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Integrated artificial intelligence in pest and disease management

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Abstract

The world is also losing up to 40 percent of the agricultural produce to intractable farm pests and diseases and they are necessitating inevitable intervention and mitigation strategies that look innovative. Conventional methods- such as bare treatments by means of chemicals and manual measurements, are generally inadequate due to dynamic resistance, dearth of labor and so on. The development of the pest and disease control with artificial intelligence (AI) has disrupted the entire process due to amplified surveillance, prediction, and precision control ensured with the help of data-driven methodologies. The components of AI-built systems are machine learning, computer vision and remote sensing applied to predict pests earlier and identify the species and better foresee the outbreak. Such technology may support Integrated Pest Management (IPM) to provide actionable decision-support, provide intervention timing to maximize the benefit of intervention, and reduce agrochemical usage. UAVs armed with these facilitate real-time surveillance, IoT-enabled monitoring and mobile diagnostic programs, intelligent prescription of solutions to farmers, large and small, are enable-weighted. However, data heterogeneity, rural connectivity gaps and model behavior in other ecological contexts present problems to the implementation of large scale. The fact that studies continue to be interdisciplinary makes it evident that there is a need to ensure that AI is strongly incorporated in various aspects of agriculture not only to ensure food security but also environmental sustainability. The review is a compilation of prevailing events, technological deliverables and impediments to execution with the critically-reviewing role of AI in pest and disease remain and its cohesion with environmentally friendly methods of managing crop protection.

Keywords: Artificial intelligence, pest management, disease forecasting, precision agriculture, decision support systems

Introduction

The development of ADI and artificial intelligence (AI) is transforming the future of the pests and diseases management in agriculture; it is now possible to develop management of crop protection with more efficient, limited, and enduring ways. Food and Agriculture Organisation estimates that there is an average of upto 40 percent of the yearly production in the world which is wasted due to agricultural pest and diseases. Conventional crop defense strategies have numerous issues such as dearth of labor, excessive use of chemicals, pesticide resistance and pest and illness accustomed climatic environment. The surrounding artificial intelligence is machinery learning, digital and accurate image and vision, has evolved as an evolutionary tool on improving the performance, precision and viability of plant protection techniques.

It considers data assistance and machine learning to improve monitoring and early detection, epidemic forecasting, and directed activities, which helps in the future preventations. The importance of those AI advances lies in their ability to add to the problems such as climate change and high price of production. AI made the routine of thoughtless dumping of pesticides a forerunner of the real time environmental scanning and predictable analytics-driven resolution. It is possible to say that this process has indeed been linked to the objectives of the Integrated Pest Management (IPM), all of which are revolving around the peaceful coexistence of the actions ensuring the maintainability of food and nature integrity. Amid new pest infections, unpredictable weather, the fast evolution of diseases among many other problems in the agricultural sphere, approaches to AI are assured to be beneficial in both the highest yield and profitably as well as in getting the world secure and sufficient nutrition.(Paul *et al.*, 2024) ^[10].

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In this review, the current innovations in AI-pest/disease management are discussed and encompass the ecosystem of sensing technologies, algorithm prototypes, application settings, and policies. This includes focus on inter-subject synthesis and exploration of possibility.

to impact effective research in agriculture, practical research must have. Therefore, the fusion of artificial intelligence with Entomology will be useful for better, efficient and in time forecasting and management of pests and diseases.

Overview of crop pest and crop diseases

1. Global impact and current challenges

Crop pests (consisting of insects, mites, nematodes, and weeds) and crop diseases (typically due to fungi, bacteria, viruses, and oomycetes) are the primary agents underlying agricultural losses and reduced quality, compounded by food insecurity. Their price they have forced the world over is already high: the large swarms of locusts, wheat rust and citrus greening have ravaged vast plots of land. It is further complicated by the spread of pests and pathogens through international trade (globalisation), surprise of climate and rising agriculture that makes it difficult

- to respond to those in a meaningful and timely way.
- Conventional practices used in pest and disease control are:
- Surveillance:** Manual searches to search, visual observations and by means of traps.
 - Targeted intervention:** The intervention that occurred to a specified economic plane.
 - Chemical control:** Pesticides might use the least fruit damages as compared to the biological controls, but with excessive usage they can result in resistance and environmental damages.
 - Cultural and biological control:** Rotation of crops, refuges, or augmentation with natural enemies.

