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Integrated pest management of fall armyworm (*Spodoptera frugiperda*) in maize

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Abstract
Maize, known as the "queen" of cereals for its high yield potential in a short time. Recently it has been severely affected by the fall armyworm (FAW), *Spodoptera frugiperda*, a new invasive pest that feeds on over 80 plant species, causing major crop losses. Integrated pest management (IPM) is a crucial solution to combat this threat. Field experiments tested various IPM strategies, including the use of Azadirachtin, Emamectin benzoate, and *Metarhizium anisopliae* which reduced FAW infestation. IPM plots showed significantly lower egg mass and larval infestations compared to conventional methods. Pheromone-based monitoring also reduced adult moth populations, making these strategies promising for similar regions worldwide.

Keywords: Fall army worm (FAW), Integrated Pest Management (IPM), Traps, Farmer's practice (FP)

Introduction
In India, maize (*Zea mays L.*) is the third most important crop after rice and wheat, playing a vital role in providing food, feed, and fodder (Acharya *et al*., 2020) [24]. With a cultivation area of 8.69 million hectares, India's maize production stands at 21.81 million tonnes, with a productivity rate of 2509 kg/ha. Major maize-producing states include Andhra Pradesh, Karnataka, Bihar, Maharashtra, Rajasthan, Madhya Pradesh, and Uttar Pradesh, with the highest cultivation concentrated in Karnataka's Shimogga, Belgaum, and Hassan districts. A significant threat to maize production emerged in May 2018 with the detection of the fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), in Karnataka. This invasive pest, originally from the Americas, has since caused substantial damage across India. The ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, reported FAW infestation rates between 9% and 62%, leading to a 34% yield loss (Khatri *et al*., 2020) [28]. The pest has a wide host range of over 353 plant species, primarily from the Poaceae, Asteraceae, and Fabaceae families (Samal *et al*., 2020) [11]. Its early crop emergence, high fecundity, voracious feeding habits, and rapid migration make it a particularly challenging pest to manage. FAW's management is further complicated by its resistance to various pesticides, its strong flight capability, and the cryptic feeding habits of mature larvae, which often render chemical treatments ineffective. Farmers in India have attempted various physical, chemical, and biological control measures, but these have generally been ineffective when applied individually and there is a need for more sustainable, integrated approaches (Deshmukh *et al*., 2023) [18]. Integrated Pest Management (IPM) programs offer a promising solution by combining biological control, habitat manipulation, cultural practice modifications, and the use of resistant crop varieties. This study aims to assess IPM modules against FAW in maize, evaluate traps for FAW monitoring, and test the efficacy of specific insecticides.

Materials and Methods
This study focused on various approaches for the collection, identification, and management of the fall armyworm (FAW). A field study was conducted with two treatments:
1. Technology assessment (IPM module)
2. Farmers' practice (control)

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Two plots per location (1 acre each) were established in farmers' fields. In farmers practice spray of synthetic pesticides twice - Cartap Hydrochloride 50% SP @ 400 gm/acre & Lambda Cyhalothrin 5% EC @ 250 ml/acre were given alternatively @ 15 days interval. In IPM module scouting involved a thorough inspection for FAW egg masses, damaged whorls, and larvae in a "zig-zag" pattern across the field, excluding 3-4 outer rows. Observations were recorded for FAW incidence based on the number of damaged whorls in 50 randomly selected maize plants. The treatments used in the technology assessment plot (IPM module) included avoiding staggered maize sowing, installing pheromone traps @ of 5/acre, clean cultivation, a balanced fertilizer application, erecting bird perches @ 10/ acre, applying Azadiractin 1500 ppm to deter egg laying, and need based application of Emamectin benzoate 5% SG @ 0.5g/l and *Metarhizium anisopliae* at 5g/l. The bio-efficacy of Azadirachtin, Emamectin benzoate, and *M. anisopliae* was evaluated by counting FAW larvae 3 days before and after insecticide application in each 50 m² area (minimum of 50 plants). FAW incidence was recorded before and after treatment in both IPM and control plots. The percentage reduction in the FAW population was calculated using:

Percent population reduction= (Xi−Xo) Xi ×100

Where:

Xi = Number of larvae before insecticide application

Xo = Number of larvae after insecticide application

Results and Discussion

An examination of damaged whorls and a count of larvae in infested whorls were conducted on 45-day-old plants (Table 1). The pheromone traps were observed daily and represented by weekly basis (Table 2). FAW (fall armyworm) infestation was assessed by observing whorl damage in 50 randomly selected maize plants from both the fields following farmer practices and those using integrated pest management (IPM). The whorls were manually opened and checked for the presence of FAW larvae. The infestation rate was calculated by counting the number of infested whorls and expressing it as a percentage. Additionally, the total number of male adult moths caught in each trap was counted weekly, with the average number of moths recorded up until the crop was harvested.

