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Large scale field validation of integrated pest management strategies in maize (*Zea mays*) through farmers' participatory approach

M K KHOKHAR[1], ANOOP KUMAR[1]*, DEEPAK JAIN[2], SUBY S B[3], RICHA VARSHNEY[4], RAKESH KUMAR[1], L K ACHARYA[1], AJANTA BIRAH[1], MANOJ CHOUDHARY[1] and RASHID PARVEZ[5]

ICAR-National Research Institute for Integrated Pest Management, New Delhi 110 068, India

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ABSTRACT

The present study focused on the synthesis, validation and promotion of an Integrated Pest Management (IPM) strategy in maize (*Zea mays* L.) cultivation through farmer participation in Udaipur, Rajasthan, from 2022–24. The results showed significantly lower mean infestation of fall armyworm [*Spodoptera frugiperda* (J E Smith)] in IPM (17%) compared to farmer practices (FP) (32.9%). Maydis leaf blight severity was 14.6% in IPM fields and 23.2% in FP, while banded leaf and sheath blight severity was 7.4% in IPM and 11.5% in FP demonstrating the effectiveness of IPM in reducing pest infestation over farmer practices. Natural enemy populations were recorded higher in IPM (7.2/50 plants) compared to FP (3.6/50 plants). The economic analysis demonstrated the superior profitability of the IPM approach, which recorded increase in grain yield (20%) and net return (51.73%) over FP. The benefit-cost ratio in IPM (2.39) further emphasised its profitability compared to FP (1.87). IPM field recorded >83 % reduction in chemical pesticides application over FP which facilitated the conservation of natural enemies resulting in 100% increase in predators population in IPM over FP. The study concludes that participatory IPM implementation in maize reduced pest infestation, enhanced yield and profitability with environmental sustainability.

Keywords: Economics, Fall armyworm, Maize IPM, Maydis leaf blight, Natural enemies, Yield

Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat. It serves as a staple food, livestock feed and an essential raw material for industries producing starch, ethanol and biofuels. The average maize productivity in India is approximately 3.5–4.0 t/ha, which is lower than the global average of 5–6 t/ha. Maize cultivation in India faces significant challenges from various insect pests and diseases, which can substantially impact crop yield and quality.

Among the major insect pests, the fall armyworm (FAW) [*Spodoptera frugiperda* (J E Sminth)], first reported in India in 2018, has emerged as a devastating threat, capable of causing 20–80% yield losses (Early *et al.* 2018). The stem borer (*Chilo partellus*), oriental armyworm (*Mythimna separata*), and the cob borer (*Helicoverpa armiger*a) are other serious pest, particularly in the *kharif* season (Abebe 2023). In addition to insects, maize crops suffer from several fungal, bacterial and viral diseases (Gogoi *et al.* 2020). Maydis Leaf Blight (MLB), caused by *Bipolaris maydis*, is a significant foliar disease, with yield losses reaching 40–70% (Gogoi *et al.* 2022). Banded Leaf and Sheath Blight (BLSB), caused by *Rhizoctonia solani* f. sp. *sasakii*, is a major concern in humid regions. Additionally, post flowering stalk rot, caused by *Fusarium verticillioides*, leads to plant wilting and yield decline (Devi and Thakur 2018, Kaur *et al.* 2020). Despite the availability of several management options for insect pests and diseases in maize, important research gaps still exist, particularly in the context of integrated management of FAW and major maize diseases under Indian agro-ecological conditions. Most of the studies conducted on FAW management in India have primarily focused on chemical insecticides, while limited attention has been given to developing location-specific, eco-friendly, and economically viable Integrated Pest Management (IPM) modules. Climate variability further complicates pest and disease dynamics, necessitating the development of resilient and sustainable IPM strategies.

Therefore, there is a critical need to develop and validate comprehensive IPM module integrating insect pest and disease management approaches for enhancing maize productivity, reducing pesticide dependence and ensuring environmental sustainability under diverse maize-growing

[1]ICAR-National Research Institute for Integrated Pest Management, New Delhi; [2]Krishi Vigyan Kendra, Vidya Bhavan, Udaipur, Rajasthan; [3]ICAR-Indian Institute of Maize Research, Ludhiana, Punjab; [4]ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, Karnataka; [5]ICAR-Indian Agricultural Research Institute, New Delhi. *Corresponding author email: anooptiwariento@gmail.com

regions of India. In view of above, an IPM module was synthesised and validated under farmers' field conditions for its large scale adoption to safeguard maize yields and promote sustainable maize production.

