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Field validation of integrated pest management strategy in *Bt* cotton (*Gossypium hirsutum*) under farmers' participatory mode in central India

AJANTA BIRAH[1], LICON KUMAR ACHARYA[1]*, M K KHOKHAR[1], ANOOP KUMAR[1], REKHA BALODI[1], KARUNESH K SHUKLA[1], RISHI KUMAR[2] and SATISH PARSAI[3]

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

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ABSTRACT

A field study was carried out during rainy (*kharif*) season of 2022 to 2024 in Khandwa district, Madhya Pradesh to evaluate the performance of Integrated Pest Management (IPM) in *Bt* cotton (*Gossypium hirsutum* L.) under farmers' participatory mode. The experiment was conducted using a randomised complete block design (RCBD) having three treatments, viz. T_1, Integrated Pest Management (IPM); T_2, Farmers' Practice (FP); and T_3, Untreated Control (UC). IPM packages included timely sowing with refugia, border cropping, cowpea intercropping for natural enemy conservation, neem oil sprays (Azadirachtin 1500 ppm), need-based application of Flonicamid for sucking pests, SPLAT pheromone formulations for pink bollworm management, selective insecticides (spinetoram or emamectin benzoate), and crop termination with residue destruction. IPM fields were compared with Farmers' Practice (FP) and Untreated Control (UC). Data were analysed using ANOVA under a mixed-effect model. IPM adoption significantly reduced pest infestations up to 81% over FP across major pests, accompanied by higher populations of beneficial insects. Pesticide sprays were reduced by 46.55% without yield penalty. Instead, seed cotton yield increased by 25.38%, and net returns improved by more than 56% over FP. IPM strategy proved highly effective in reducing major cotton pests, ecologically safer by enhancing natural enemy population, and significantly lowering pesticide use across three seasons along with high benefit-cost ratio. Scaling this validated strategy through farmer field schools and improved access to pheromone-based tools can support wider adoption in future throughout the country.

Keywords: Cotton, Integrated pest management, Natural enemies, Pink bollworm, Sucking pests

Cotton (*Gossypium hirsutum* L.), popularly referred to as "white gold," plays a central role in the livelihoods and economic fabric of rural India, contributing significantly to the livelihood of millions of farmers and workers involved in cotton production, processing, and marketing. India ranks among the largest producers and consumers of cotton globally. However, cotton cultivation in India is highly input-intensive, especially in terms of pesticide usage, making it one of the crops most vulnerable to pest-induced yield losses. In the current scenario, key pests affecting cotton include jassids (*Amrasca biguttula biguttula* Ishida), whiteflies (*Bemisia tabaci* Gen), thrips (*Thrips tabaci* Lindeman), mealybugs, and the resurgence of pink bollworm (*Pectinophora gossypiella* Saunderd) (Naik *et al.* 2017 and 2018, Nagrare *et al.* 2018). Since 2016, the resurgence of pink bollworm (PBW) has posed a serious threat to cotton production in the Central Zone of India. As the season progresses, the late-formed fruiting bodies become increasingly susceptible to PBW infestation, prompting farmers to resort to insecticide sprays. However the conventional insecticides have shown limited effectiveness against PBW due to the internal feeding habit of larva within developing cotton bolls. The extent of lint damage is often so severe that farmers are forced to abandon harvesting, as the affected seed cotton loses its market value. These challenges underscore the urgent need for the development and implementation of ecologically sustainable and integrated pest management (IPM) strategies targeting major cotton pests.

Historically, farmers have depended heavily on indiscriminate and prophylactic use of chemical pesticides for pest management, resulting in adverse outcomes such as pesticide resistance, pest resurgence, secondary pest outbreaks, and detrimental impacts on non-target organisms, such as pollinators and predators. Furthermore, excessive pesticide use increases the cost of cultivation and poses risks to human health and the environment. IPM is an ecosystem-based approach that emphasizes long-term pest suppression through biological control, habitat management,

[1]ICAR-National Research Institute for Integrated Pest Management, New Delhi; [2]ICAR-Central Institute of Cotton Research, Sirsa, Haryana; [3]B M College of Agriculture, Khandwa, Madhya Pradesh. *Corresponding author email: likuamir24@gmail.com

cultural practices, resistant varieties, and the rational use of pesticides. IPM promotes decision-making based on economic thresholds and pest monitoring, thus minimizing unnecessary pesticide applications. While IPM has been promoted through various national programmes and extension services, its adoption remains limited, especially among smallholder farmers. This gap can be attributed to factors such as lack of awareness, technical knowledge, and locally adapted IPM modules. Therefore, it is critical to involve farmers directly in the process of technology validation and adaptation through participatory approaches. This study was carried out with the objectives to validate the effectiveness of IPM practices for managing major pests in *Bt* cotton, to assess the impact of IPM on pesticide usage, crop yield, and profitability to encourage farmer participation in pest monitoring and management and thereby to evaluate the ecological benefits of IPM, including the conservation of natural enemies.

