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# Evaluation of bio-intensive, chemical intensive and integrated pest management modules against fall armyworm, *Spodoptera frugiperda* (J. E. Smith) infesting maize

**Mohapatra AR, Sisodiya DB, Parmar RG, Thumar RK and Patel NB**

**Abstract**
Fall armyworm (FAW) is an important and destructive pest causing heavy damage to maize crops throughout India and abroad. Considering the importance of FAW, an experiment was conducted to evaluate various modules against *Spodoptera frugiperda* infesting maize. Modules *viz*., Bio-intensive module, chemical intensive module and Integrated Pest Management (IPM) Module were framed and the its evaluation was carried out under field conditions for two years during *kharif*, 2021 and 2022. The IPM module consisted of border crop of sunflower; seed treatment with cyantraniliprole 19.8% + thiamethoxam 19.8% FS, 2.38 g a.i./kg seeds (6 ml/kg seeds); collection and destruction of egg masses and neonate larvae during initial crop stages; spraying of *Bacillus thuringiensis* 1% WG, 20 g/10 litres of water at 30 DAS; whorl application of soil, 5 g/plant at 45 DAS; and spraying of chlorantraniliprole 18.5 SC (3 ml/10 litres of water) at 60 DAS. Of the evaluated modules significantly the least larval population (0.44 larva/10 plants), plant (5.14%) as well as cob damage (17.77%) and highest grain (2945 kg/ha) as well as dry fodder yield (4132 kg/ha) and ICBR (1:2.37) was recorded in the Integrated Pest Management (IPM) module. It was followed by the chemical intensive module with mediocre and bio-intensive module with lesser effectiveness against fall armyworm infesting maize.

**Keywords:** Fall armyworm, *S. frugiperda*, IPM, module

## 1. Introduction

Maize (*Zea mays* Linnaeus) is one of the most popular cereal crops not only due to its high value as a staple food but also for its straw demand for animal feed, fuel and construction purposes (Abebe and Feyisa, 2017 [1]; Mohapatra and Sisodiya, 2022) [8]. It belongs to the family Poaceae being cultivated throughout tropical, sub-tropical and temperate regions. The crop is attacked by about 130 species of insect-pests in India alone (Atwal and Dhaliwal, 2002) [3]. The fall armyworm (FAW), *S. frugiperda* (Lepidoptera: Noctuidae) is an invasive pest of maize. With a mild to severe infestation, it was firstly reported in West and Central Africa in early 2016 (Goergen *et al*., 2016) [6]. Its first report in India was published during June, 2018 by Sharanabasappa *et al.* (2018) [13] on maize from Karnataka consequently, Sisodiya *et al.* (2018) [15] first time reported the occurrence of FAW on sweet corn from Anklav taluka of Anand district and now, it has infested every maize field in the state.

It is a highly polyphagous pest, insatiably feeding on maize and surviving on more than 76 plant families and 353 crop plants (Montezano *et al*., 2018) [9] not only on cereals (maize, wheat, sorghum, millet, rice) and pasture grasses but also on sugarcane, cotton, potato, sweet potato, ginger, chrysanthemum, tomato, tobacco, spinach, crucifers, cucurbits, cucumber, cowpea, common bean, soybean, groundnut, banana *etc* (Anonymous, 2018) [2] and many such insects have also started making havoc in Gujarat like the black thrips (Lodaya *et al*., 2022) [7]. Farmers often rely heavily on chemical control, generally practiced for higher gains, but improperly by its injudicious application. Moreover, inferences drawn for the management of this invasive pest are confusing and intensive in approach. Considering the havoc, proper incorporation of the chemical insecticides that too more importantly in the proper method, directed towards its greater reachability and increased efficacy is also needed. Therefore, there is an urgent need to assess effective and low risk strategies available for the management of this pest. Microbials (SfNPV by Raghunandan *et al*., 2019 and *Bacillus thuringiensis* as well as *Nomurea rileyii* by Dhobi *et al*., 2020) [11, 5], botanicals and semio chemicals are commonly considered as an effective option for pest management, when utilised in unification with judicious utilization of chemical pesticides and its application method, Good Agricultural Practices (GAP) contributing to cultural control and mechanical exclusion of the pest as well as continuous monitoring for surveillance on resistance, diversification and its introduction into various population on the molecular level. By coordinating these measures harmoniously, it can help to restrict pest levels and reducing the need to apply pesticides.

## 2. Materials and Methods

### 2.1 Methodology

In order to evaluate different modules for its efficacy against FAW, *S. frugiperda* infesting maize, an experiment was carried out at Entomology farm, BACA, AAU, Anand during *kharif*, 2021 and 2022. To evaluate different modules for their efficacy against fall armyworm, maize crop was grown by adopting all recommended agronomical practices except insecticidal applications as shown Table 1. Application of treatments under respective modules was made as described in the Table 1. For recording observations, ten plants were randomly selected from the net plot area of each treatment and replication. From selected plants, total number of larva(e) and damaged as well as healthy plant(s) were recorded at weekly interval starting from two weeks after sowing till the harvest of the crop. Whereas, observations on healthy and damaged cob(s) as well as maize seed and dry fodder yield were recorded at harvest. The observations were recorded at weekly interval starting from two weeks after sowing till the harvest of the crop. The data obtained were analyzed following standard statistical procedure (Steel and Torrie, 1980) [16] to draw valid conclusion after adopting square root transformation for data on number of larvae and arcsine transformation for data on damaged plants as well as cobs.

