

AI Smart Trap for Area-wide Real-time Monitoring of Pink bollworm in Cotton

A Success Story



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FOREWORD


The rapid advancement of digital technologies is transforming modern agriculture by enabling data-driven decision-making and precision crop protection. Among these innovations, sensor-based monitoring systems and Internet of Things (IoT) technologies are playing a pivotal role in strengthening pest surveillance and improving the efficiency of pest management strategies. While traditional methods rely on labour-intensive and time-consuming manual field observations, IoT-enabled systems allow for continuous, automated, and real-time data collection, significantly enhancing the effectiveness of surveillance programs.



Insect pest outbreaks, particularly those caused by highly destructive pests such as the pink bollworm in cotton, require timely detection and rapid response to prevent severe crop losses. Sensor-enabled smart traps integrated with artificial intelligence provide an innovative solution for addressing this challenge. The real-time transmission of pest data through cellular networks allows researchers, extension agencies, and farmers to access actionable information instantly and initiate timely pest management interventions.

The AI Smart Trap developed by ICAR-Central Institute for Cotton Research represents an important milestone in the application of IoT and artificial intelligence in agricultural pest surveillance. This technology transforms conventional pheromone traps into intelligent monitoring devices capable of automatically detecting and quantifying pest population while simultaneously recording environmental parameters. The integration of sensor networks, machine learning algorithms, and digital communication platforms enables area-wide pest monitoring and facilitates the generation of early warning advisories.

The successful deployment of the AI Smart Trap for monitoring pink bollworm in cotton has demonstrated the potential of digital agriculture tools to reduce pesticide use, improve crop productivity, and support sustainable pest management practices. It is expected that such sensor and IoT-based innovations will play an increasingly important role in the digital transformation of agriculture and in ensuring sustainable crop protection in the years to come.


(V N Waghmare)
Director, ICAR-CICR

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1. Executive Summary

The pink bollworm (*Pectinophora gossypiella* Saunders) is one of the most destructive pests of cotton, causing significant yield and economic losses across major cotton-growing regions of India. Conventional pest monitoring methods based on manual observation of pheromone traps have several limitations. To address these constraints, ICAR–Central Institute for Cotton Research (ICAR-CICR) developed the AI Smart Trap, an innovative sensor- and IoT-based pest monitoring system that integrates pheromone trapping with artificial intelligence, imaging technology, and real-time data transmission. The system automates pest detection and counting using deep learning algorithms and transmits data through cellular networks to a cloud-based platform, enabling continuous, real-time monitoring of pest population along with associated weather parameters.

Pilot-scale deployment of the technology in Punjab during the 2024–2025 cropping season demonstrated its effectiveness in area-wide pest monitoring and timely advisory generation. The system enabled early detection of pest incidence and facilitated timely pest management interventions, resulting in a substantial reduction in pesticide use. Despite high pest pressure, boll damage was successfully maintained below the Economic Threshold Level (ETL) of 10%, compared to historical infestation levels of 30–65%.

The technology also delivered significant socio-economic and environmental benefits. Reduced pesticide application lowered input costs for farmers, minimized environmental contamination, and supported conservation of beneficial organisms. The availability of real-time pest data enhanced decision-making at both farm and institutional levels, strengthening Integrated Pest Management (IPM) strategies and improving crop productivity and quality.

The successful implementation of the AI Smart Trap has demonstrated its scalability and adaptability for large-scale deployment across diverse agro-ecological regions. The technology has since been expanded to multiple states in the North Zone during the 2025–2026 season, establishing a robust digital pest surveillance framework. Its recognition at national platforms and integration into policy-level initiatives underscore its potential as a transformative tool in precision agriculture.

The AI Smart Trap represents a significant advancement in the digital transformation of agricultural pest management. By enabling real-time, data-driven, and area-wide pest surveillance, the technology offers a sustainable and efficient approach to managing pink bollworm in cotton and holds strong potential for adaptation to other crops and pest systems.

2. Introduction

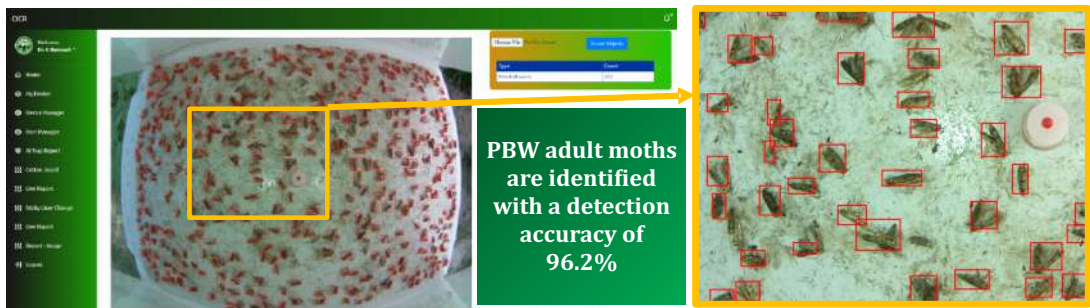
The AI Smart Trap is an advanced automated system developed for real-time monitoring of the pink bollworm (PBW) (*Pectinophora gossypiella* Saunders) in cotton. The technology integrates artificial intelligence (AI) – based image recognition and Internet of Things (IoT) – enabled data transmission with conventional pheromone trap technology, thereby transforming a traditional pest monitoring tool into a smart digital surveillance device. This integration enables accurate detection and quantification of pest population under field conditions and facilitates continuous monitoring without the need for manual inspection.

The system operates by capturing high-resolution images of insects trapped on the sticky surface of the pheromone trap. These images are analysed using machine-learning algorithms trained to automatically detect and count adult pink bollworm moths. The processed data are then transmitted through cellular communication networks to a central server, along with associated weather parameters such as temperature and relative humidity. The integration of pest monitoring data with environmental variables provides a robust framework for understanding pest population dynamics and forecasting pest outbreaks.

The AI Smart Trap generates real-time information on pest incidence, which can be accessed through a centralised digital platform by farmers, extension personnel and researchers. This enables the rapid dissemination of location-specific pest advisories and supports timely decision-making in crop protection. By facilitating early detection of pest build-up, the system helps farmers adopt appropriate pest management interventions at the right time, thereby reducing unnecessary pesticide applications and improving the efficiency of integrated pest management strategies.