MATERIALS AND METHODS

Study area and climatic conditions: The study was carried out during the rainy (*kharif*) seasons of 2022–2024 across three selected villages within Khandwa district, Madhya Pradesh, a key cotton-growing region located in Central India. The area is characterised by black cotton soils with moderate fertility, a semi-arid climate, and a monsoon-dependent cropping pattern. The average annual rainfall during the study period ranged from 800–950 mm, received mostly between June–September. The temperature varied between 22°C–39°C. Field trial on cotton IPM was conducted at Chichgohan, Bherukheda and Bamjhar villages of Khandwa district in Madhya Pradesh in farmer participatory mode in an area of 20 ha covering 26 farm families in 2022, 40 ha covering 36 farm families in 2023 and 50 ha covering 39 farm families in 2024.

Baseline information: The baseline data were collected through farmer interviews involving 30 cotton growers (each village) from Chichgohan, Bherukheda and Bamjhar village of Khandwa district in Madhya Pradesh. Data were collected on cropping pattern, existing agronomic practices, major pest incidence in cotton, pest management practices, number of pesticide sprays, farmers' awareness of pests and natural enemies, sources of technical and crop protection inputs, input and advisory sources, and yield obtained.

Experimental design and treatments: A total of 30 farmers were selected from different villages using a stratified random sampling method. The farmers were trained on IPM concepts and implementation protocols before the initiation of the trials. Each field included three replicates, and farmer fields were considered independent experimental units within the randomized complete block design (RCBD). The same farmers and field replicates were monitored consistently across all three years. Each farmer allocated two 1-acre plots: one managed under the IPM module (Table 1) and the other under their regular pest management practices (Farmers' Practice, FP). A third treatment, Untreated Control (UC), was maintained on research-managed fields for comparison. The experiment was conducted using RCBD having three treatments, such as, T_1, Integrated Pest Management (IPM); T_2, Farmers' Practice (FP); and T_3, Untreated Control (UC). The IPM package was developed based on regional pest profiles, prevailing cropping practices, and locally available resources (Table 1).

Awareness programmes: Farmers' Field Schools (FFS) were conducted at each fortnight intervals to educate farmers on pest and predator identification, economic threshold levels (ETL) of pests, safe and judicious use of pesticides, balanced plant nutrition, awareness about pink bollworm and demonstration of SPLAT (Specialized Pheromone and Lure Application Technology) formulations. In the IPM fields, relatively safer chemical insecticides were used.

Table 1 Integrated Pest Management (IPM) components implemented in *Bt* cotton

IPM Component	Practices Implemented
Cultural practices	• Timely sowing in June along with refugia to avoid peak pest infestation.
	• Use of pest-tolerant *Bt* cotton hybrids; deep summer ploughing to expose pupae.
	• Removal and destruction of crop residues and infested bolls.
	• Crop termination by last week of December followed by destruction of all residues.
Mechanical and physical control	• Installation of pheromone traps @2/acre for bollworm monitoring and yellow sticky traps @10/acre for whitefly monitoring.
	• Collection and destruction of fallen squares/flowers/bolls during early pink bollworm infestation.
	• Application of SPLAT (Gossyplure 4% RTU) @125 g/acre, applied four times (Aug–Nov); dollops placed at 400–500 spots/acre (3 m apart, zigzag) for mating disruption.
Biological control	• Border cropping with sorghum/bajra/maize and cowpea intercropping for conservation of predators (ladybird beetles, spiders, green lacewings).
	• Two sprays of neem oil (Azadirachtin 1500 ppm) @5 mL/L for sucking pests and pink bollworm.
Chemical control	• Selective insecticides applied only when pest levels exceeded ETL.
	• Need-based use of flonicamid 50 WG @200 g/ha for sucking pests.
	• Need-based use of Spinetoram 11.7 SC @0.8 mL/L or Emamectin benzoate 5 SG @ 0.5 g/L for pink bollworm.