MATERIALS AND METHODS

Experimental site: The study was carried out during rainy (*kharif*) season 2022–25 by ICAR-National Research Institute for Integrated Pest Management, New Delhi through farmers participatory approach at Turgarh village, Udaipur (24°28'40.4"N, 73°35'80.02"E), Rajasthan. The trial initially covered 8.0 ha with 30 progressive farming families in 2022–23 and was expanded to 50 ha with 100 families in 2024–25. Population and incidence of major pests were compared with Farmer Practices (FP) and untreated control plots.

Baseline information collection: Baseline information data were collected by interviewing 50 maize growing farmers in 2022. The survey focused on cropping patterns, agronomic practices, key pests affecting maize, farmers' knowledge of pests and natural enemies, crop protection practices, number of pesticides sprayed, sources of technical and crop protection inputs and the maize yields obtained by the farmers.

IPM strategy: IPM module consisted of seed treatment with *Trichoderma asperellum* @10 g/kg of seeds, installation of pheromone trap @10/ha, spray of azadirachtin 1,500 ppm @5 m/L at 10 days after planting (DAP), spray of biopesticide *Metarhizium anisopliae* (1×10^8 cfu/g @10 g/L), and release of *Trichogramma chilonis* @1 card/acre (16,000–20,000 eggs). The pheromone lures were fixed in the lure holder and changed once in a month. The traps served as a monitoring tool. The neem pesticides were used early, when one moth/trap was trapped, since they act as oviposition deterrent against egg-laying female moths, and feeding deterrent against the larvae. The chemical pesticide was the last component in the IPM package. Application of bio-pesticide or pesticide treatments started after one week of emergence of seedling, when the *S. frugiperda* infestation built-up and exceeded the economic threshold level (about 1 larvae/plant). The IPM package was compared with the farmers' practice, and untreated control of 100 m^2 was maintained to ascertain the presence of pest in the area. Farmers' practice mainly involved calendar-based spraying of chemical pesticides for management of pests as per the advice of pesticides dealers.

Data collection: The pest incidence was weekly monitored from seedling emergence till the final harvest from five IPM and five FP fields of one acre each. For all the treatments, the observation on pest incidence were recorded from 50 randomly selected plants with 10 plants/spot from five spots in 'W' pattern in the field after leaving 4–5 outer rows and the percentage of infestation was calculated. Plants with window pane symptoms or fresh excreta in the whorl was counted as FAW infested one. For diseases, % severity was calculated using the standard rating scale. The population of predators (coccinelids, spiders) were recorded per 50 plants. The data on yield, cost of cultivation and pesticides applications were recorded and economics was worked out.

Data analysis: Weekly data on pests and natural enemies were subject to statistical analysis with student t test (p<0.05) using r software. IPM fields were compared with farmers practice (FP). Further, the benefit cost (B:C) ratio was calculated for the farmers' practice and IPM package.

RESULTS AND DISCUSSION

Baseline information: Baseline information about the villages was collected, which indicated that the total cultivated area in the village is about 300 ha out of which maize occupies an area of about 150 ha and other crops grown in the area are soybean, mung, ginger and few vegetables. Majority of the farmers do not have irrigation facility. Ninety per cent of the area is under rainfed condition. The source of irrigation was tube well with 40–50 ft water table. Farmers did not face any significant pest problem in maize earlier except FAW, which appeared since 2020, and they never required to spray any insecticides or fungicides. The yield of maize was 24 q/ha which ranges between 18–30 q/ha. Baseline information revealed that chemical pesticides were the primary method of pest management in the village, and farmers lacked awareness of the IPM concept. Pesticide applications were solely based on recommendations from pesticide dealers. Farmers had limited knowledge of the effects of high nitrogen doses, timely sowing, and an ETL-based approach to plant protection. Key pest problems in the area are fall armyworm, stem borer, maydis leaf blight, post flowering stalk rot, and banded leaf and sheath blight.