AI Smart Trap



Detection and counting of pink bollworm adults in AI Smart Trap

2.1 Challenges in the Monitoring and Management of Pink bollworm in cotton

The cotton pink bollworm is recognised worldwide as the most injurious pest on cotton and its infestation ranges from 8 to 92% while yield losses range between 10 and 30%. The PBW developed resistance to two Cry toxins (cry1Ac+cry2Ab) deployed in Bt cotton and became a menace to the crop in major cotton growing areas of India since 2015. The cryptic behaviour and lifecycle of PBW renders it less amenable for the regular pest management practices. The larvae bore into cotton bolls immediately after hatching, remain inside the boll feeding on seeds and later pupate in the soil, thus offering a very narrow window of control opportunity by the conventional strategies. Alternative tools like behaviour-modifying chemicals or pheromones provide a pragmatic approach in monitoring and managing the internal feeders like PBW.



PBW Adult



PBW Larva



Cotton boll damage

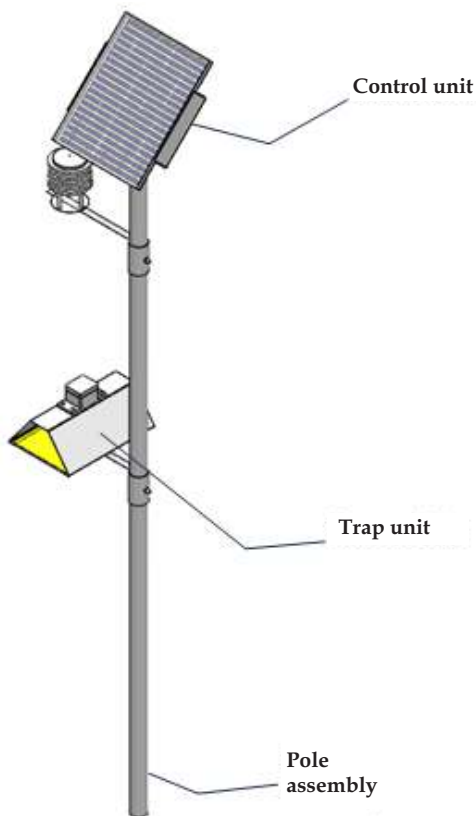
Pheromone traps
in cotton fieldAdult PBW moths in
Pheromone trap

Insect sex pheromones are vital for species-specific communication between the sexes for mating and perpetuation of populations. Synthetic pheromone compound blends are available commercially which are deployed in lures at specified concentration. The lure is installed in collection traps of suitable design. Pheromone traps are effective tools in cotton pest management because they are cost effective, eco-friendly and amenable for organic cultivation. However, the conventional pheromone trap technologies have inherent limitations. The collection of trap data consists of repeated field surveys, where visual observation of traps is performed by a human operator to record the number of captured insects. The process is laborious, time consuming, costly and prone to human error. The manual data only gives the trap catch i.e, insects trapped between two consecutive surveys, usually between 7-15 days. With poor temporal resolution of measurement in conventional trap count, the

dynamics of pest population density in the field cannot be accurately monitored. Multi location trap data cannot be synchronized to measure the target pest population.

By integrating the traditional trapping method with modern communication technology, the AI Smart trap system is able to provide real-time information on the field conditions and the dynamics of the pest at different monitoring sites. This makes the system especially helpful for large scale monitoring areas, which is a major obstacle for the traditional monitoring methods. By integrating the latest imaging and weather sensors and machine learning techniques, an automated pest and environment monitoring system can be established, together with powerful processing ability. Furthermore, it will reduce the labour cost of collecting environmental data by combining the automated monitoring system with wireless telecommunication technology. By having real-time environmental data available to us, we can better understand the variation among cropland areas, increase the effectiveness and the precision of cultivation management and establish a highly reliable pest forecast system. As a result, the automated, wireless pest monitoring system can serve as the major information source for timely plant protection initiatives.

3. Major Components and Operational Workflow of AI Smart Trap system



AI Smart Trap (*Orthographic illustration*)

COMPONENTS OF AI TRAP

1. Control unit

- 20W solar panel
- 12 V rechargeable Li-polymer battery
- Wi-Fi/Bluetooth module
- GSM module (5G/4G)
- PCB control board

2. Trap unit

- Modified delta trap enclosure
- Pheromone septa to attract the insect.
- Sticky liner to trap the insect
- Single board computer
- Camera module

3. Pole assembly

- Galvanized iron pipe of 1" dia and 250 cm height
- Delta trap holder with height adjustment provision
- Solar trap holder
- Weather sensor in shield enclosure