### 2.2 Observations recorded

1. Number of larva(e)/ 10 plants
2. Number of healthy and damaged plant(s)/ 10 plants
3. Number of healthy and damaged cob(s)/ 10 plants
4. Grain and fodder yield (kg/ net plot)

**Table 1:** Experimental details

| | | | |
|---|---|---|---|
| 1. | Season and years | : | *Kharif*, 2021 and 2022 |
| 2. | Crop and variety | : | Maize, GAYMH 1 |
| 3. | Design | : | Randomized Block Design |
| 4. | Modules | : | 4 |
| | Module No. | | Details |
| | M1 | : | **Bio-intensive Module**<br>1. *Sf*NPV (AAUBC SpfrNPV1), 20 g/10 litres of water - commercial sticker 0.15% (15 g/ 10 litres of water)<br>2. *Nomuraea rileyi* (AAU strain) 1% WP (2x10$^{8}$ cfu/g), (40 g/10 litres of water) at 10 days after 1st spray<br>3. *Bacillus thuringiensis* (NBAIR BtG4)1% WG, (20 g/ 10 litres of water) at 10 days after 2nd spray |
| | M2 | : | **Chemical Intensive Module**<br>1. Emamectin benzoate 5 SG, 0.0025% (5 g/10 liters of water)<br>2. Chlorantraniliprole 18.5 SC, 0.006% (3 ml/10 litres of water) at 15 days after 1st spray<br>3. Spinetoram 11.7 SC, 0.0117%, (10 ml/10 litres of water) at 15 days after 2nd spray |
| | M3 | : | **Integrated Pest Management Module**<br>1. Growing sunflower as border crop<br>2. Seed treatment - cyantraniliprole 19.8% + thiamethoxam 19.8% FS, 2.38 g a.i./ kg seeds (6 ml/ kg seeds)<br>3. Collection and destruction of egg masses and neonate larvae during initial crop stages<br>4. 30 DAS - spraying of B. thuringiensis 1% WG, 20 g/ 10 litres of water<br>5. 45 DAS - whorl application of soil, 5 g/ plant<br>6. 60 DAS - spraying of chlorantraniliprole 18.5 SC, 3 ml/ 10 litres of water |
| | M4 | : | Control |
| | **Note**: 1. In each module i, ii, iii *etc* indicate sequence of application<br>2. DAS – Days After Sowing<br>3. Total 500 litres of water/ ha was used for each spray | | |
| 6. | Replications | : | 5 |
| 7. | Spacing | : | 60 × 20 cm |
| 8. | Plot size | : | Gross plot : 4.8 × 6.0 m<br>Net plot : 3.6 × 5.6 m |
| 9. | Method of sowing | : | Dibbling |
| 10. | Fertilizer dose (N:P:K) | : | 150:60:0 kg/ha |

## 3. Results and Discussion

A field experimental data on larval population as well as plant damage (%) caused by fall armyworm were recorded at weekly interval starting from 3 weeks after sowing until harvest of the crop. While, the cob damage (%) and grain as well as dry fodder yield were recorded at harvest. The weekly as well as pooled over weeks and years data are presented hereunder.

### 3.1 Evaluation Based on Larval Population

All the modules showed significant effect against fall armyworm population during *kharif*, 2021 and 2022 as well as pooled over periods and years (Table 2 and Fig. 1).

**Table 2:** Evaluation of different modules against larval population of fall armyworm, S. frugiperda infesting maize

| M. No. | Modules | No. of larva(e)/10 plants | | |
|---|---|---|---|---|
| | | ***Kharif*, 2021** | ***Kharif*, 2022** | **Pooled over years** |
| M1 | Bio-intensive Module | 1.85 (2.92) | 1.86 (2.96) | 1.86 (2.96) |
| M2 | Chemical Intensive Module | 1.62 (2.12) | 1.66 (2.26) | 1.64 (2.19) |
| M3 | Integrated Pest Management Module | 0.95 (0.40) | 0.98 (0.46) | 0.97 (0.44) |
| M4 | Control | 2.56 (6.05) | 2.62 (6.36) | 2.59 (6.21) |
| S. Em. ± Treatment (T) | | 0.02 | 0.02 | 0.02 |
| Period (P) | | 0.04 | 0.04 | 0.02 |
| Year (Y) | | - | - | 0.01 |
| T × P | | 0.08 | 0.08 | 0.05 |
| T × Y | | - | - | 0.02 |
| P × Y | | - | - | 0.04 |
| T × P × Y | | - | - | 0.08 |
| C. D. at 5% T | | 0.11 | 0.10 | 0.07 |
| P | | 0.07 | 0.07 | 0.05 |
| Y | | - | - | 0.03 |
| T × P | | 0.10 | 0.09 | 0.08 |
| T × Y | | - | - | NS |
| P × Y | | - | - | NS |
| T × P × Y | | - | - | NS |
| C. V. (%) | | 10.26 | 10.00 | 10.13 |