Table 2 Effect of IPM strategy on population of sucking pests in *Bt* Cotton

Pest	Year	Treatment	*Mean ± SE	Range	CD (p=0.05)	% Reduction in IPM over FP and UC
Whitefly population (adults/ leaf)	2022	T_1	2.26 ± 0.41^b	0.30–5.60	1.92	-
		T_2	4.45 ± 0.72^a	2.01–12.16		48.40
		T_3	6.13 ± 0.81^a	1.03–13.84		63.08
	2023	T_1	3.35 ± 0.48^c	0.40–8.60	2.33	-
		T_2	6.21 ± 0.80^b	1.80–15.12		45.28
		T_3	9.13 ± 1.05^a	2.22–20.84		63.51
	2024	T_1	1.44 ± 0.28^b	0.12–4.60	1.24	-
		T_2	2.46 ± 0.72^b	0.10–10.16		41.48
		T_3	6.13 ± 0.81^a	1.03–13.84		76.38
	Pooled	T_1	2.35 ± 0.39^c	0.12–8.60	1.86	-
		T_2	4.37 ± 0.75^b	0.10–15.12		45.61
		T_3	7.13 ± 0.89^a	1.03–20.84		67.08
Jassid population (nymphs and adults/ leaf)	2022	T_1	1.39 ± 0.17^c	0.22–2.71	1.16	-
		T_2	3.59 ± 0.39^b	0.80–6.84		61.29
		T_3	4.86 ± 0.56^a	1.33–9.90		71.40
	2023	T_1	1.56 ± 0.22^c	0.21–3.70	1.27	-
		T_2	3.56 ± 0.53^b	0.10–7.40		56.25
		T_3	5.10 ± 0.53^a	1.10–7.90		69.52
	2024	T_1	1.21 ± 0.29^b	0.11–5.50	1.24	-
		T_2	2.27 ± 0.36^b	0.20–6.40		46.92
		T_3	4.05 ± 0.60^a	0.15–8.60		70.27
	Pooled	T_1	1.38 ± 0.23^c	0.11–5.50	0.69	-
		T_2	3.14 ± 0.43^b	0.10–7.40		55.59
		T_3	4.67 ± 0.56^a	0.15–9.90		70.39
Thrips population (nymphs and adults/ leaf)	2022	T_1	5.33 ± 1.12^b	0.13–16.76	6.33	-
		T_2	7.47 ± 1.16a^b	0.04–17.07		28.77
		T_3	13.19 ± 3.41^a	0.12–47.73		59.67
	2023	T_1	7.41 ± 1.16^b	0.11–17.07	6.53	
		T_2	9.39 ± 2.35^b	0.12–29.50		21.23
		T_3	16.67 ± 2.88^a	4.12–47.73		55.15
	2024	T_1	4.45 ± 1.05^b	0.13–15.76	4.70	-
		T_2	6.55 ± 1.10^{ab}	0.16–16.07		31.96
		T_3	9.39 ± 2.35^a	0.12–29.50		52.59
	Pooled	T_1	5.73 ± 1.11^b	0.11–17.07	3.34	-
		T_2	7.80 ± 1.54^b	0.04–29.50		26.63
		T_3	13.08 ± 2.88^a	0.12–47.73		56.07

*Mean of 31–51 Standard Metrological Week; IPM, Integrated pest management; FP, Farmer's practice; UC, Untreated control; CD, Critical Differences. Treatment details are given under Materials and Methods.

Data collection and monitoring: Pest population monitoring was carried out weekly during the active crop growth stage (Standard Meteorological Week, SMW 31–51) using standard entomological methods. Observations included: Population counts of sucking pests such as whitefly (adults), jassid (nymphs and adults), and thrips (nymphs and adults) were recorded per leaf by taking one from the top, middle, and lower canopy. Natural enemies, including ladybird beetles (adults), lacewings (eggs and larvae), and spiders (adults and spiderlings), were monitored per plant at weekly intervals. Pink bollworm damage was assessed by collecting 20 green and open bolls (destructive sampling) from each of 30 IPM and 30 FP fields. Bolls were dissected to determine infestation, and percent damage was calculated based on the number of affected bolls out of the total examined. Seed cotton yield measured in quintals per hectare (q/ha). Economics data including cost of cultivation, gross income and net returns.