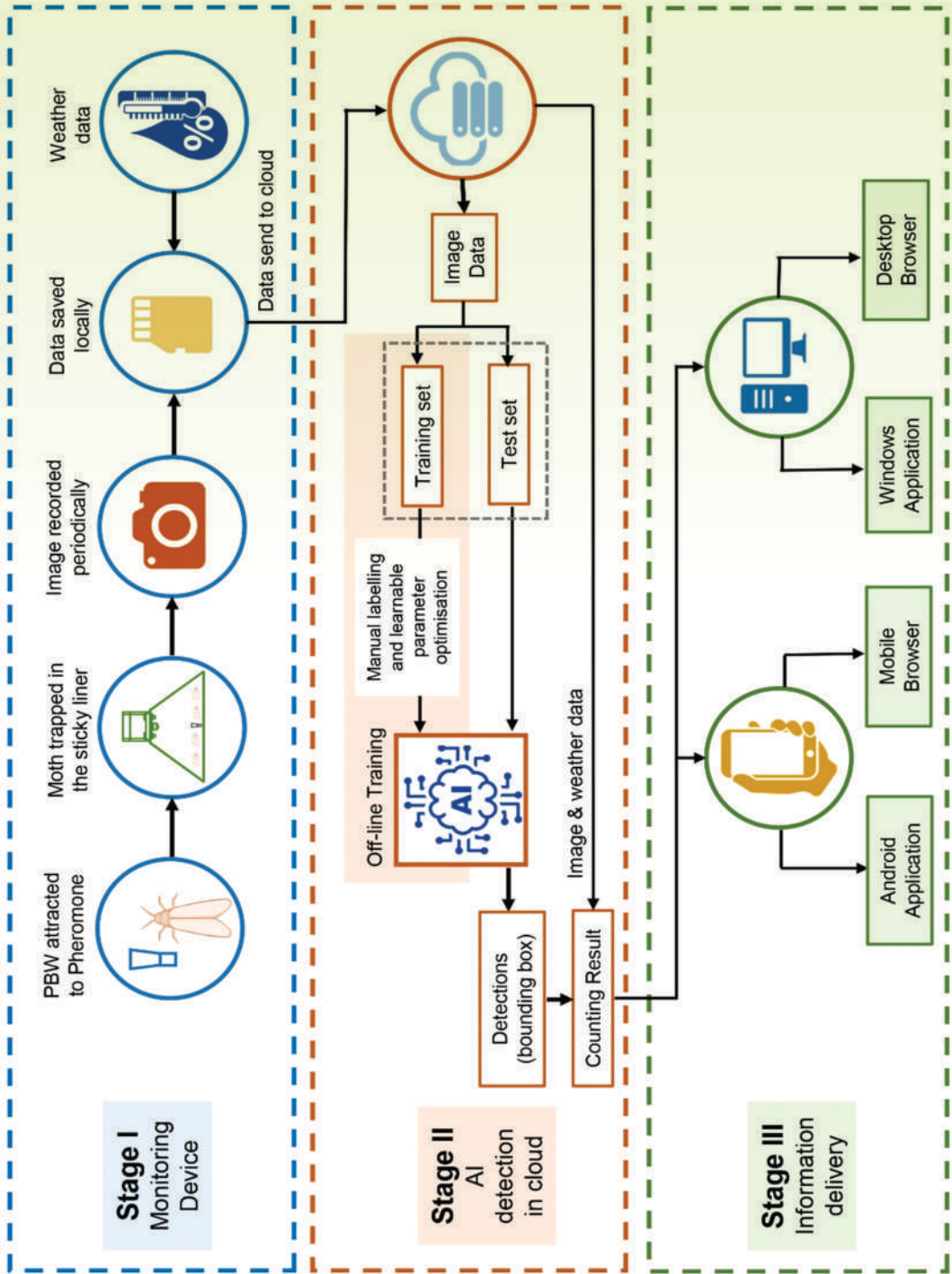
The AI Smart trap used for the real-time monitoring is a standalone unit powered by solar panel. It has three components viz. trap unit, control unit and pole unit. The trap unit comprises of pheromone septa containing sex pheromone of PBW, gossyplure (Z, Z- and Z, E- isomers of 7,11-hexadecadienyl acetate) @ 2mg/septa to attract the insect; sticky liner to trap the insect; camera module to record trapped insect as image file and a single board computer with a Wi-Fi/Bluetooth module to process and transmit the image. The control unit comprises of 20W solar panel, rechargeable Li-polymer battery; PCB with battery recharge controller and timer for regulating the trap unit and GSM / Wi-Fi / Bluetooth module for communication. The pole unit comprises galvanized iron pipe, trap holder with height adjustment provision, weather sensors in shield enclosure and holder with height adjustment provision.

3.1 Operational Workflow of the AI detection System

The AI-powered pest monitoring system for cotton PBW operates through an integrated three-stage architecture consisting of Monitoring Device (Stage I), AI Detection in the Cloud (Stage II), and Information Delivery (Stage III). This workflow enables automated pest surveillance from field-level data capture to real-time dissemination of pest incidence information for timely pest management decisions.

Stage I - Monitoring Device: In the first stage, pest monitoring is carried out using a AI smart pheromone trap installed in cotton fields. A high-resolution camera module integrated into the smart trap automatically records images of the sticky liner containing trapped insects at predefined intervals (typically every hour). This automated image acquisition eliminates the need for manual inspection of traps and ensures continuous pest monitoring throughout the cropping season. In addition to trap images, the device also records weather parameters, including temperature and relative humidity, through onboard sensors. All collected data—including trap images and weather information—are stored in the device's local memory and the system then transmits the data through a high-speed 5G cellular network to a cloud-based server for further processing and analysis.

Stage II - AI Detection in the Cloud: The second stage involves automated image analysis using a deep learning-based machine learning algorithm deployed on the cloud server. The uploaded trap images are processed using the YOLO v8x object detection model, which has been specifically trained to identify pink bollworm adult moths captured on sticky traps. During algorithm development, a large dataset of annotated insect images was used to train the model. Images were manually labelled using bounding boxes around PBW adults, and the dataset was divided into training and testing subsets to optimize model performance. Through iterative training and parameter optimization, the algorithm learned to accurately distinguish PBW moths from other insects and non-target objects present on the sticky liner.



AI Smart Trap: Flow Chart of processes in real time monitoring of PBW in cotton

Once deployed in the operational system, the trained model performs automatic detection of PBW moths in incoming trap images. The algorithm identifies individual insects using bounding box detection and subsequently calculates the total number of moths present in each image. This automated counting process ensures high accuracy and consistency while eliminating human errors associated with manual counting. The processed outputs—comprising PBW detection results, insect counts, and associated weather data—are stored in the cloud database. These results serve as the basis for generating pest surveillance information and advisory alerts.

Stage III - Information Delivery: In the final stage, the processed pest monitoring information is delivered to end users through multiple digital platforms. The system automatically integrates the AI-enabled insect counts with associated trap location and weather information, enabling the generation of real-time pest surveillance outputs. The results are made accessible through mobile and desktop interfaces, including Android mobile application, Windows-based application and web browser in a mobile or PC. These platforms provide real-time updates on pink bollworm trap catches, enabling farmers to monitor pest activity continuously. The system can also generate automated alerts, graphical dashboards, and location-based PBW incidence reports, which support rapid decision-making. By providing timely and accurate PBW population data, the AI smart trap system facilitates area-wide pest surveillance and early warning of PBW outbreaks. This enables farmers to adopt timely integrated pest management (IPM) interventions, thereby reducing unnecessary pesticide applications and minimizing crop losses.