The efficacy of Integrated Pest Management (IPM) components in reducing *Spodoptera frugiperda* (FAW) infestation was evaluated by analyzing the mean percent infestation three days before and after the application of different treatments and presented in (Table 3). The use of three key components in IPM- Azadirachtin, Emamectin benzoate, and *Metarhizium anisopliae* resulted in a significant reduction in FAW infestation levels. The application of *M. anisopliae* was particularly effective, reducing infestation from 37% to 16.5%, while Azadirachtin reduced the mean infestation from 53.5% to 26.5%. The most significant impact was observed with Emamectin benzoate (EB), which reduced FAW infestation from 46.5% to 20%. The combined use of Azadirachtin, Emamectin benzoate, and *M. anisopliae* in IPM led to a notable decrease in FAW infestation from an initial 49% to 17% which accounts 67.3% of overall control efficiency. When comparing the efficacy of chemical insecticides in farmers' practice (Table 4), Cartap hydrochloride reduced infestation from 45% to 27%, with a control efficiency of 40%, while Lambda cyhalothrin reduced infestation from 37% to 20%, with a control efficiency of 46%. On average, the farmer's practice showed a mean reduction from 41% to 23.5%, achieving a control efficiency of 43%. A comparison between IPM and farmers' practice (FP) (Table 5) also revealed a clear difference in FAW infestation levels. The infestation rate in the IPM plots was 20%, which is significantly lower than the 47.05% observed in FP fields, representing a difference of 27.05%. Additionally, the mean number of larvae per plant in IPM fields was 1.0, compared to 1.9 in FP, while an average of four male adult moths were trapped weekly in IPM fields highlighting the effectiveness of pheromone traps in FAW population management. The reduction in egg masses and larvae per plant observed in IPM fields indicates that IPM practices contribute to improved yield, gross returns, net returns, and favourable benefit-cost ratios when compared to traditional farmer practices.

Spodoptera frugiperda (FAW) has severely impacted maize production in India since its invasion, threatening yield stability across the region. In our study, the reduction in FAW egg masses observed in IPM fields can be attributed to the integration of pheromone traps, which target adult male moths, and selective insecticides, which suppress future populations. Traditional reliance on chemical insecticides alone has proven insufficient. Recent findings indicate that integrated pest management (IPM) strategies are more effective and sustainable. By combining cultural practices, biological agents, and selective insecticides, IPM enhances pest control. Pheromone traps effectively monitor adult populations, aiding in timely insecticide applications. Azadirachtin and *M. anisopliae* have shown significant reductions in FAW infestation, while Emamectin benzoate also yielded positive results. Overall, IPM integration offers a balanced approach in managing FAW and minimizing crop losses.

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Table 1: Mean number of larvae per plant on observing 50 plants / week in FP and IPM field

Week	Farmer practices	integrated pest management
1	1.2	0.6
2	1.3	0.8
3	1.8	1.2
4	2.2	1.4
5	2.5	1.5
6	2.3	1.6
7	2.1	1.1
8	1.7	0.9

Table 2: Number of adults per trap per week

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Trap No.1	6	5	4	3	3	2	2	1
Trap No.2	5	4	3	2	2	1	1	1
Trap No.3	3	3	3	2	2	2	0	0
Trap No.4	4	5	2	1	2	1	2	1
Trap No.5	5	4	1	1	2	1	0	0

Table 3: Percent infestation of FAW, *Spodoptera frugiperda* 3 days before and after application of different components of IPM on examining 50 plants

Components	Mean percent infestation		Control efficiency (%)
	Pre-treatment infestation	Post-treatment infestation	
Azadirachtin	53.5	26.5	50.46
Emamectin benzoate	46.5	20	57
Metarhizium anisopliae + *Beauveria bassiana* (GRUBKILL)	37	16.5	55.4
Combined use of key components	49	17	67.3

Table 4: Percent infestation of FAW, *Spodoptera frugiperda* before and after application of Farmer's practice on examining 50 plants

S. No.	Components	Mean percent infestation		Control efficiency (%)
		Pre-Treatment infestation	Post-Treatment infestation	
1	Cartap hydrochloride	45	27	40
2	Lambda cychalothrin	37	20	46
	Mean	41	23.5	43