Yet these methods are often reactive, manual-based, and not scalable. Agroecological systems are complex, and pest and pathogen evolution occur rapidly, requiring proactive, data-driven, and emergency research into integrated weed, insect, and disease management strategies (Rahman & Ravi, 2022) [11].

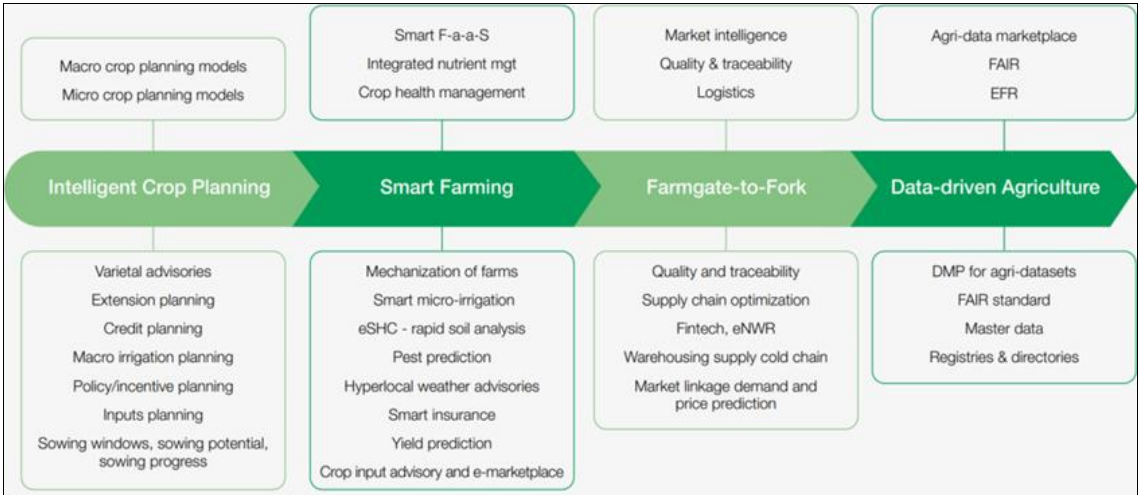
Table 1: Major Pests and Diseases:(Rahman & Ravi, 2022) [11]

Crop	Major Pests and Diseases	Loss (%)
Soybean	Soybean cyst nematode, White mold, Rust, Charcoal rot, Root-knot nematode	11-32
Maize	Armyworm, Fusarium stalk rot, Gibberella rot, Anthracnose	20-41
Rice	Sheath blight, Stem borers, Blast, Brown spot, Brown planthopper	25-41
Potato	Late/early blight, Brown rot, Cyst nematode	8-21
Wheat	Leaf rust, Fusarium blight, Stripe rust, Aphids, Powdery mildew	10-28

2. Artificial intelligence and machine learning in agriculture

The utilization of artificial intelligence in Agriculture consists of crop surveillance, targeted arbitration, and disease and pest

- recognition.
- Early Detection and Diagnosis.
- Integrated Pest Management (IPM).
- Decision Support and Precision Arbitration.



Source: (Maraveas, 2023) [7]

Fig 1: Smart farming and other emerging innovations in the agricultural sector

3. Decision Support and Precision Intervention

AI-based platforms analyze large datasets (satellite images, IoT data) to forecast pest outbreaks and optimize pesticide application. Predictive modeling, such as the use of extreme gradient boosting or random forests, harnesses environmental, genetic, and management data to provide site-specific interventions. The integration of AI with robotics automates tasks such as targeted pesticide spraying or mechanical removal of infected plants, thereby enhancing precision while

minimizing environmental impact (Paul *et al.*, 2024) [10].

4. Integrated Pest Management (IPM)

AI enhances IPM by supporting real-time, data-driven decisions and enabling automated monitoring of pest populations and beneficial organisms. Computer vision systems can distinguish between pests and natural enemies, promoting biological control strategies over chemical interventions (Leybourne *et al.*, 2025) [5].