Statistical analysis: Data were subjected to analysis of variance (ANOVA) using linear mixed-effects model in R software (v4.4.3). Treatment means were compared using Fisher's Least Significant Difference (LSD) test at α=0.05, and pairwise differences with p<0.05 were considered statistically significant. Pooled mean values across years were used to draw overall interpretation, and variability was expressed as Mean ± Standard Error (SE). All statistical analyses were conducted using R version 4.4.3 (R Core Team 2024) and data restructuring were performed using the 'dplyr' and 'tidyr' packages (Wickham *et al.* 2023). For analysis of variance and comparison of treatment means, appropriate functions from the Agricolae package (de Mendiburu 2021) were used. Where required, linear mixed-effects models were fitted using the lmerTest package (Kuznetsova *et al.* 2017), and post-hoc comparisons were obtained using Emmeans (Lenth 2024).

RESULTS AND DISCUSSION

Baseline information: Baseline socio-economic data revealed that more than 90% of the cultivated area was under rainfed *Bt* cotton, with the remaining land under maize, soybean, and vegetables. Irrigation was mainly through tubewells, and only a few farmers used drip systems. Cotton yields ranged from 3–4 q/acre in rainfed fields to 5–6 q/acre with surface irrigation and 7–8 q/acre under drip irrigation. Most farmers relied on pesticide dealers for insecticide recommendations, while only a few followed scientific advisories/guidance from the College of Agriculture, Khandwa. Farmers typically applied 9–20 pesticide sprays (average 14) per season, using chemicals such as fipronil, lambda-cyhalothrin, cypermethrin, imidacloprid, acephate, diafenthiuron, flonicamid, and others. Tank-mixing of two insecticides with growth promoters and foliar fertilisers was common.

Pest incidence and population dynamics: IPM fields recorded a significant reduction in sucking pest population over FP and untreated control. During 2022–24, reduction over FP was 45.61%, 55.39% and 26.63% in whitefly,

Table 3 Effect of IPM strategy on boll damage due to pink boll worm

Treatments	Statistical parameters	Green boll damage (%)			Pooled mean	Open boll damage (%)			Pooled mean
		2022	2023	2024		2022	2023	2024	
T_1	*Mean ± SE	5.59 ± 0.41^{C}	4.50 ± 0.44^{b}	3.76 ± 0.50^{C}	4.62 ± 0.45^{C}	3.77 ± 0.42^{b}	4.69 ± 1.32^{c}	5.61 ± 0.71^{b}	4.69 ± 0.82^{b}
	Range	2.00–8.10	1.00–7.10	1.00–6.80	1.00–8.10	1.20–6.30	0.20–13.20	3.40–12.10	0.20–13.20
T_2	*Mean ± SE	15.79 ± 1.87^{b}	24.45 ± 2.51^{a}	12.42 ± 1.34^{b}	17.5 ± 1.91^{b}	5.61 ± 0.71^{b}	6.63 ± 1.41^{ab}	8.01 ± 1.18^{b}	6.75 ± 1.10^{b}
	Range	3.50–31.50	3.60–37.10	3.60–22.60	3.50–37.10	3.40–12.10	0.50–14.50	0.20–14.50	0.20–14.50
T_3	*Mean ± SE	24.45 ± 2.51^{a}	27.79 ± 3.36^{a}	22.50 ± 3.52^{a}	24.91 ± 3.13^{a}	14.48 ± 1.93^{a}	10.96 ± 2.29^{a}	12.48 ± 1.58^{a}	12.64 ± 1.93^{a}
	Range	3.60–37.10	7.50–51.50	7.10–46.20	3.60–51.50	3.10–25.50	1.20–25.30	4.30–22.50	1.20–25.50
	CD at (p=0.05)	3.46	4.93	3.44	2.27	5.20	6.95	6.26	3.55
% Reduction in IPM over FP		64.63	81.61	69.71	73.71	32.81	29.18	30.3	30.52
% Reduction in IPM over UC		77.15	83.82	83.28	81.48	73.99	57.18	55.07	62.90

*Mean of 31–51 Standard Metrological Week; IPM, Integrated pest management; FP, Farmer's practice; UC, Untreated control; CD, Critical Differences. Treatment details are given under Materials and Methods.

jassid and thrips, respectively. Whereas, the reduction in IPM over untreated control was much higher i.e. 67.08%, 70.39%, 56.07% in whitefly, jassid and thrips, respectively (Table 2). The results demonstrated that the participatory IPM approach effectively reduced pest populations in cotton crops. This finding aligns with study by various workers (Ameta *et al.* 2006, Patil *et al.* 2014, Chandi *et al.* 2015, Birah *et al.* 2019 and 2023, Kumar *et al.* 2021) which revealed that the application of IPM components, judicious use of insecticides and planting of maize/cowpea as border crop provided successful pest management along with optimum conditions for multiplication and augmentation of natural enemies. Saravanan *et al.* (2015) also reported that IPM technologies like border cropping, use of 5% NSKE, use of recommended insecticides on economic threshold basis were successful in managing the *Bt* cotton pests.