**Note: 1.** Figures outside the parentheses are √(x+0.5) transformed values and those inside the parentheses are retransformed values 2. NS = Non-Significant

#### 3.1.1 First year (*Kharif*, 2021)

The data on pooled over periods population of *S. frugiperda* recorded during *kharif*, 2021 exhibited that all the evaluated modules were significantly superior over control in managing fall armyworm infesting maize (Table 2). Integrated pest management (IPM) module emerged as the best module by registering the least larval population of *S. frugiperda* (0.40 larva/10 plants). It was followed by the chemical intensive module with a larval population of 2.12 larvae per 10 plants. While, bio-intensive module exhibited a larval population of 2.92 larvae per 10 plants, indicating mediocre efficacy in managing fall armyworm. Analysis of variance (ANOVA) of the pooled over periods data for *kharif*, 2021 revealed significant effect of periods as well as interaction between modules (treatments) and periods (Table 2). This implies that over the course of weeks, the modules exhibited significantly different efficacy owing to the application of different treatments spanning throughout the cropping period.

#### 3.1.2 Second year (*Kharif*, 2022)

During the second year (*kharif*, 2022), pooled over periods data as depicted in Table 4.13, revealed the lowest (0.46 larva/ 10 plants) larval population of *S. frugiperda* from the plots with IPM module, followed by the chemical intensive module (2.26 larvae/10 plants). However, bio-intensive module exhibited 2.96 larvae per 10 plants exhibiting mediocre efficacy, but remained significantly superior to control (6.36 larvae/10 plants). The pooled over periods data of *kharif*, 2022 exhibited significant difference associated with different periods (Table 2) as per the ANOVA. This suggested that alongside the modules, the larval population also fluctuated significantly over the span of cropping periods. Population fluctuation was also attributed to significant interaction of modules and weeks, due to the different treatment applications under each module spanning over different weeks during the cropping period.

#### 3.1.3 Pooled over periods and years (*Kharif*, 2021 and 2022)

Pooled over periods and years data (Table 2 and Fig. 1) revealed the lowest (0.44 larva/10 plants) larval population of *S. frugiperda* from the IPM module. Next in effectiveness was the chemical intensive module (2.19 larvae/10 plants), which was followed by the bio-intensive module (2.96 larvae/10 plants). All the evaluated modules proved superior against fall armyworm as compared to control (6.21 larvae/ 10 plants). Subsequent ANOVA of data on pooled over periods and years as presented in the Table 2, revealed significant population fluctuation with varying periods, years as well as interaction of modules with periods. This infers that the larval population differed significantly during different weeks as well as under the combined effect of module with periods, due to the periodical application of treatments under different modules. The yearly significance in larval population of fall armyworm was due to increased infestation during the year, 2022 as compared to previous year, 2021.

### 3.2 Evaluation Based on Plant Damage (%)

Of the four modules evaluated against plant damage caused by *S. frugiperda*, significant reduction in infestation was recorded during *kharif*, 2021 and 2022 as well as pooled over periods and years (Table 3).

#### 3.2.1 First year (*Kharif*, 2021)

Significantly lowest (4.58%) plant damage due to fall armyworm was observed in plots with IPM module during pooled over periods data of the first year (Table 3). The chemical intensive module (18.75%) stood next in order of effectiveness followed by the bio-intensive module, which recorded 24.59 per cent plant damage. However, the control plots registered the highest plant damage of 59.56 per cent. The ANOVA of the data on pooled over periods of the first year indicated that the periods as well as its interaction with modules significantly affected the plant damage inflicted by fall armyworm. These results represent that the plant damage varied considerably under the.

influence of periods owing to the maturity of crop and subsequent shifting of *S. frugiperda* population towards developing cobs. Moreover, due to varying treatments applied under different modules, the interaction of modules with periods was found significant (Table 3).