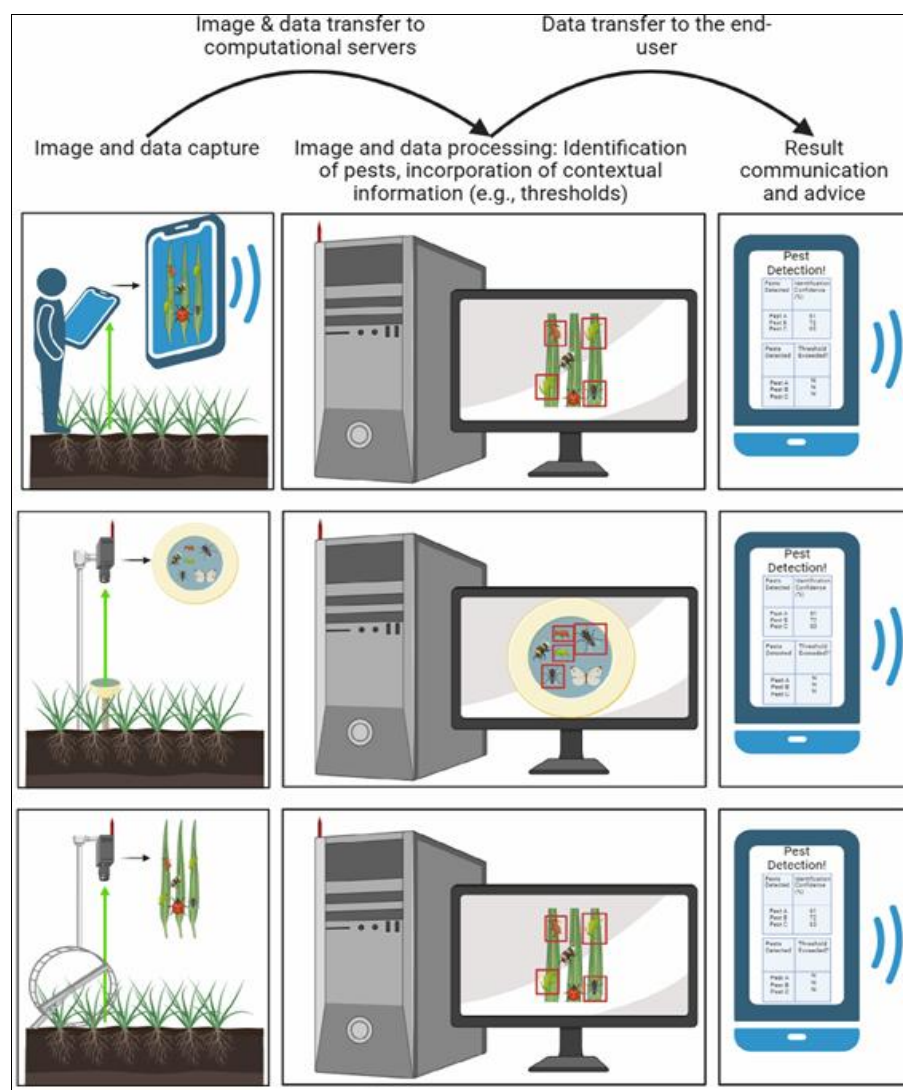


Fig 2: Graphical overview showing how artificial intelligence-techniques can be integrated with automated detection, classification and quantification of insect pests to develop smart herbivorous pest monitoring systems. (a) A mobile smart system supports farmers with ad hoc herbivorous pest identification; (b) A remote imaging station captures images from in-field traps; (c) A mobile monitoring station captures images from the crop canopy. All systems transmit images to a computer server where AI-driven models identify pest species present in the image and provide the end user with an output that can be used to guide decision-making processes. Source: (Leybourne *et al.*, 2025)^[5]

Data Acquisition Methods High-quality data is fundamental to the performance of any AI system. Integrated systems rely on several advanced sensing modalities:

- Remote sensing using satellites and UAVs gathers high-resolution RGB, multispectral, hyperspectral, and thermal images of crops, which are then processed to extract relevant vegetation indices (VIs) such as NDVI, PRI, and MSI to monitor both biotic and abiotic stresses (Aziz *et al.*, 2025)^[2].
- Ground-based sensors and IoT devices provide real-time measurements of soil moisture, temperature, humidity, and other environmental parameters, creating a rich dataset that feeds into predictive models (Maraveas, 2023)^[7].

Novel acoustic and optical sensors can detect insect-specific parameters such as wing beat frequency or sound patterns, supporting the classification of flying pests via machine learning algorithms (Sargunar Thomas *et al.*, 2023)^[13]

Data annotation is performed by experts or via crowdsourcing, with techniques such as semi-supervised learning facilitating the labelling of large datasets for robust model training

5. Model Development and Optimization After data acquisition

The next crucial stage is the creation of reliable AI models that can precisely identify and categorize pests and diseases. Important advancements have been made in computer vision. have been accomplished using deep learning frameworks, in which CNNs outperform conventional image processing methods in terms of feature extraction (Maraveas, 2023)^[7].