Green and open boll damage due to pink bollworm was found significantly lower in IPM fields as compared to farmer's practice and untreated control (Table 3). The pooled mean (average of three years) reduction in green boll damage in IPM over farmer's practice and untreated control was 73.71% and 81.48%, respectively. Similarly, open boll damage in IPM recorded 30.52% lower as compared to FP and 62.90% than untreated control. These findings align with earlier national trials in central and southern cotton zones where SPLAT-based strategies prevent buildup of insect pest population due to reduced mating rates and substantially reduced bollworm damage. The ecological integration of SPLAT with cultural practices, such as intercropping and crop sanitation, further hindered pest establishment and reproduction. This layered defense system demonstrates that IPM's effectiveness arises from combining behavioural, cultural, and biological principles rather than depending on any single tactic (Srinivas *et al.* 2019, 2021, 2022).

Significantly higher population of natural enemies comprising spiders, coccinellids and green lacewing species were observed in IPM and untreated control as compared to FP. Among beneficials mean population of spiders, lady bird beetle and green lacewing remained higher in IPM (0.66, 0.75, 0.85 adults/plant) and untreated control (0.89, 1.14, 1.13) as compared to farmers' practice (0.33, 0.28, 0.42 adults/plant), respectively (Fig.1). The population of natural enemies remained low in FP which received a higher number of insecticides application (6.78 spray) compared to IPM (3.63 spray) with judicious use of safer insecticides for pest management. Increased in natural enemies under IPM can be attributed to cultural practices such as border cropping with sorghum/bajra/maize and intercropping with cowpea which likely allowed these beneficial species to thrive upon. Findings of Naik *et al.* (2017) suggested that using IGR group insecticide (Flonicamid 50 WDG) in IPM practices sustained a higher population of natural enemies, which played a crucial role in controlling sucking pest populations. These findings were also in accordance with those of Tanwar *et al.* (2007) and Birah *et al.* (2019), Kumar *et al.* (2021, 2023).

Yield performance and economic analysis: IPM fields yielded significantly higher than conventional FP fields (Table 4). IPM reported a mean yield of 15.05 q/ha compared to 11.23 q/ha in the FP fields. On an average, IPM-managed cotton fields recorded a 25.38% increase in seed cotton yield. However, the economic analysis in this study challenges this notion, showing that IPM can reduce overall pest management costs while improving yields. The increased yield was attributed primarily to reduced pest damage and improved plant health due to good agricultural practices. The net profit was increased by 56.18% in IPM over FP, mainly because of reduced pesticide use resulted in high benefit-cost ratio in IPM (2.92) as compared to FP fields (2.09).

