosad control (44%). These results are in agreement with earlier results of Batool *et al*., (2022) who found that, among EPF, *M. anisopliae* showed signifcantly higher entomopathogenicity and caused 20–53% larval mortality than *B. bassiana* (5–35%) in 3–10 days post-exposure. Moreover, the binary combinations of *M. anisopliae* and chlorantraniliprole exhibited synergistic efect on *S. litura* larvae.

### 4.3 Corrected per cent mortality of FAW on maize

Highest corrected mortality was recorded in the sole treatment of Emamectin benzoate followed by joint application of Emamectin benzoate and *M. anisopliae*. These findings are supported by the earlier work of Soyel (2020) who concluded that Emamectin benzoate gave higher mortality for reducing FAW damage and provided maximum productivity of maize. These results are in conformity with the earlier work of Viteri *et al*. (2018) who reported entomopathogenic nematode *Steinernema carpocapsae* with low toxicity insecticide of Chlorantraniliprole or Spinetoram combination imposed higher mortality of more than 90 % observed after 72 hrs on the 5th instar of FAW larvae as compared to the insecticide alone. The results are in agreement with Bissiwu *et al*. (2016) who concluded that a combination treatment of *Heterorhabditis bacteriophora* + *M. anisopliae* + Chlorpyrifos gave an effective control for FAW and it also minimized in crop damage. Similarly Silva *et al*. (2020) reported that combination of Deltamethrin and *Ocimum basilicum* gave higher mortality on 3$^{rd}$ instar larvae of FAW. Sisay *et al*. (2019) also reported that Chlorantraniliprole gave the second most larval mortality with first spray (mortality 33.3 %) and second spray (mortality 46.7 %).

**4.4 Reduction of FAW population over control**

In the context of reduction over control sole application of Emamectin benzoate had shown the best rest followed by joint application of Emamectin benzoate and M. anisopliae. These results are similar to the findings of the Kushwaha (2022) who observed that insecticide Emamectin benzoate gives promising results for killing most of the larvae in the treated plots. These results are in agreement with earlier results of Bajracharya *et al*. (2020) who concluded Emamectin benzoate, Chlorantraniliprole and Spinosad were found to give promising results for controlling most of larvae of *S. frugiperda* in maize in both first and second spray. In that Emamectin benzoate showed reduction of 43.33 % of larvae at first spray and reduction of 13.33 % at second spray.

**5. Conclusion**

Among different treatment combinations of entomopathogen *M. anisopliae* with chemical insecticides at sub-lethal doses in field conditions showed that Emamectin benzoate @ 0.2 g/L (SLD) in combination with *M. anisopliae* @ 10 ml/L can be recommended as a component of IPM. Furthermore, it can be popularized among farmers for managing insect pests of different crops.

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