**Table 3:** Evaluation of different modules against plant damage caused by fall armyworm, S. frugiperda infesting maize

| M. No. | Modules | Plant damage (%) | | |
|---|---|---|---|---|
| | | ***Kharif*, 2021** | ***Kharif*, 2022** | **Pooled over years** |
| M1 | Bio-intensive Module | 29.73 (24.59) | 30.40 (25.61) | 30.07 (25.11) |
| M2 | Chemical Intensive Module | 25.66 (18.75) | 28.22 (22.36) | 26.94 (20.53) |
| M3 | Integrated Pest Management Module | 12.36 (4.58) | 13.85 (5.73) | 13.11 (5.14) |
| M4 | Control | 50.51 (59.56) | 50.56 (59.64) | 50.54 (59.61) |
| S. Em. ± Treatment (T) | | 0.50 | 0.52 | 0.26 |
| Period (P) | | 0.82 | 0.87 | 0.45 |
| Year (Y) | | - | - | 0.50 |
| T × P | | 1.65 | 1.74 | 0.89 |
| T × Y | | - | - | 0.41 |
| P × Y | | - | - | 0.45 |
| T × P × Y | | - | - | 1.09 |
| C. D. at 5% T | | 1.37 | 1.45 | 0.87 |
| P | | 2.28 | 2.41 | 1.51 |
| Y | | - | - | NS |
| T × P | | 4.56 | 4.83 | 2.20 |
| T × Y | | - | - | NS |
| P × Y | | - | - | 1.96 |
| T × P × Y | | - | - | NS |
| C. V. (%) | | 11.80 | 12.68 | 12.24 |

**Note:** 1. Figures outside the parentheses are arcsine transformed values and those inside the parentheses are retransformed values 2. NS = Non-significant

#### 3.2.2 Second year (*Kharif*, 2022)
The pooled over periods data on plant infestation due to *S. frugiperda* recorded during *kharif*, 2022 (Table 3) exhibited that the IPM module was found superior over other modules by recording least plant damage (5.73%). It was followed by the chemical intensive module with an infestation of 22.36 per cent. While, bio-intensive module exhibited a higher plant damage (25.61%) exhibiting mediocre effectiveness against fall armyworm. ANOVA of the pooled over periods data for *kharif*, 2021 revealed significant effect of periods as well as interaction between modules and periods (Table 3). This implies that over the course of weeks, the modules exhibited significantly differing effectiveness owing to the application of different treatments spanning throughout the cropping period.

#### 3.2.3 Pooled over periods and years (*Kharif*, 2021 and 2022)
After the pooled over periods and years analysis as given in Table 3 and depicted in Fig. 1, the data revealed the least (5.14%) plant damage by *S. frugiperda* was found in the plots with IPM module, followed by the chemical intensive module (20.53%). However, bio-intensive module recorded 25.11 per cent plant damage by fall armyworm indicating moderate effectiveness, while remaining significantly superior over control (59.61%). The data on pooled over periods and years of plant damage exhibited significant difference associated with different periods (Table 3) as per the ANOVA. This suggested that the larval population varied significantly during the cropping period owing to the maturity of crop as well as shift in infestation from leaves to cobs. Fall armyworm plant damage also exhibited significant association with interaction of modules and weeks owing to the application of different treatments in various modules. Furthermore, the interaction effect of periods with years was also found significant, which was associated with relatively higher infestation prevailed during *kharif*, 2022 as compared to *kharif*, 2021.

### 3.3 Evaluation Based on Cob Damage (%)
The data clearly indicated that the evaluated modules exhibited significant effectiveness against cob damage caused by fall armyworm during *kharif*, 2021 and 2022 as well as pooled over years (Table 4).

#### 3.3.1 First year (*Kharif*, 2021)
Cob damage due to *S. frugiperda* was recorded the least (15.65%) in the IPM module during *kharif*, 2021 (Table 4). The chemical intensive module (23.82% cob damage) emerged as the next effective module followed by the bio-intensive module (31.76% cob damage). All the modules proved significantly superior in comparison to control (62.01% cob damage).

#### 3.3.2 Second year (*Kharif*, 2022)
During the second year (*kharif*, 2022), the data presented in Table 4.15 revealed 19.98 per cent cob damage caused by *S. frugiperda* from the plots under IPM module, followed by the chemical intensive module (27.67%). However, the plots under bio-intensive module exhibited 35.90 per cent cob damage by fall armyworm. It shows its mediocre performance, but it stood significantly superior over the control (58.06%).

#### 3.3.3 Pooled over years (*Kharif*, 2021 and 2022)
The data on pooled over years indicated the lowest cob damage (17.77%) caused by *S. frugiperda* in the plots under IPM module (Table 4 and Fig. 1). Next in effectiveness was the chemical intensive module (25.73%), which was followed by the bio-intensive module (33.90%). All the evaluated modules were found superior in managing fall armyworm as compared to control (60.04%). The pooled over years data of *kharif*, 2021 and 2022 exhibited non-significant difference

associated with different periods as well as interaction between periods and modules (Table 4) as per the ANOVA. This suggested that cob damage inflicted by *S. frugiperda* and effect of modules was substantially stable over the experimental years and periods.