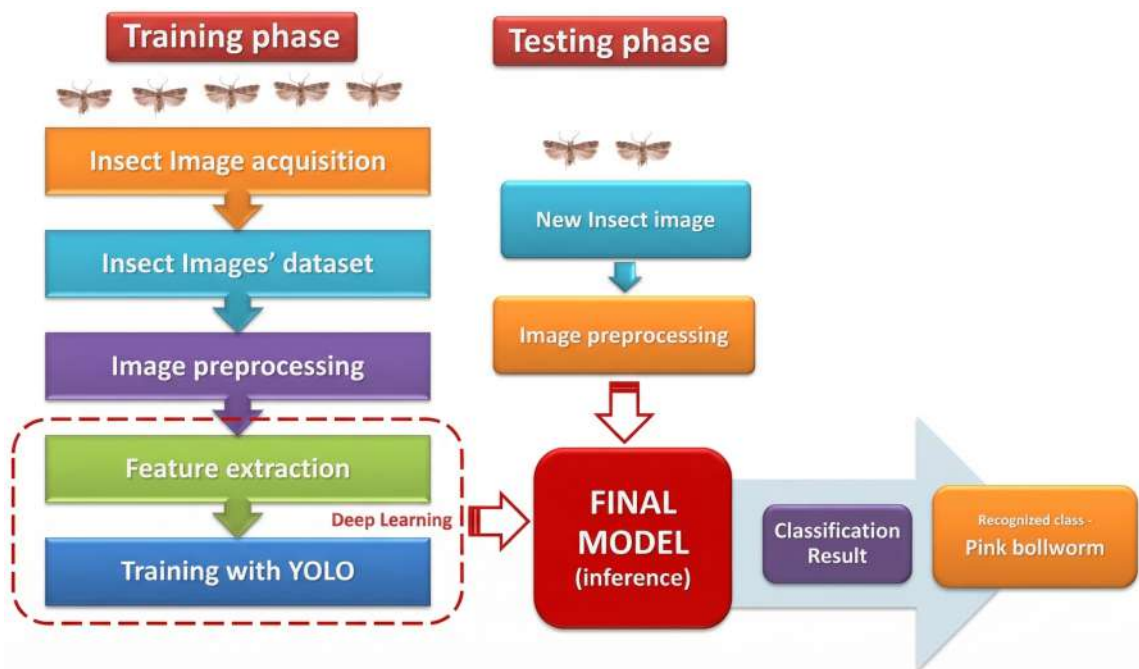
4. Development of Machine Learning Algorithm for Detection of Pink Bollworm

An automated image-based system was developed to detect and count cotton pink bollworm adults captured in sticky traps using deep learning techniques. The framework integrates insect image acquisition, dataset preparation, image preprocessing, deep learning-based feature extraction, and object detection using the YOLO v8 algorithm.

During the initial stage, a curated dataset of sticky trap images was collected from cotton fields. High-resolution photographs of pheromone sticky liner containing trapped moths were captured using digital cameras and smartphone devices under natural field conditions. The dataset included images taken at different times of the day and under varying environmental conditions such as changes in lighting, background contamination, and trap aging. A total of 1400 images of sticky traps containing approximately 16,000 cotton pink bollworm adults were collected and used for model development. The dataset contained variations in moth orientation, overlapping insects, dust particles, and the presence of other non-target insects to ensure that the model could learn robust features applicable to real field conditions.

Following image acquisition, the collected images were organised into an annotated dataset. Each pink bollworm adult present in the trap images was manually labelled using bounding boxes to identify the exact location of the insect within the image. Annotation was performed using standard image labelling tools such as Labellmg, and the labelled dataset was saved in a format compatible with the YOLO framework. The annotated dataset was then divided into training, validation, and testing subsets following a typical 70:20:10 ratio. This dataset partitioning ensured that the model could be trained effectively while maintaining independent datasets for validation and performance evaluation.

Prior to training, the images were subjected to preprocessing procedures to improve model learning efficiency. All images were resized to a fixed resolution compatible with the YOLOv8 input layer, and pixel values were normalized to maintain consistency across the dataset. Additional preprocessing steps included contrast enhancement and noise reduction to minimize the influence of background artifacts such as dust particles, trap glue reflections, and leaf debris. Data augmentation techniques such as horizontal flipping, rotation, scaling, and brightness variation were also applied to artificially increase dataset diversity. These augmentation techniques helped improve the robustness of the model by enabling it to recognize insects under different orientations and lighting conditions.



Development of Machine Learning Algorithm for Detection of Pink Bollworm

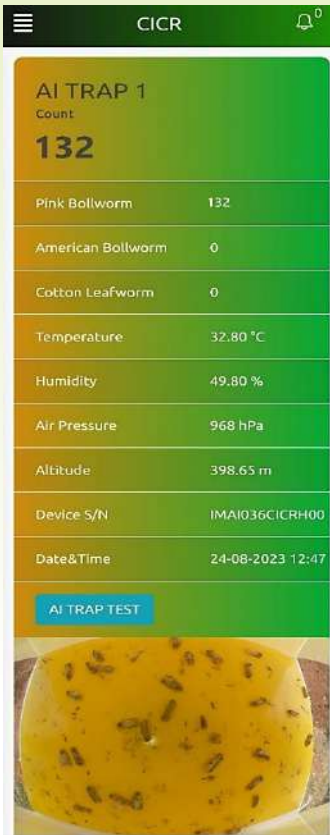
Feature extraction and insect detection were performed using the YOLO v8 (You Only Look Once version 8) deep learning architecture, which is a state-of-the-art object detection model designed for real-time detection tasks. Unlike traditional machine learning approaches that rely on manually engineered features, YOLO v8 automatically learns hierarchical visual features directly from the images through convolutional neural network layers. These layers progressively capture complex

The YOLO v8 model was trained using the annotated dataset through iterative optimization. The performance of the model was evaluated using standard object detection metrics such as precision, recall, and mean Average Precision (mAP). Training continued until the model achieved satisfactory accuracy in detecting pink bollworm adults while minimizing false detections caused by other insects or debris present in the sticky traps. Once the training process was completed, the trained model was deployed for the testing or inference phase. The final output of the system included visual detection and automated counting of pink bollworm adults present in the sticky trap image. Each detected bounding box corresponded to an individual insect, allowing the algorithm to automatically determine the total number of moths captured in the trap.

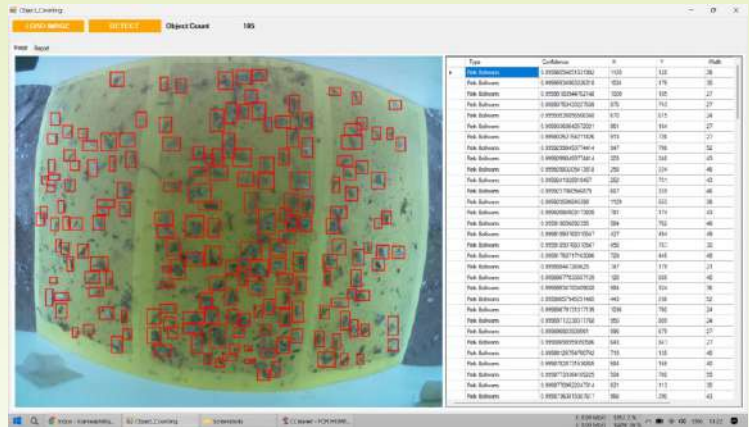
5. Information delivery from AI Smart Trap

The real-time trap catch information generated by the AI Smart Trap system is made accessible to users through multiple digital platforms to ensure ease of access, flexibility, and rapid dissemination of pest surveillance data. The system provides three primary modes for accessing monitoring results: Android Mobile Application, Windows Desktop Application, and Web Portal. These platforms enable the stakeholders to obtain timely updates on pink bollworm incidence and support informed pest management decisions.