Pest status: The results on pest and natural enemy dynamics in maize under IPM, FP and untreated control during *kharif* 2022–24 at Udaipur revealed significant differences among the treatments (Table 1, Fig. 1 and 2). The pooled mean data indicated that the IPM module consistently reduced the incidence of major insect pests and diseases while simultaneously conserving higher populations of natural enemies compared to FP.

The incidence of FAW remained significantly lower in IPM plots during all the years of study. The pooled mean of FAW infestation under IPM was 17.5% as against 32.9 and 55.2% in FP and untreated control plots, respectively. The IPM module recorded 46.81% reduction in FAW infestation over FP. During 2022, FAW incidence in IPM plots was restricted to 17.2% compared to 35.9% in FP and 52.4% in control. Similar trends were observed during 2023 and 2024, indicating the sustained effectiveness of IPM practices in suppressing FAW population (Table 1).

Weekly observations further revealed that FAW infestation gradually increased from Standard Meteorological Week (SMW) 30 onwards and reached peak levels between SMW 35 and 39 in all treatments (Fig. 1). However, the magnitude of infestation remained considerably lower in IPM plots throughout the crop season. In untreated control plots, FAW infestation exceeded 70–80% during peak infestation weeks, particularly during 2023, whereas IPM plots maintained infestation mostly below 20% during the same period. FP plots showed intermediate infestation levels ranging from 30–40% during peak activity. The lower infestation in IPM plots might be attributed to regular monitoring, timely installation of pheromone traps, biological interventions and need-based application of safer insecticides. This reduction highlights the effectiveness of IPM in managing FAW populations across multiple years. IPM's success can be attributed to the strategic combination of biological and chemical control measures. The use of *Metarhizium anisopliae,* a naturally occurring entomopathogenic fungus, combined with the release of *Trichogramma chilonis* parasitoids targets FAW eggs and larvae, providing effective suppression (Giri *et al.* 2026). The neem-based formulations applied in this study might have exhibited antifeedant, repellent or toxic effects against FAW. Azadirachtin, a key component, has been shown to delay larval development and significantly increase mortality rates (Santos *et al.* 2015). In comparison, FP treatments, which primarily rely on calendar-based chemical spraying, had higher infestation rates due to spray timing, limited efficacy, and harm to natural predators. Control plots, which received no pest management intervention, experienced the highest infestations, as expected, demonstrating the importance of active pest control measures. These findings are consistent with other studies that have shown the effectiveness of IPM in controlling FAW infestations, underscoring its role in sustainable pest management and environmental conservation (Sanon *et al.* 2025). The consistent performance of IPM over the three years reinforces its value as a reliable strategy for reducing FAW populations while minimising the environmental and economic costs associated with conventional pesticide use.

The incidence of Maydis leaf blight (MLB) was also recorded lower in IPM plots. The pooled mean of MLB incidence was 14.6% under IPM compared to 23.2% in FP and 30.2% in untreated control, accounting for a 37.07% reduction over FP. The disease incidence remained comparatively higher in control plots throughout the study period, suggesting the effectiveness of integrated disease management practices in minimising disease development. Similarly, banded leaf and sheath blight (BLSB) incidence was significantly lower under IPM treatment. The pooled mean of BLSB incidence was 7.4% in IPM plots compared to 11.5 and 18.6% under FP and control, respectively. The IPM approach achieved 35.65% reduction in disease incidence over FP. The reduction in BLSB under IPM may be due to improved crop canopy management, balanced nutrient application, and reduced pathogen build-up. Post flowering stalk rot (PFSR) incidence followed a similar trend. The pooled mean of PFSR incidence under IPM was 7.3% whereas FP and control plots recorded 12.3 and 15.4% incidence, respectively. The IPM module reduced PFSR incidence by 40.65% over FP. Lower stalk rot incidence in IPM plots might be associated with reduced plant stress and improved plant vigour resulting from integrated crop

Table 1 Pest and natural enemy status in maize under IPM, FP and control fields at Udaipur (*kharif* 2022–24)