**Table 4:** Evaluation of different modules against cob damage caused by fall armyworm, S. frugiperda infesting maize

| M. No. | Modules | Cob damage (%) | | |
|---|---|---|---|---|
| | | ***Kharif*, 2021** | ***Kharif*, 2022** | **Pooled over years** |
| M1 | Bio-intensive Module | 34.30 (31.76) | 36.81 (35.90) | 35.61 (33.90) |
| M2 | Chemical Intensive Module | 29.21 (23.82) | 31.74 (27.67) | 30.48 (25.73) |
| M3 | Integrated Pest Management Module | 23.30 (15.65) | 26.55 (19.98) | 24.93 (17.77) |
| M4 | Control | 51.95 (62.01) | 49.64 (58.06) | 50.79 (60.04) |
| S. Em. ± | Treatment (T) | 1.46 | 1.59 | 1.06 |
| | Year (Y) | - | - | 0.75 |
| | T × Y | - | - | 1.50 |
| C. D. at 5% | T | 4.50 | 4.89 | 2.55 |
| | Y | - | - | NS |
| | T × Y | - | - | NS |
| C. V.% | | 9.41 | 9.79 | 9.47 |

**Note:** 1. Figures outside the parentheses are arcsine transformed values and those inside the parentheses are retransformed values
2. NS = Non-significant

### 3.4 Evaluation Based on Yield

Impact of various modules on grain as well as dry fodder yield of maize during *kharif*, 2021 and 2022 as well as pooled over years (Table 5) exhibited significant yield increase in all the 3 modules over control for both the years as described hereunder.

#### 3.4.1 Grain yield (Kg/ha)

**First year (*Kharif*, 2021)**

Grain yield of maize harvested from the plots of IPM module (2927 kg/ha) was recorded significantly the highest, followed by the chemical intensive module with yield of 2629 kg per ha (Table 5). While, bio-intensive module produced average yield of 2317 kg per ha indicating mediocre impact on maize grain yield. However, all the modules evaluated in present study produced significantly higher grain yield of maize as compared to control (1989 kg/ha).

**Second year (*Kharif*, 2022)**

The data of maize grain yield recorded during *kharif*, 2022 revealed that the plots with IPM module recorded significantly highest yield of 2964 kg per ha (Table 5). Next in order of grain yield was the chemical intensive module (2667 kg/ha) followed by the bio-intensive module (2366 kg/ha). Significantly lowest grain yield was harvested from the control (2025 kg/ha) plots.

**Table 5:** Impact of different modules evaluated for the management of fall armyworm, S. frugiperda on grain and dry fodder yield of maize

| Tr. No. | Modules | Grain yield (kg/ha) | | | Dry fodder yield (kg/ha) | | |
|---|---|---|---|---|---|---|---|
| | | ***Kharif*, 2021** | ***Kharif*, 2022** | **Pooled** | ***Kharif*, 2021** | ***Kharif*, 2022** | **Pooled** |
| M1 | Bio-intensive Module | 2317 | 2366 | 2341 | 3223 | 3267 | 3245 |
| M2 | Chemical Intensive Module | 2629 | 2667 | 2648 | 3662 | 3719 | 3690 |
| M3 | Integrated Pest Management Module | 2927 | 2964 | 2945 | 4092 | 4172 | 4132 |
| M4 | Control | 1989 | 2025 | 2007 | 2759 | 2817 | 2788 |
| S. Em. ± Treatment (T) | | 94 | 93 | 61 | 139 | 142 | 92 |
| Year (Y) | | - | - | 43 | - | - | 65 |
| T × Y | | - | - | 87 | - | - | 131 |
| C. D. at 5% T | | 290 | 286 | 148 | 427 | 439 | 222 |
| Y | | - | - | NS | - | - | NS |
| T × Y | | - | - | NS | - | - | NS |
| C. V.% | | 8.56 | 8.27 | 8.42 | 9.03 | 9.12 | 9.08 |

**Pooled over years (*Kharif*, 2021 and 2022)**

The data on pooled over years of grain yield of maize are presented in Table 5 and depicted in Fig. 1, which indicated the highest grain yield was obtained from the plots with IPM module (2945 kg/ha). While, the plots with application of chemical intensive module revealed a grain yield of 2648 kg per ha, followed by the bio-intensive module (2341 kg/ha). All the modules tested were found significantly superior over control (2007 kg/ha) as exhibited in the pooled over years results. The ANOVA of pooled over years data also revealed non-significant impact of years and its interaction with modules (Table 5). This reveals that the yield performance of different modules was solely aligned with the effectiveness and was stable over the years of experiment.

#### 3.4.2 Dry fodder yield (Kg/ha)

**First year (*Kharif*, 2021)**

Harvested dry fodder yield of maize was recorded significantly highest from the IPM module (4092 kg/ha), followed by the chemical intensive module (3662 kg/ha) as shown in Table 5. Both the modules differed significantly. While, mediocre yield performance was recorded by the bio-intensive module (3223 kg/ha), but it exhibited significant impact on dry fodder yield as compared to control (2759 kg/ha).

**Second year (*Kharif*, 2022)**

During *kharif*, 2022, the data on maize dry fodder yield (Table 5) revealed the IPM module with significantly the highest yield of 4172 kg per ha. Next in order of yield was the chemical intensive module (3719 kg/ha) followed by the bio-intensive module (3267 kg/ha). Significantly lowest grain yield was harvested from the control (2817 kg/ha) plots.