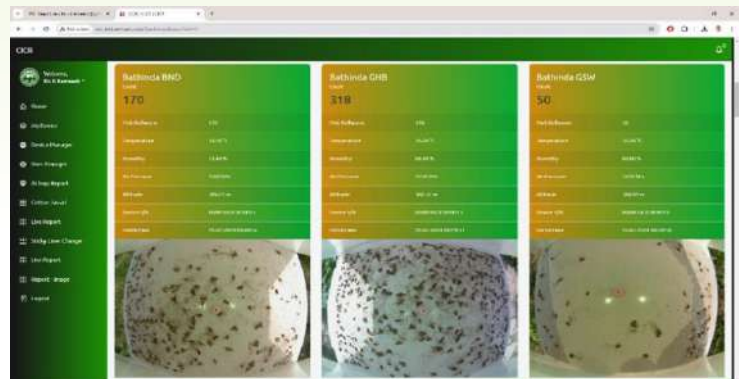
5.1 Android Mobile Application: The Android-based mobile application provides a convenient and portable interface for accessing trap catch information directly on smartphones. The application retrieves data from the cloud server and displays real-time updates on the number of pink bollworm moths detected in each smart trap. Users can view trap-wise insect counts, date and time of observations, and associated weather parameters such as temperature and relative humidity. The mobile application also enables instant notifications and alerts, which inform users when pest population reach economic threshold levels. This feature is particularly beneficial for farmers and field-level extension workers, as it allows them to monitor pest activity in their fields without the need for physical inspection of traps. The mobile interface is designed to be user-friendly and supports rapid decision-making for timely pest management interventions.



Android Mobile App



Windows Desktop Application



Web portal

5.2 Windows Desktop Application: The Windows-based desktop application provides a comprehensive interface for visualizing pest monitoring data collected from multiple traps deployed across different locations. Through the desktop application, users can access historical trap catch records, graphical trends of pest population, and spatial monitoring information. The system also allows users to retrieve trap catch data, download datasets, and generate reports for research and pest surveillance.

5.3 Web Portal: The web-based portal serves as a universal platform that can be accessed through any internet-enabled device using a standard web browser. The portal provides centralized access to pest monitoring data stored on the cloud server and enables users to view trap catch information from multiple locations in real time. The web interface typically includes interactive dashboards, graphical visualisations of pest population trends, and map-based displays of trap locations and pest incidence levels. Since the portal does not require installation of specialized software, it is highly suitable for remote monitoring by policymakers, researchers, and extension agencies. The web portal also facilitates data sharing, monitoring of large geographical areas, and dissemination of pest alerts to relevant stakeholders.

The availability of multiple access platforms ensures that the AI Smart Trap system provides flexible, real-time, and user-friendly access to pest monitoring data. This multi-platform approach enhances the effectiveness of pest surveillance programs and supports data-driven pest management strategies in cotton cultivation.

6. Key Advantages of the AI Smart trap

The AI Smart Trap offers several operational and technological advantages that make it an effective tool for real-time monitoring of pink bollworm in cotton ecosystems. The system is designed as a self-contained and autonomous monitoring unit, allowing it to be easily installed and operated under open-field conditions without requiring extensive infrastructure.

One of the major advantages of the system is its solar-powered operation. The trap is equipped with a solar panel and rechargeable battery system, enabling continuous operation in remote agricultural fields without dependence on external electrical power sources. This feature makes the technology particularly suitable for off-grid rural areas and large agricultural landscapes, where access to reliable electricity may be limited. The system uses 4G/5G cellular network connectivity to transmit captured images and environmental data to a cloud-based server for automated processing. This wireless communication capability enables real-time data transfer from field locations to centralised servers, ensuring timely pest monitoring and rapid dissemination of pest incidence information to end users.

Another important advantage is the area-wide monitoring capability of the AI Smart Trap. Since the system continuously records and analyses trap catches, a limited number of traps can effectively represent pest population dynamics over a larger geographical area. In many cases, one AI Smart Trap installed per village or monitoring zone can provide sufficient surveillance data for tracking pest activity and generating timely pest alerts.

The trap also requires minimal maintenance, making it practical for long-term deployment in farmers' fields. Routine servicing primarily involves periodic replacement of the pheromone septa, which typically needs to be changed once every month to maintain effective attraction of pink bollworm moths. Additionally, the sticky liner used for capturing insects should be replaced approximately once every two weeks, or earlier if the surface becomes saturated with trapped insects or debris. These simple maintenance requirements ensure reliable trap performance throughout the cropping season.

Overall, the AI Smart Trap provides a cost-effective, energy-efficient, and automated pest monitoring solution. By reducing the need for manual trap inspection and enabling real-time data availability, the technology significantly improves the efficiency of pest surveillance programs and supports timely, data-driven pest management decisions in cotton cultivation.

Advantages of the AI Smart Trap over Conventional Trap

Particulars	Conventional Trap	AI Smart Trap
Observation	Manual	Automatic
Remote monitoring	Not possible	Possible
Real-time information	Not available	Available
Observation frequency	Weekly	Hourly
Remote verification of data	Not possible	Possible
Weather data	Not available	Available
Communication protocol	Manual	Wireless (5G)
Data synchronisation	Not possible	Possible
Timely pest management	Difficult	Possible
Wider area monitoring	Not possible	Possible
Pest modelling and forewarning	Difficult	Possible

6.1 Adaptability and Scalability of AI Smart Trap Technology

The technology demonstrates a high level of adaptability of the deployment and operation of the AI Smart trap due to its compact modular design and technology-driven approach. The system can be used in various agricultural landscapes, from smallholder farms to large-scale commercial farms that encourage flexible deployment. While initially designed for PBW monitoring in cotton, the system can be adapted for other pests in different crops by changing the pheromone-based attractant and AI detection models. The project leverages universal LTE GSM connectivity, but it can be modified to support LoRaWAN, Wi-Fi, or satellite communication, ensuring adaptability in remote or low-network areas. The solar-powered design ensures functionality even in off-grid rural regions, making it suitable for diverse and remote agricultural environments.