Year	Treatments	FAW (%)	MLB (%)	BLSB (%)	PFSR (%)	Predators (Nos./50 plants)
	IPM	17.2 ± 2.08	10.4 ± 2.43	9.18 ± 2.01	8.7 ± 1.61	7.0 ± 1.01
2022	FP	35.9 ± 4.24	18.6 ± 2.61	12.8 ± 242	14.3 ± 2.25	3.5 ± 1.25
	Control	52.4 ± 4.05	22.8 ± 3.69	12.8 ± 2.78	18.5 ± 3.66	12.2 ± 0.95
	% Change in IPM over FP	-52.09	-44.09	-28.28	-39.16	100.00
	IPM	18.2 ± 2.69	15.5 ± 1.07	4.53 ± 1.03	5.63 ± 0.70	8.46 ± 2.53
2023	FP	30.0 ± 4.61	22.4 ± 1.06	8.62 ± 1.48	10.1 ± 0.99	3.96 ± 0.94
	Control	58.3 ± 3.98	30.0 ± 1.71	21.6 ± 1.73	12.3 ± 1.31	13.5 ± 1.25
	% Change in IPM over FP	-39.33	-30.80	-47.45	-44.26	113.64
	IPM	17.1 ± 1.07	18.0 ± 1.90	8.4 ± 1.26	7.6 ± 0.84	6.2 ± 1.15
2024	FP	32.8 ± 1.42	28.7 ± 2.10	13.2 ± 1.60	12.5 ± 1.21	3.4 ± 0.84
	Control	55.0 ± 2.35	37.7 ± 2.84	21.3 ± 2.30	15.3 ± 1.40	10.0 ± 1.01
	% Change in IPM over FP	-47.87	-37.28	-36.36	-39.20	82.35
	IPM	17.5 ± 0.61	14.6 ± 3.87	7.4 ± 2.49	7.3 ± 1.56	7.2 ± 1.15
Pooled mean	FP	32.9 ± 2.95	23.2 ± 5.10	11.5 ± 2.54	12.3 ± 2.11	3.6 ± 0.30
	Control	55.2 ± 2.96	30.2 ± 7.45	18.6 ± 5.00	15.4 ± 3.10	11.9 ± 1.77
	% Change in IPM over FP	-46.81	-37.07	-35.65	-40.65	100.00

Values are the mean of 10 weeks ±Standard deviation. FAW, Fall armyworm; MLB, Maydis leaf blight; BLSB, Banded leaf and sheath blight; PFSR, Post flowering stalk rot; IPM, Integrated pest management; FP, Farmers practice.

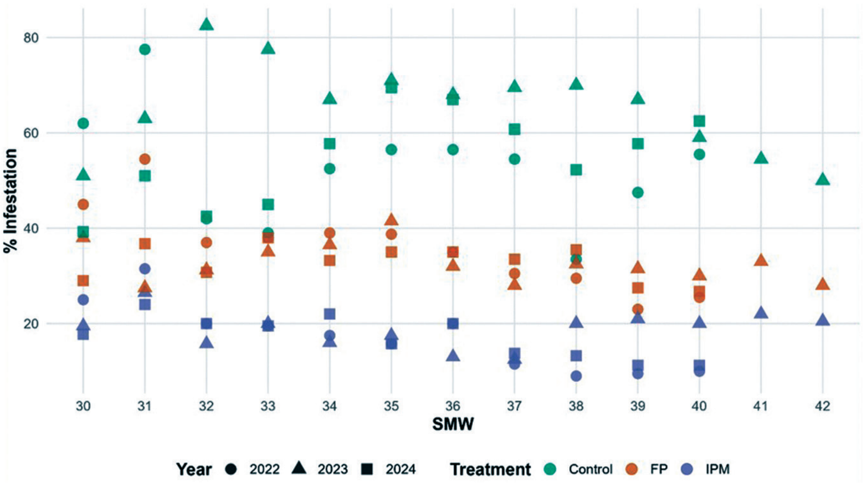

Fig. 1 Average Fall army worm (*S. frugiperda*) infestation in maize at Udaipur during 2022–24.
FP, Farmers practice; IPM, Integrated pest management; SMW, Standard meteorological week.