**Pooled over years (*Kharif*, 2021 and 2022)**

The pooled over years data on dry fodder yield of maize implied the highest (4132 kg/ha) harvest was obtained from the plots with IPM module (Table 5 and Fig. 1). While, plots with the chemical intensive module revealed a dry fodder yield of 3690 kg per ha, followed by the bio-intensive module (3245 kg/ha). All the 3 modules produced substantial increase in dry fodder yield over control (2788 kg/ha) as exhibited in the pooled over years results. The harvested dry fodder yield exhibited non-significant influence of any other parameter or interaction of parameter as revealed by ANOVA (Table 5). This represents that the module yield difference was the only significant factor, which was also observed consistent over the course of *kharif*, 2021 and 2022.

### 3.5 Economics

The economics of various modules evaluated against fall armyworm was worked out based on the yield data of pooled over years (*Kharif*, 2021 and 2022). The incremental cost benefit ratio (ICBR) of different modules is presented in the Table 5. The IPM module emerged as the most economical with an ICBR value of 1:2.37. It was followed by the chemical intensive (1:1.24), while the bio-intensive modules registered the lowest ICBR of 1:1.06. This reveals that besides being efficacious, treatments applied under the IPM module were economically profitable, which was followed by the chemical intensive module.

## 4. Discussion

Though the modules differ, treatments under the effective module against fall armyworm reported by Ompraksh *et al*. (2020) [10], Thilagam *et al*. (2020) [17], Babu *et al*. (2021) [4], Warkad *et al*. (2021) [19] are more or less similar to the treatments under IPM module evaluated under present study. These reports suggests that the current findings are in accordance with earlier reports and also ascertain higher financial gains obtained from the IPM modules or its equivalent. While, the results obtained by Sharanabasappa *et al*. (2019) [14] who reported that removal of egg masses and application of chlorantraniliprole, spinetoram and emamectin benzoate provided effective management of fall armyworm are in partial accordance to the present findings. Alongside this, Reddy *et al*. (2023) [12] also reported module consisting of seed treatment with cyantraniliprole + thiamethoxam as effective against *S. frugiperda*, which is moderately analogous to the present experimental results. However, Varshney *et al*. (2020) [18] reported the biocontrol-based module as highly efficacious against fall armyworm which differs with current findings. Such discrepancy may have raised owing to the different in treatment schedule of current module as well strain of biocontrol agents utilised in the respective studies.

## 6. Conclusion

The initial efficacy of IPM modules was attributed to the control obtained by cultivation of sunflower as border crop, seed treatment (cyantraniliprole 19.8% + thiamethoxam 19.8% FS) as well as periodical collection and destruction of egg masses of *S. frugiperda*, which persisted for a period of 4 weeks from sowing. Subsequently, scheduled application of *B. thuringiensis* 1% WP at 30 DAS, soil at 45 DAS and chlorantraniliprole 18.5 SC at 60 DAS maintained the population of fall armyworm below concerning levels in the IPM modules. While, the chemical intensive module with adjacent application of chemical insecticides also evinced significant efficacy against fall armyworm. Insecticidal treatments of emamectin benzoate 5 SG, chlorantraniliprole 18.5 SC and spinetoram 11.7 SC substantially managed the fall armyworm population.

Looking to the expanding horizon of insect-pests, managing tactics are shrinking on part of farmers, as the later deploys injudicious amounts of pesticides. Evaluation of IPM modules consisting of various economically beneficial and ecologically sustainable tactics are required to cope up with the current status of invasive insect-pests like fall armyworm. The current study presents a viable IPM module that could be employed to fight the menace of *S. frugiperda* in maize. However, under the present investigations the bio-intensive module also recorded with a profitable ICBR presenting feasible option for farmers cultivating maize under natural or organic farming.

## 7. Acknowledgement

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**Table 5:** Economics of modules evaluated against fall armyworm, S. frugiperda infesting maize