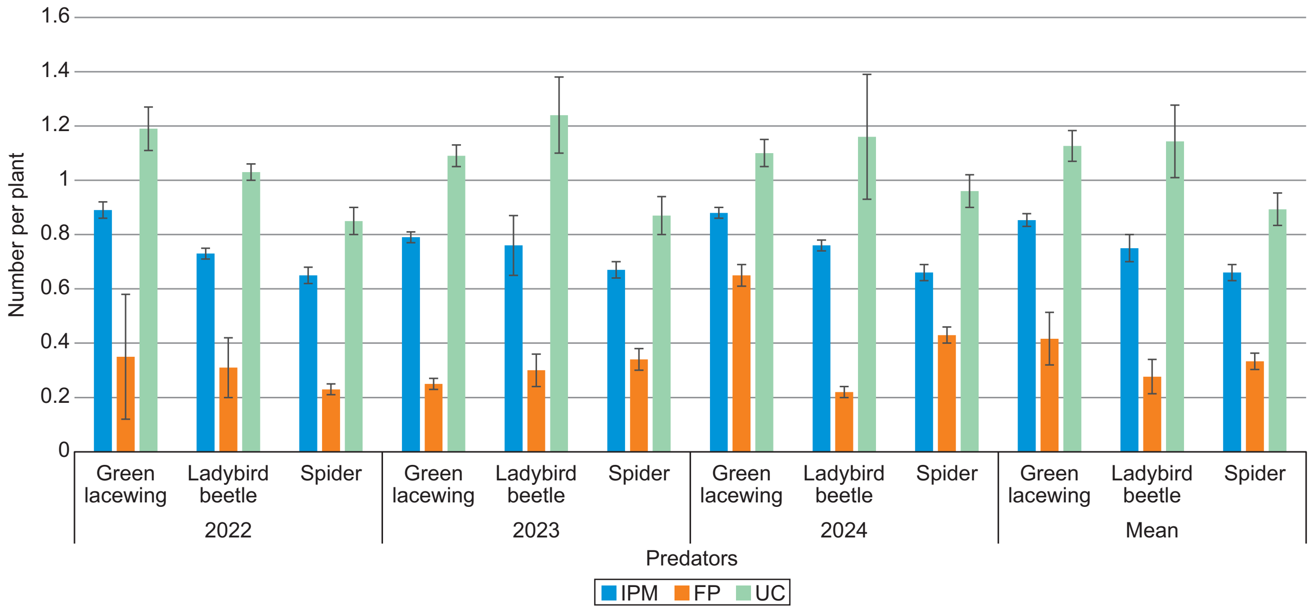

Fig. 1 Mean population of natural enemies in *Bt* cotton fields under different pest management practices during 2022–24. IPM, integrated pest management; FP, Farmer's practices; UC, Untreated control.

Table 4 Economic analysis of pest management strategies in *Bt* cotton during 2022–24

Particulars	2022		2023		2024		Pooled mean		% Change in IPM over FP
	IPM	FP	IPM	FP	IPM	FP	IPM	FP	
Insecticide Spray (Nos.)	5.50	8.66	2.15	5.4	3.22	6.3	3.63	6.78	-46.55
Seed cotton yield (q/ha)	9.25	5.80	11.36	7.37	18.74	15.1	15.05	11.23	25.38
Gross Income (₹/ha)	55500	34800	76112	49379	168660	135900	122386	92639	24.30
Net Profit (₹/ha)	9850	7560	35612	8579	126110	90150	80861	35429	56.18
Benefit Cost Ratio	1.92	1.27	1.88	1.21	3.96	2.97	2.92	2.09	-

*Average costs of seed cotton yield were ₹6000, 6700 and 9000/q during 2022, 2023 and 2024, respectively. IPM; Integrated pest management; FP, Farmer's practice.

Farmer participation and adoption: Farmer's Field School (FFS) and awareness programmes were organised at 15–30 days interval in adopted village; Chichgohan, Bherukheda, Bamjhar and at College of Agriculture, Khandwa, Madhya Pradesh during the crop season for dissemination of integrated pest management strategies which resulted in increased participation of farmers in IPM adoption from 20 ha covering 26 farm families in 2022 to 40 ha covering 36 farm families in 2023 and 50 ha covering 39 farm families in 2024. Training programmes and field demonstrations equipped farmers with practical knowledge on pest identification, monitoring, and non-chemical control options.

A key outcome of this study was the successful involvement of farmers in the IPM process, leading to increased awareness and acceptance of sustainable pest management practices. Additionally, the participatory mode ensured that farmers were not passive recipients but active contributors to decision-making, thus improving their confidence and commitment to the IPM practices and trust in the technology. Such farmer-centered approaches are essential for sustainable pest management adoption, as they bridge the gap between research and real-world farming conditions. Despite the positive outcomes, the study identified some challenges in IPM implementation. Some limitations included year-to-year climatic variability affecting pest dynamics, farmers' initial skepticism, lack of timely access to trap free technologies and importance of natural enemies, and variable pest pressure due to climatic factors, which constrained full potential of IPM. To overcome these challenges, strengthening supply chains for eco-friendly inputs, continuous farmer education, and adaptive management based on local pest dynamics are recommended. The validation of the IPM strategy in cotton under farmers-participatory mode clearly demonstrates the potential of this approach to enhance pest management, improve yield and quality, reduce costs, and promote environmental sustainability.

The study concluded that IPM strategy proved highly effective in reducing major cotton pests, ecologically safer by enhancing natural enemy population, and significantly lowering pesticide use across three seasons along with high benefit-cost ratio. Scaling this validated strategy through farmer field schools and improved access to pheromone-based tools can support wider adoption across the country in future.

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