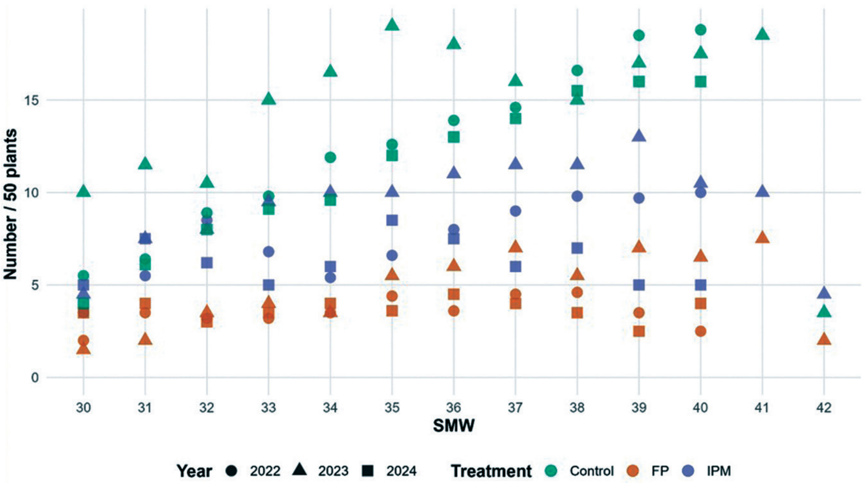

Fig. 2 Average natural enemies' population in maize at Udaipur during 2022–24.
FP, Farmers practice; IPM, Integrated pest management; SMW, Standard meteorological week.

and pest management practices. IPM emphasises the use of seed treatment with *Trichoderma asperellum* @10 g/kg of seeds, proper field sanitation, crop rotation, spray of neem oil, balanced fertilisation, proper plant spacing and timely removal of infected plant material that help to reduce the spread of fungal spores, minimising disease outbreaks which collectively reduces disease prevalence (Patel *et al.* 2023). *Trichoderma,* a beneficial fungus, significantly reduces soil-borne diseases in maize through multiple mechanisms. It directly competes with parasitises and pathogenic fungi by producing enzymes that degrade their cell walls and secreting antibiotics that inhibit their growth (Singh *et al.* 2018). The application of *Trichoderma* as a seed treatment, soil drench, or in organic amendments has been shown to significantly reduce disease incidence and improve crop yields (Sharma *et al.* 2020).

Natural enemies: The population of natural enemies was comparatively higher in IPM plots than in FP plots during all the years of experimentation. The pooled mean predator population in IPM plots was 7.2 predators/50 plants, which was double than that recorded under FP (3.6 predators/50 plants). Although untreated control plots recorded the highest predator population (11.9 predators/50 plants), they also harboured maximum pest infestation owing to the absence of any management intervention. The weekly dynamics of natural enemies indicated that predator populations gradually increased from SMW 30 and attained peak abundance between SMW 35 and 41 (Fig. 2). During peak activity period, untreated control plots recorded the highest predator population (15–19 predators/50 plants), followed by IPM plots (8–13 predators/50 plants), whereas FP plots consistently maintained lower predator abundance. The comparatively higher predator population under IPM than FP suggests that the IPM module was relatively safer to beneficial fauna and favoured conservation of natural biological control agents. In contrast, indiscriminate pesticide use under FP might have adversely affected predator survival and activity. The results indicate that IPM significantly supported higher populations of natural enemies in maize ecosystems. The enhanced abundance of natural enemies under control and IPM can be attributed to minimal or no use of broad-spectrum insecticides, instead relying on eco-friendly alternatives such as Azadirachtin, *Metarhizium anisopliae* and biological control agents like *Trichogramma chilonis*. These practices reduce pesticide-induced mortality among beneficial arthropods and create a more favourable habitat for predators and parasitoids (Pretty and Bharucha 2015, Gurr *et al.* 2017). Moreover, the conservation and augmentation of natural enemies are central to the IPM strategy which emphasises the ecological balance between pest and predator populations. Studies have shown that natural enemies such as coccinellids, spiders and parasitoid wasps play a crucial role in regulating pest outbreaks like fall armyworm and stem borers when chemical disruption is minimised. The higher natural enemy population in IPM plots underscores the system's sustainability and its potential to maintain pest levels below economic thresholds without compromising environmental health.