Particular strategies include: CNN models that accurately identify pest species, distinguish between healthy and sick plants, and recognize early signs of illness (Aziz *et al.*, 2025)^[2]. Combining CNNs with RNNs or LSTM networks in hybrid models has been demonstrated to increase prediction accuracy in yield forecasting and dynamic pest outbreak simulation. through the identification of time dependencies in the data (Aziz *et al.*, 2025)^[2].

To improve the accuracy of predictions and optimize resource management strategies in various agricultural situations, AI models are sometimes combined with meta-heuristic approaches and bio-inspired algorithms, like particle swarm optimization.

Automated machine learning frameworks are beginning to appear, which will lessen the need for expert tweaking by enabling models to automatically modify hyperparameters and architectures in response to the dataset's features (Sargunar Thomas *et al.*, 2023)^[13].

6. Decision Support and Automated Intervention Systems

The ultimate goal of incorporating AI into pest and disease management is to facilitate prompt, accurate, and affordable interventions. DSS is based on decision support systems that AI offers actionable advice on pesticide application, irrigation planning, and biological control tactics by collecting real-time information from integrated data streams (Mourtzinis *et al.*, 2021)^[9].

These systems enable the conversion of raw sensor data and predictive outputs into user-friendly graphics, such as heatmaps, time-series graphs, and GIS maps. These visual aids help users comprehend the information and forecasts. With the aid of technology, farmers and agronomists may readily analyze the geographical and temporal patterns of pest infestations and disease transmission. Furthermore, the combination of robotics and artificial intelligence. Additionally, automated spraying systems allow for the implementation of targeted interventions. Intelligent agricultural robots and drones have been used to administer specific pesticide applications and to minimize chemical inputs and lessen environmental effects by conducting regulated releases of biological control agents (Maraveas, 2023)^[7].

Remote Sensing and UAV Applications

The way agricultural fields are monitored and managed has been transformed by remote sensing. While UAVs provide high spatial and temporal resolution useful for local evaluations, satellite pictures give wide spatial coverage and frequent observations necessary for large-scale monitoring.

Hyperspectral and multispectral imaging provide precise spectral signatures of plants, allowing for the identification of minute alterations linked to the initial stages of pest infestations and disease epidemics.

By enabling quick aerial surveys, UAVs equipped with sophisticated sensors help pinpoint pest hotspots and evaluate plant health using spectral indices. These systems, which are based on UAVs, may integrate with AI algorithms to automatically classify the severity of pests and provide information to variable rate application systems. (Aziz *et al.*, 2025)^[12].

Recent studies demonstrate the usefulness of UAV data in fine-tuning irrigation and fertilizer methods as well, with accurate mapping of afflicted locations resulting in better outcomes. resource distribution. The integration of satellite and UAV data with in-situ sensor readings offers a multi-scale view that is necessary for successful integrated pest management. (Maraveas, 2023)^[7].

7. Sensor-based monitoring and data collection

The integration of artificial intelligence into pest and disease control comprises many important subfields, each of which emphasizes different technical and real-world aspects of agriculture. Sensor-based monitoring and data gathering—which uses field sensors and Internet of Things devices to monitor elements like soil moisture, temperature, humidity, and crop health—underlies AI integration. This ongoing flow of data enables early identification of the threat of pest infestation and the beginning of disease, therefore facilitating prompt

interventions.

Gathers real-time data on insect behavior, soil quality, and temperature using IoT sensors.

Early detection of risk elements is made possible by continuous crop monitoring (Vidya Madhuri *et al.*, 2025)^[14].

AI-driven diagnostic mobile apps have gained more and more significance as a farmer in recent years, particularly in remote and under-served regions. Such applications will allow quick Analysis and tailored recommendations on pest and disease management assistance to increase the frequency of access and utilization of intelligent technologies in agriculture. Nevertheless, obstacles still exist in regards to Data scarcity, excellent model generalization in a plethora of dissimilar settings, user interface simplicity, and socioeconomic barriers should be addressed in case of scalable and sustainable adoption of AI-based solutions that promise a future of stable and efficient agronomic frameworks (Yang *et al.*, 2024)^[15].

8. Predictive Analytics and Outbreak Forecasting

Machine learning models are used to forecast when and where infestations or outbreaks with the help of past and real-time information such as crop cycles, pest movement, farming techniques, and temperature data. The methods such as time-series analysis, regression models, and ensemble techniques provide realistic forecasts that are likely to be realized. Accurate warning assists in enhanced resource distribution, reduce losses of crops, and can reinforce sustainable pest and illness management procedures.