The centralised AI model ensures that the system can process data from multiple monitoring devices simultaneously, making it easily scalable to regional or national levels. With relatively low-cost components (Raspberry Pi, sensors, and camera modules), mass production and deployment of AI Smart Traps can be achieved at a reasonable investment cost. The use of machine learning and cloud computing ensures that as more farms adopt the system, the AI model can handle increasing data loads without additional labour costs. The information delivery stage is designed for Android, Windows, and web-based applications, making it easily expandable to more users without the need for major software modifications. Since the system is not crop-specific and is based on general IoT-based pest monitoring principles, it can be scaled to multiple agricultural crops by adjusting pheromone lures and AI training data.

6.2 Sustainability and economic benefits from AI Smart Trap Technology

AI Smart Trap technology is self-sustainable with proper revenue models, partnerships, and cost-effective technology deployment. By leveraging subscription-based AI services, government funding, and industry collaborations, it can scale efficiently, benefiting both small farmers and large agribusinesses. With accurate pest detection and reduced crop losses, the long-term economic and environmental benefits outweigh initial investment costs. The possibility of data monetization is bright as the aggregated pest monitoring data can be marketed to agriculture research firms, pesticide companies, and weather forecasting services. By investigating the real-time trap catch with corresponding weather data, the pest dynamics over a wider area could be comprehended in a better way and subsequently it helps to establish a reliable pest forewarning system and better pest management practices in cotton. Since cotton is a commercial crop, there is ample opportunities for the corporate partnerships; integration with agribusinesses, seed companies and pesticide manufacturers as the analytics and AI-driven predictive pest control insights provide premium service to them. The technology promotes an environmentally sustainable approach to pest management by minimising chemical pesticide usage. The integration of AI-driven monitoring and targeted interventions ensures a precise and timely pesticide application, reducing excessive chemical use; preservation of beneficial insects, such as predators and parasitoids, which play a crucial role in natural pest control; protection of non-target organisms (such as pollinators, birds, and soil microbes), maintaining biodiversity in cotton fields.

The AI smart trap is useful especially in case of area wide pest monitoring. By integrating the traditional trapping method with modern communication technology, the AI smart trap system provides real-time information on the dynamics of the pest population with corresponding weather parameters over a wider area. This makes the system helpful for large scale monitoring, which is a major obstacle for the traditional monitoring methods using pheromone trap in cotton. Due to timely pest alerts on real-time basis, a decrease in cost of cultivation due to the reduction in number of pesticide sprays can be achieved. By reducing the need for broad-spectrum pesticides, the technology supports Integrated Pest Management (IPM) strategies, lower risk of pesticide resistance in PBW population by preventing overuse of chemicals leading to healthier crops, safer farm environments, and improved soil health. Increased cotton yield and quality leads to higher market value. By minimising input costs and maximising output, farmers can improve their profit margins while adopting a more sustainable and efficient pest management approach.

7. Official Launch of AI Smart Trap

The AI Smart Trap was formally launched by Shri. Shivraj Singh Chouhan, Hon'ble Union Minister of Agriculture & Farmers Welfare, and Shri. Devendra Fadnavis, Hon'ble Chief Minister of Maharashtra at Nagpur on 18 May 2025. The event was graced by the presence of Dr M. L. Jat, Secretary, DARE and Director General of Indian Council of Agricultural Research, along with Dr D. K. Yadav, DDG (Crop Science); Dr A. K. Nayak, DDG (Natural Resource Management); and Dr Sanjay Kumar Singh, DDG (Horticultural Science), Dr. Rajbir Singh, DDG (Agricultural Extension) and other distinguished dignitaries.



Intellectual Property and Patent Registration

A patent application (No. 202421072205) entitled “A System for Attracting Pink Bollworms, Trapping and Reporting, and a Method Thereof” has been filed with the Indian Patent Office in September 2024. Subsequently, the corresponding international patent application under the World Intellectual Property Organization Patent Cooperation Treaty (PCT) was filed as Application No. PCT/IB2025/059551 on 23 September 2025, facilitating protection of the technology in multiple jurisdictions.

8. Pilot scale deployment in Punjab during 2024-2025



The AI Smart trap has been deployed for the real-time monitoring of PBW in Punjab State during the crop season 2024-2025, with the financial assistance from the Directorate of Plant Protection Quarantine & Storage (DPPQ&S), Department of Agriculture & Farmers Welfare, Government of India. The smart traps were installed at 18 villages in three major cotton growing districts of Punjab viz., Mansa, Bathinda and Sri Muktsar Sahib at the identified farmers' fields at the rate of 6 units per district. At all the locations, conventional pheromone traps were also installed @ 3 per village and the weekly trap catch data are being observed for comparison. A dedicated web portal <https://cicr.aitrap.in/> was developed for the real-time information of PBW trap catch and corresponding weather data. Log-in credentials for the web portal were circulated to all the stakeholders in the state for data access. The web portal provides access to the live trap information with the image, count of insects and weather data across all locations. Additional reports on the hourly trap catch, daily count report, ETL report and historical report can be generated by the end user. The information can be viewed and downloaded as Excel file for the required period.

Based on the data from the AI Smart trap, daily alerts and weekly advisories on PBW damage status and management strategies were issued to all the stakeholders and cotton farmers in Punjab. Pre-recorded voice messages of 30 seconds duration in punjabi language were sent through the GSM network at weekly intervals to a total of 28,190 cotton growers in state. Alert voice messages are also being sent to individual district farmers whenever the particular a district records trap catch above the ETL. Mass media and social media channels are also being used to send alert messages and control measures for the pink bollworm. Pest alerts are also sent via personal phone calls to farmers, group messages and announcements in village Gurudwara Sahibs on regular basis. With the area wide monitoring and issue of timely alerts, the infestation of PBW has been brought down significantly during the season.