Economic analysis: The economic analysis further substantiated the superiority of the IPM module over FP

Table 2 Economic analysis of IPM and FP fields at Udaipur during 2022–24

Parameters	2022		2022		2023		Pooled		
	IPM	FP	IPM	FP	IPM	FP	IPM	FP	% change in IPM over FP
Chemical pesticide sprays (No.)	0	1	1	2	0	3	0.33	2.00	-83.50
Pesticide active ingredient (g/ha)	0.0	27.75	27.75	55.50	0.0	83.25	9.25	55.50	-83.33
Yield (q/ha)	36	30	40	32	32	27.5	36.00	29.83	20.68
Gross income (₹/ha)*	66,600	55,500	78,480	62,784	62,784	53,955	69,288	57,413	20.68
Cost of cultivation (₹/ha)	28,800	29,200	29,700	30,450	28,450	32,900	28,983	30,850	-6.05
Net income (₹/ha)	37,800	26,300	48,780	32,334	34,334	21,055	40,304	26,563	51.73
Benefit-cost ratio	2.31	1.90	2.64	2.06	2.20	1.63	2.39	1.86	

*IPM, Integrated pest management; FP, Farmers practice. Market price of maize ₹1,962/q.

(Table 2). The pooled data indicated that IPM plots required only 0.33 chemical pesticide sprays compared to 2.0 sprays under FP, resulting in 83.50% reduction in pesticide application frequency. Likewise, the quantity of pesticide active ingredient used under IPM was drastically reduced to 9.25 g/ha compared to 55.50 g/ha in FP, representing 83.33% reduction in pesticide load. Despite lower pesticide usage, the IPM module produced significantly higher grain yield (36.0 q/ha) than FP (29.83 q/ha), accounting for 20.68% yield enhancement. Higher productivity under IPM consequently resulted in greater gross return (₹69,288/ha) compared to FP (₹57,413/ha). Furthermore, the cost of cultivation under IPM was lower (₹28,983/ha) than FP (₹30,850/ha), mainly due to reduced expenditure on chemical pesticides and plant protection operations. Consequently, IPM plots recorded substantially higher net income (₹40,304/ha) compared to FP (₹26,563/ha), with 51.73% increase in profitability over FP. The benefit-cost ratio was also higher under IPM (2.39) than FP (1.86), indicating better economic feasibility and sustainability of the IPM approach. These findings align with recent studies emphasising the economic and ecological benefits of IPM, such as reduced pesticide dependency, enhanced yields, and improved profitability (Pretty *et al.* 2018). This analysis underscores IPM as a viable pathway for sustainable intensification, offering a balanced approach to achieving food security and economic viability in maize production systems. These findings align with earlier studies suggesting that IPM reduces unnecessary pesticide use, lowers input costs, and improves yield stability (Pretty and Bharucha 2015). The use of biological control agents and botanical formulations in IPM not only maintains pest populations below economic thresholds but also ensures higher economic return by minimising losses due to pest damage and reducing pesticide-related expenditures. Additionally, IPM fosters long-term sustainability by preserving beneficial organisms and preventing pest resistance, contributing to both economic and environmental resilience (Kumar and Shaijumon 2026).

Knowledge improvement: Farmers meetings, farmer's field school and IPM field day were organised at regular intervals in the village that helped in developing strong linkages among farmers, scientists and extension workers and enabled 100% of IPM farmers to identify the major pests and natural enemies (spiders, coccinelid), understand the role of installation of pheromone trap in monitoring, role of seed treatment, field sanitation and weed removal in pest management, concept of ETL and need based application of safer pesticides. These findings are in agreement with earlier studies, which reported that Farmers' Field Schools and enhanced farmer awareness are among the most effective approaches for improving IPM knowledge among farmers (Srinivasan *et al.* 2019, Dhakal and Poudel 2020).

In conclusion, the present study demonstrated that the IPM module was effective in suppressing major insect pests and diseases of maize while conserving natural enemies and reducing pesticide dependence under field conditions. The reduced pest and disease incidence, enhanced predator population, lower pesticide load, and higher economic return under IPM indicated the ecological and economic viability of integrated pest management strategies for sustainable maize production under southern Rajasthan conditions.

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