Table 5: Comparison of farmers practices with the IPM practices for FAW infestation

S. No	Parameters	Farmers' practice	IPM	Difference between IPM & FP
1	Infestation level (%) (By observation of larvae on 50 plants)	47.05	20	27.05
2	Mean No. of larvae per plant	1.9	1.0	0.8
3	Mean No. of adults per trap	-	4	-

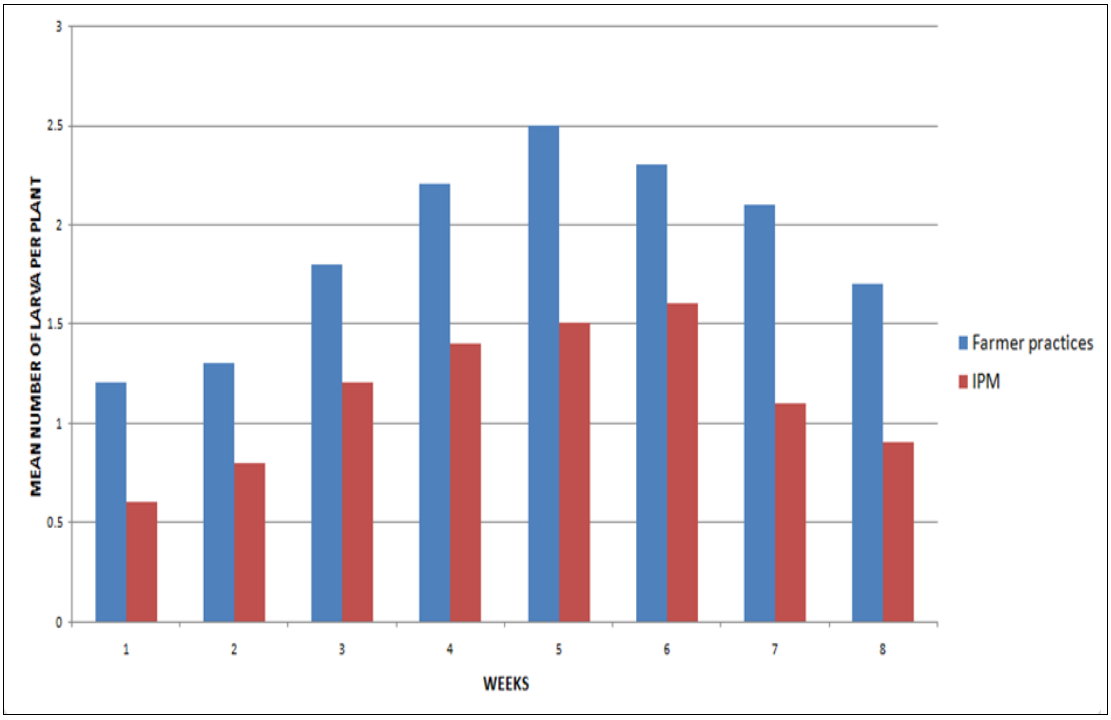

Fig 1: Mean number of larvae per plant on observing 50 plants /week in FP and IPM field