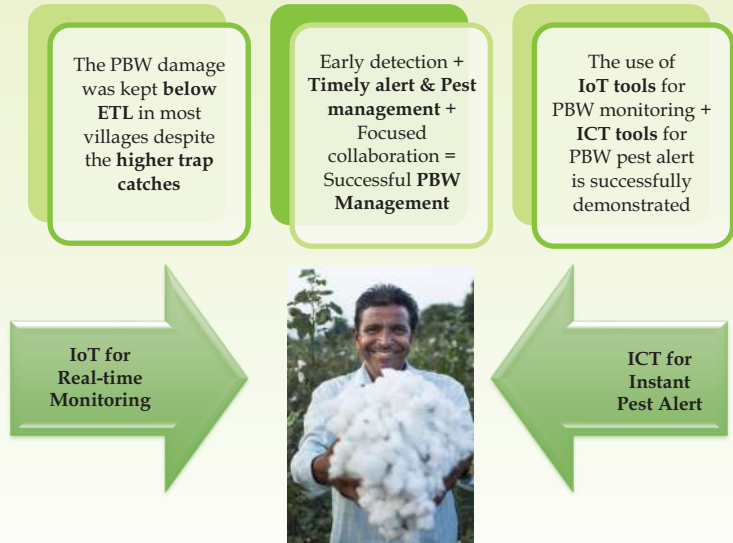
9. Scientific, technological and socio-economic impact

Data collected from AI traps revealed that PBW exhibited four to five population peaks per season, with a maximum catch of 447 moths per trap per week. From the 38th Standard Meteorological Week (SMW) onward, trap catches remained consistently high. However, despite this, boll damage in AI-monitored fields was maintained below the Economic Threshold Level (ETL) of 10%, demonstrating the effectiveness of timely pest control interventions.

Previously, PBW infestation levels in Punjab ranged between 30-65%, but due to the AI Smart Trap initiative, infestation was successfully reduced to below 10% levels during the 2024-2025 season. Furthermore, the real time PBW alerts allowed farmers to optimize their pesticide usage, reducing the number of insecticide sprays to an average of 6.2, compared to 10.1 sprays by conventional farmers. This led to a 38.6% reduction in pesticide application, demonstrating the efficacy of AI-driven pest monitoring in minimizing chemical dependency without compromising crop protection.

On the technological front, the AI Smart Trap project marked the first large-scale deployment of AI-powered pest monitoring in the country. By integrating artificial intelligence with precision pest management, the system automated pest data collection, analysis, and dissemination through mobile alerts, allowing farmers to make data-driven decisions in real time. Recognizing the success of this approach, the Ministry of Agriculture and Farmers Welfare has decided to expand the AI Smart Trap technology beyond Punjab to other cotton-growing states during the 2025-2026 crop season.

From a socio-economic perspective, the project has yielded tangible benefits for farmers by significantly reducing input costs while maintaining crop productivity. The reduction in pesticide sprays translated into substantial cost savings, lowering farmers' financial burden while ensuring effective pest control. With PBW infestation controlled below ETL, yield losses were minimized, leading to improved profitability for cotton growers. Environmentally, the 38.6% reduction in pesticide application contributed to lowering chemical residues in the soil and water, promoting sustainable farming practices and reducing environmental pollution. Additionally, the widespread adoption of AI-generated alerts empowered farmers with scientific pest management



strategies, fostering confidence in technology-assisted decision-making. The success of this initiative has set a precedent for the large-scale digital transformation of Indian agriculture, encouraging greater adoption of AI-based precision farming tools.

10. Voices from the Field : Farmer Perspectives



The joint efforts of the ICAR-CICR, Punjab Agri University and Punjab Agriculture Department, have been instrumental. With their regular monitoring, I receive timely calls and personalized field visits that help me decide when to apply pesticides and ensure my crop remains protected.....**Jagdev Singh, Khiali Chahianwali**



With the help of AI traps, I receive timely alerts about pink bollworm outbreaks. I also get regular updates from experts on pest control, and the YP's visits ensure that I apply the right insecticides at the right time to avoid crop damage.....**Sudagar Singh, Ghuduwala**



The AI traps have allowed me to detect pests early, and I get weekly phone calls from experts guiding me on which pesticides to use based on the crop's growth stage. This proactive approach helps prevent any major pest outbreaks.....**Amreek Singh, Burj Bhalaike**



In the middle of the season, my cotton field was facing significant pink bollworm damage. Thanks to the AI trap system and the timely recommendations from ICAR-CICR, I was able to take swift action. The real-time alerts not only helped me protect my crop, but also raised my awareness about pest management.....**Makhan Singh, Bhalaike**



As the head of the village, I don't have time for frequent field checks, but the AI trap and guidance from CICR have been crucial in protecting my crop. Last year, pink bollworm caused significant damage in our village, but this year, the AI system and expert advice helped prevent it.....**Kuldeep Singh, Jheryan wali**

Feedback from cotton farmers in Punjab who participated in the deployment of AI-based pest monitoring systems provides valuable insights into the practical benefits of this technology under field conditions. Farmers reported significant improvements in crop protection decision-making due to access to real-time information on pest population dynamics and timely expert advisories. The system enabled early detection of pest incidence, allowing farmers to implement timely management interventions, optimize pesticide use, reduce input costs, and improve both crop productivity and lint quality. In addition, farmers observed that the technology supports resource conservation by minimizing unnecessary pesticide applications and promoting more precise and targeted pest management practices.

The testimonials by farmers across different cotton-growing districts of Punjab further illustrate how AI-enabled pest monitoring has effectively bridged the gap between field-level pest surveillance and expert advisory services. By providing timely and location-specific information on pest incidence, the technology has empowered farmers to make informed crop protection decisions and adopt more efficient and sustainable pest management strategies in cotton cultivation.