| M. No. | Modules | Treatments | Quantity required per ha (kg or L) | Price (₹/L or kg) | Cost of treatment (₹/ha) | Labour charge (₹/ha) | Total cost of plant protection (₹/ha) | Total cost of module (₹/ha) | Yield (kg/ha) | | Net gain over control (kg/ha) | | Realization (₹/ha) | ICBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Grain | Dry fodder | Grain | Dry fodder | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | Bio-intensive Module | *Sf*NPV AAUBC SpfrNPV1*@ | 1.00 | 980 | 980 | 1232 | 2212 | 7887 | 2341 | 3245 | 334 | 457 | 8381 | 1:1.06 |
| | | *Nomuraea rileyi* (AAU strain) 1% WP (2x$10^8$ cfu/g)@ | 2.00 | 980 | 1960 | 1232 | 3192 | | | | | | | |
| | | *Bacillus thuringiensis* (NBAIR BtG4) 1% WG@ | 1.00 | 980 | 980 | 1232 | 2212 | | | | | | | |
| 2 | Chemical Intensive Module | Emamectin benzoate 5 SG@ | 0.25 | 5700 | 1425 | 1232 | 2657 | 12997 | 2648 | 3690 | 641 | 902 | 16184 | 1:1.24 |
| | | Chlorantraniliprole 18.5 SC@ | 0.15 | 10833 | 1625 | 1232 | 2857 | | | | | | | |
| | | Spinetoram 11.7 SC@ | 0.50 | 12500 | 6250 | 1232 | 7482 | | | | | | | |
| 3 | Integrated Pest | Sunflower border crop@ | 60 gram | ₹ 100/ 60 g | 100 | - | 100 | 10045 | 2945 | 4132 | 938 | 1344 | 23780 | 1:2.37 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Management Module | Cyantraniliprole 19.8% + thiamethoxam 19.8% FS** | 0.15 | 22500 | 3375 | 268 | 3643 | | | | | | | |
| | | Collection and destruction of egg masses and neonate larvae# | - | - | - | 536 | 536 | | | | | | | |
| | | *B. thuringiensis* (NBAIR BtG4) 1% WG@ | 1.00 | 980 | 980 | 1232 | 2212 | | | | | | | |
| | | Soil, 5 g/ plant## | 416.66 | - | - | 696 | 696 | | | | | | | |
| | | Chlorantraniliprole 18.5 SC@ | 0.15 | 10833 | 1625 | 1232 | 2857 | | | | | | | |
| 4 | Control | - | - | - | - | - | - | - | 2007 | 2788 | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **Note**: 1. Labour charges @ Semi skilled labour | : | ₹ 348.20 per day x 2 labour = 696.40 ₹/ ha | > | (##Module 3) |
| Farm labour | : | ₹ 268.00 per day<br>₹ 268.00 per day x 2 labour = 536.00 ₹/ ha | ><br>> | (**Module 3)<br>(#Module 3) |
| Labour charge for one spray | : | ₹ 696.40 + ₹ 536 = 1232.40 ₹/ ha | > | (@Module 1, 2 and 3) |

2. *Sticker 0.15% *i.e.* 15 ml per 10 litre of water was added. Total 750 ml sticker was used per hectare. Cost of sticker was ₹ 360/litre. So, ₹ 270 was added in total cost of plant protection