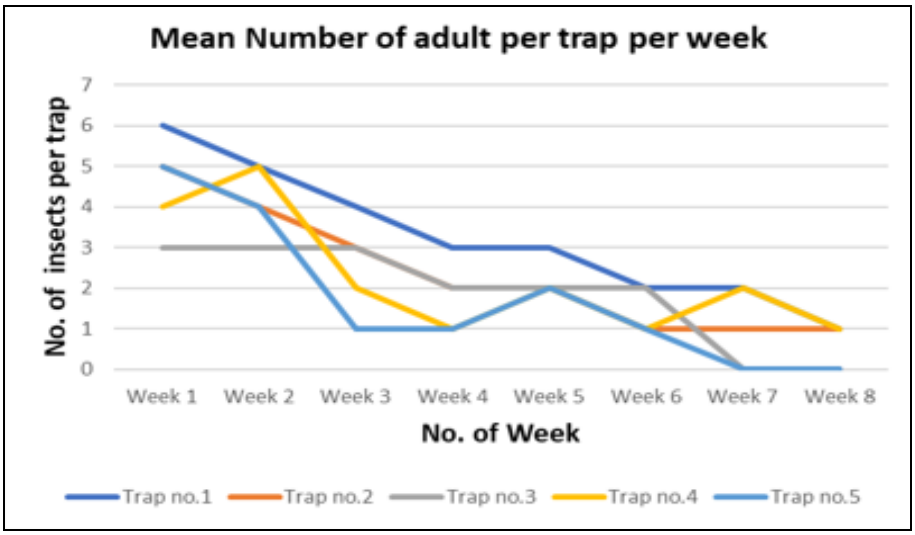

Fig 2: Number of adults per trap per week

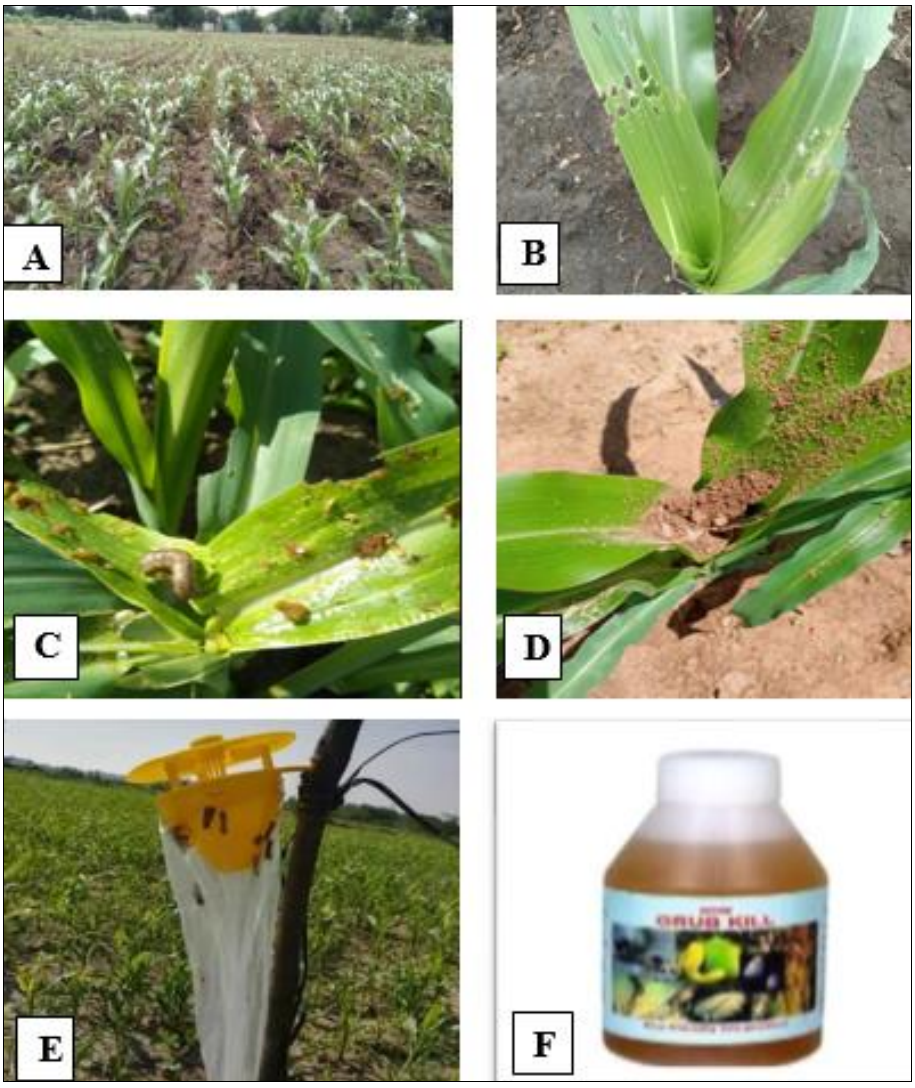

Fig 3: A. Maize field, B. Window Leaf holes, C. Larvae feeding the maize plant, D. Application of sand in infected whorls, E. Pheromone traps, F. Grub kill

Conclusion

The study demonstrates that Integrated Pest Management (IPM) is a highly effective and sustainable approach for managing the fall armyworm (FAW) in maize fields. By integrating pheromone traps, selective insecticides such as Azadirachtin, Emamectin benzoate, and Metarhizium anisopliae, along with cultural practices like clean cultivation and balanced fertilization, IPM significantly reduced FAW infestation and its detrimental effects on maize yields. The IPM treatments showed a remarkable reduction in FAW populations, outperforming traditional farmer practices that relied primarily on chemical pesticides. The results emphasize

the importance of adopting integrated pest management strategies for long-term pest control, economic sustainability, and improved crop productivity in maize farming across India.

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