Theme	Farmer Experiences & Feedback
Precision & Quality	<i>"The AI trap provides real-time population data, facilitating better management decisions. This has resulted in visibly superior lint quality compared to my conventional fields." – Sh. Boota Singh, Bathinda</i>
Economic Impact	<i>"Adopting this technology has slashed our input costs while boosting productivity. It's not just beneficial for me, but for the entire village." – Sh. Lakhwinder Singh, Bathinda</i>
Early Warning Systems	<i>"I can now identify pest incidence at an early stage. Weekly calls from experts guide me on exactly which pesticide to use based on my crop's growth stage." – Sh. Baljeet Sharma, Bathinda</i>
Recovery & Resilience	<i>"Even when we faced mid-season damage, the real-time alerts allowed for prompt action that saved the harvest. My yield and income are both higher this year." – Sh. Makhan Singh, Mansa</i>
Resource Conservation	<i>"In areas where water scarcity prevents rice cultivation, cotton is vital. This technology prevents unnecessary sprays, making cotton farming profitable again." – Sh. Beant Singh, Muktsar</i>
Technological Leap	<i>"Pest monitoring used to be labour-intensive and imprecise. These AI-powered traps have transformed the process with data-based insights and targeted interventions." – Sh. Mohinder Singh, Muktsar</i>

11. Scaled-Up Deployment in the North Zone during 2025–2026

Encouraged by the positive outcomes of the pilot-scale deployment of AI Smart Trap at Punjab, the technology was scaled up during the 2025–2026 season to strengthen digital PBW surveillance across the North zone. The expanded deployment covered 40 villages distributed across eight major cotton-growing districts in three key cotton-producing states—Haryana, Punjab, and Rajasthan. The objective of the scale-up was to establish a wider network of AI Smart Traps capable of providing continuous, real-time monitoring of pink bollworm population dynamics and enabling timely pest management advisories to the cotton growers in the entire North zone of cotton cultivation.

The expanded deployment was supported by the Directorate of Plant Protection Quarantine & Storage under the Ministry of Agriculture and Farmers Welfare. The Plant Protection Adviser to the Government of India, noted that the AI-based pheromone traps installed by ICAR-CICR in Punjab during 2024–25 yielded encouraging results as the system enabled timely dissemination of pest advisories to farmers, highlighting the potential of advanced digital technologies for strengthening pest surveillance and facilitating early intervention in pest management. Based on these observations, the Directorate recommended expanding the use of AI-based pheromone traps to other cotton-growing regions experiencing recurrent pink bollworm infestations. Accordingly, districts with a history of significant PBW incidence during the preceding years were



RAJASTHAN - Sri Ganganagar



RAJASTHAN - Hanumangarh



PUNJAB - Muktar



PUNJAB - Bathinda



PUNJAB - Mansa



PUNJAB - Fazilka



HARYANA - Hisar



HARYANA - Sirsa

AI Smart Trap Deployment in Haryana, Punjab and Rajasthan during 2025-2026

prioritised for deployment during the 2025–26 season. The large-scale deployment across multiple states demonstrates the operational feasibility and scalability of AI-driven pest monitoring systems in cotton ecosystems. The initiative represents a significant advancement towards establishing a national digital pest surveillance framework, contributing to improved pest forecasting, reduced crop losses, and more efficient implementation of integrated pest management strategies in cotton.

12. Evidence of impacts of the AI Smart Trap Technology

The impact and relevance of the AI Smart Trap technology have been widely acknowledged by national institutions, policymakers, and the media, demonstrating its growing importance in strengthening digital pest surveillance and modern crop protection strategies. The success of the technology was recognized by the Ministry of Agriculture and Farmers Welfare and the Indian Council of Agricultural Research, which highlighted the innovation through their official social media platforms to disseminate its benefits to a wider audience. The amplification of the success story through these official channels enhanced the credibility of the technology and underscored the importance of AI-driven pest monitoring systems in advancing sustainable agriculture.



Further reinforcing its significance, ICAR documented the technology as a successful digital innovation in crop protection by publishing a detailed success story on its official web portal. The impact of the AI Smart Trap technology has also been highlighted in several national-level scientific and policy forums viz., National Conference on Digital Agriculture: Empowering Indian Farming, held on 17–18 December 2024 in New Delhi and Post-Budget Webinar 2025: Mission for Cotton Productivity, organized by the Department of Agriculture and Farmers Welfare in collaboration with the Ministry of Textiles on 1 March 2025.



In addition to institutional recognition, the success and impact of the AI Smart Trap technology have been widely covered by several national and regional media outlets. Newspapers, television channels, and digital platforms reported on the technology as an innovative advancement in cotton pest management. Media coverage emphasized how AI-enabled monitoring systems are transforming conventional pest surveillance by enabling real-time monitoring, reducing indiscriminate pesticide applications, and improving farmer decision-making. Such coverage has played an important role in increasing awareness about the potential of digital agriculture technologies to enhance crop productivity, reduce chemical dependency, and improve the livelihoods of cotton farmers.

13. Recognition at National and International Levels

In recognition of its technological innovation and field-level impact, the AI Smart Trap was selected as one of the 14 technologies showcased by the Indian Council of Agricultural Research at the ICAR Pavilion on 5G Technologies during the India Mobile Congress 2024 held from 15-18 October 2024 at Pragati Maidan, New Delhi. The exhibition highlighted the role of next-generation communication technologies in transforming agricultural research and extension services. The AI Smart Trap attracted considerable attention from policymakers, technology developers, industry representatives, and agricultural stakeholders, as it demonstrates how AI-enabled field devices can generate real-time pest surveillance data and transmit it through cellular networks for rapid analysis and advisory dissemination.



AI Smart Trap
in India Mobile
Congress 2024

AI Smart Trap
in AI Impact Summit
2026



Further recognition of the technology's impact was achieved at the AI Impact Summit 2026 held in New Delhi, where the AI Smart Trap technology was shortlisted for inclusion in the “Compendium on the Real-World Impact of AI in Agriculture.” The compendium was prepared under the leadership of the Ministry of Electronics and Information Technology, which screened 264 AI use cases globally and shortlisted 26 case studies demonstrating tangible field-level impact for publication in the volume. The inclusion of the AI Smart Trap technology among these selected case studies highlights its relevance as a practical and scalable AI solution for agricultural pest surveillance. The recognition of the AI Smart Trap at these prestigious platforms underscores its growing importance as a digital innovation for pest monitoring and early warning systems in agriculture, with strong potential to strengthen integrated pest management programs and support the advancement of AI-enabled digital agriculture.

14. Conclusion

The successful deployment of the AI Smart Trap represents a pivotal shift in the monitoring and management of pink bollworm in cotton. By transitioning from manual, labour-intensive scouting to an automated, real-time surveillance framework, the ICAR-CICR effectively eliminated the 'intelligence gap' that often leads to substantial yield loss caused by the dreaded pest, PBW. Beyond automated detection, this technology provides stakeholders with high-resolution spatio-temporal data, facilitating precise, area-wide Integrated Pest Management (IPM) interventions. As we scale this AI-driven approach, the integration of machine learning into cotton protection will be the cornerstone of sustainable, resilient, and precision-led Indian agriculture, ensuring that the 'White Gold' remains a viable and profitable crop for the farming community.