3. Price of maize grain = ₹ 19.60/ kg

4. Price of maize dry fodder = ₹ 4/ kg

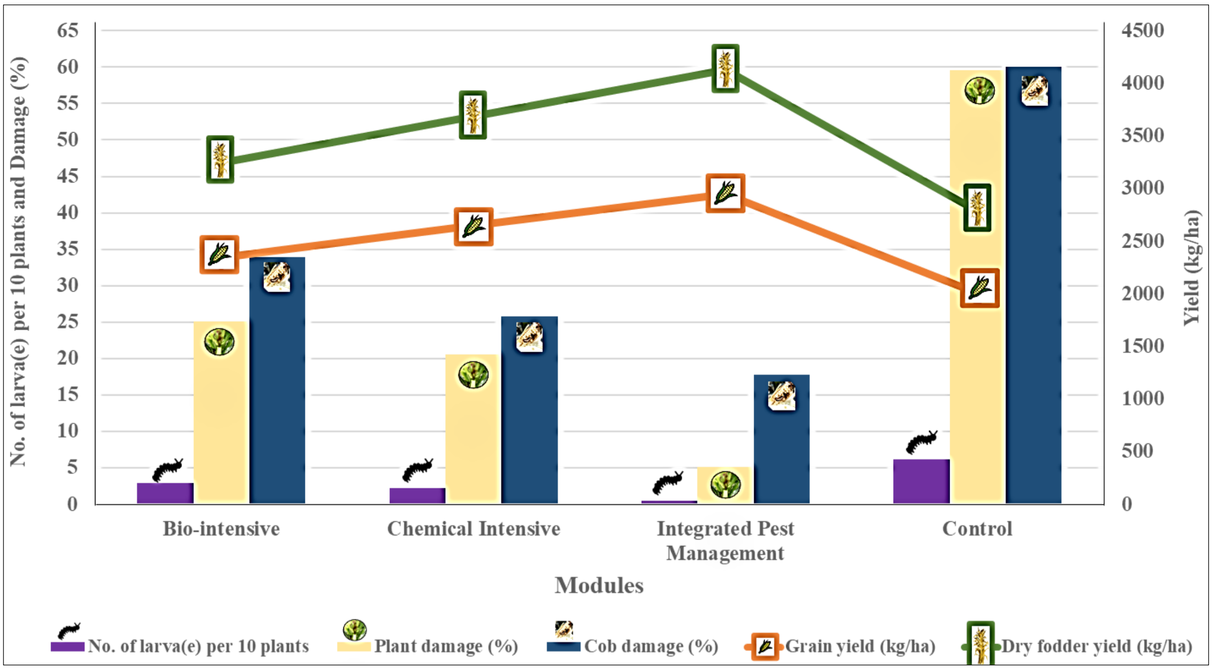


**Fig 1:** Evaluation of modules against fall armyworm, S. frugiperda infesting maize

## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## 8. References


1. Abebe Z, Feyisa H. Effects of nitrogen rates and time of application on yield of maize: Rainfall variability influenced time of N application. International Journal of Agronomy. 2017;1545280:1-10.
2. Anonymous. Fall armyworm. 2018. [Weblink: https://www.armyworm.org/ species/fall-armyworm]. [Visited on: 13 July, 2023].
3. Atwal AS, Dhaliwal GS. Agricultural Pests of South Asia and Their Management. Kalyani Publishers, New Delhi, India; c2002. p. 189-192.
4. Babu CG, Naidu CD, Rao VP. Integrated pest management of an invasive pest on maize, *Spodoptera frugiperda* (J. E. Smith) in Srikakulam district of Andhra Pradesh. Journal of Entomology and Zoology Studies. 2021;9(1):1559-1561.
5. Dhobi CB, Zala MB, Verma HS, Sisodiya DB, Thumar RK, Patel MB, *et al*. Evaluation of bio-pesticides against fall armyworm, *Spodoptera frugiperda* (J. E. Smith) in Maize. International Journal of Current Microbiology and Applied Sciences. 2020;9(8):1150-1160.
6. Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. Plos One. 2016;11(10):1-9.
7. Lodaya JP, Suthar MD, Patel HC, Sisodiya DB, Acharya RR, Raval AT, *et al*. Status of invasive species of thrips, *Thrips parvispinus* (Karny) infesting chilli grown in middle Gujarat. The Pharma Innovation Journal. 2022;11(3):1298-1302.
8. Mohapatra AR, Sisodiya DB. Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith): A serious threat to maize and its management. Land Bank Journal. 2022;61(4);10-11.
9. Montezano DG, Specht A, Gomez DR, Specht VF, Silva JC, Moraes SV, *et al*. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. African Entomology. 2018;26(2):286-300.
10. Ompraksh S, Reddy SS, Reddy LR, Reddy UR. Evaluation of different modules for the management of fall army worm *Spodoptera frugiperda* in maize. Journal of Pharmacognosy and Phytochemistry. 2020;9(3):1765-

1767.
11. Raghunandan BL, Patel NM, Dave HJ, Mehta DM. Natural occurrence of *nucleopolyhedrovirus* infecting fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) in Gujarat, India. Journal of Entomology and Zoology Studies. 2019;7(2):1040-1043.
12. Reddy BKK, Jyothi VS, Sadhineni M, Johnson M, Swamy GN. Evaluation of IPM Modules against Fall Armyworm in Maize through Frontline Demonstration and Its Economic Impact. International Journal of Environment and Climate Change. 2023;13(1):24–29.
13. Sharanabasappa D, Kalleshwaraswamy CM, Asokan R, Swamy HM, Maruthi MS, Pavithra HB, *et al*. First report of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. Pest Management Horticulture Ecosystem. 2018;24(1):23-29.
14. Sharanabasappa D, Kalleshwaraswamy CM, Shivanna BK, Hosamani AC, Jaba J, *et al*. Fall armyworm, *Spodoptera frugiperda* (J. E. Smith): incidence, host range and its management. Paper presented at the XIX International Plant Protection Congress on Crop Protection to Outsmart Climate Change for Food Security & Environmental Conservation, Symposium, Hyderabad, Telangana, India; c2019. [Weblink: http://oar.icrisat.org/11675/]. [Visited on: 23 March, 2021].
15. Sisodiya DB, Raghunandan BL, Bhatt NA, Verma HS, Shewale CP, Timbadiya BG, *et al*. The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae); first report of new invasive pest in maize fields of Gujarat, India. Journal of Entomology and Zoology Studies. 2018;6(5): 2089-2091.
16. Steel RGD, Torrie JH. Principles and procedures of statistics. Publ. McGraw Hill Book Company, New York, USA; c1980. p. 137.
17. Thilagam P, Dinakaran D, Nanthakumar S, Gopikrishnan A. Reduction of maize fall armyworm (*Spodoptera frugiperda*, J. E. Smith) population with the use of TNAU technology capsule. International Journal of Current Research in Life Sciences. 2020;09(09):3322-3325.
18. Varshney R, Poornesha B, Raghavendra A, Lalitha Y, Apoorva V, Ramanujam B, *et al*. Biocontrol-based management of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on Indian Maize. Journal of Plant Diseases and Protection; c2020. Retrieved from: https://doi.org/10.1007/s41348-020-00357-3.
19. Warkad TP, Bhede BV, Shinde GS. Development of integrated pest management module for fall armyworm *Spodoptera frugiperda* (J. E. Smith) on maize. International Journal of Zoological and Entomological Letters. 2021;1(2):22–25.