Sensor networks and agricultural databases on many farms collect an assortment of data, such as humidity, temperature, precipitation patterns, stages of crop growth, and pest numbers.

Model Training: This information is analyzed using regression analysis, time series models, neural networks, and ensemble based on other artificial intelligence and machine learning algorithms to discover complex Relationships and causal dynamics between environmental variables and pest / disease outbreaks.

Forecasting: Predicting: Trained models are able to decode incoming data which is often in real time to predict probability of an outbreak and risk maps of specific crops and regions.

Actionable Information: Predictive models enable agronomists and farmers to prepare mitigation plans even before the outbreak of epidemics, optimize scanning routes in fields, and rationalize the timing and amount of pesticides/fungicides to apply (Jafar *et al.*, 2024)^[3].

9. Automated Decision Support Systems (DSS)

To create focused suggestions, modern DSS combine field data, lab results, and specialist knowledge with artificial intelligence. These might include the kind and timing of treatment. threshold-based interventions, or choices among organic, biological, or chemical controls. Such systems empower farmers to make data-driven decisions that optimise effectiveness while minimising environmental impact—an key element of integrated pest management (IPM). Designed to help farmers, agronomists, and others, an Automated Decision Support System (DSS) in agriculture is a computer-based system. It combines information from agricultural managers in making informed and timely choices regarding crop production, pest and disease control, resource allocation, and environmental sustainability. Several sources provide complicated information and actionable advice fit for particular agricultural settings (Manoj M U *et al.*, 2024)^[6].

Key Features of Agricultural DSS

Data Integration: Melds information from satellite and drone imagery, soil databases, pest/disease monitoring, crop growth models, weather stations, and IoT sensors.

Data analysis and forecasting of results including irrigation requirements, nutrient deficiencies, and pest outbreaks rely on artificial intelligence, machine learning, statistical models, and simulation.

Provides farmers user-friendly dashboards or mobile applications giving unambiguous, situation-based advice and warnings.

Automation lowers human error and allows for real-time decision-making by automatically updating recommendations based on the most current incoming data (Manoj M U *et al.*, 2024)^[6].

10. Mobile Applications and On-Farm Diagnostic Tools

Equipped with onboard artificial intelligence, mobile apps level access to diagnostics by letting farmers use portable sensors or cellphone cameras to scan crops and obtain immediate feedback. These apps leverage expert systems and cloud-based data to offer customized management guidance. Their use has speeded the influence of artificial intelligence, especially in resource-limited and smallholder agriculture environments. Mobile applications and on-farm diagnostic instruments have revolutionized pest and disease control in farming, so democratizing access to expert advice and cutting-edge diagnostics for farmers, particularly in distant or resource-poor regions. To photograph plants displaying symptoms, farmers employ smartphones or tablets. Built-in artificial intelligence algorithms (typically based on convolutional neural networks) examine these images in real-time to quickly diagnose diseases or pest damage and sometimes pinpoint the insect species.

Advanced applications extend the range of diagnostics beyond visual inspection by connecting with portable sensors that assess soil moisture, pH, or plant biochemical markers as well as climatic factors. Following diagnosis, applications provide evidence-based management recommendations, including organic and biological control measures, pesticide selection, application dosage, timing, or suggestions (Manoj M U *et al.*, 2024)^[6].

The availability of excellent, varied datasets gathered through several sensing devices determines the success of AI-integrated diagnostic systems' data acquisition and advanced analytics. Explainability techniques are frequently used to enhance the understandability of AI models, which aids agronomists in determining the essential characteristics that contribute to the model's predictions. are suggestive of certain illnesses or pest infestations (Raj & Prahadeeswaran, 2025)^[12].

Additionally, real-time analytics carried out on the edge, using devices with local processing capabilities, makes certain that actionable insights are given without unnecessary latency, which is essential for timely intervention in circumstances involving a quickly spreading pest outbreak (Miller *et al.*, 2025)^[8]. Cloud-based services are also essential as they make it possible to combine and cross-analyze data provided by many sources over time and obtain predictive models that forecast the dynamics of pest populations and spread of diseases (Ali *et al.*, 2024)^[1]. These data collecting and analytical processes ensure that advice is contextually relevant and aid the accuracy and dependability of AI-incorporated pest and disease management systems. (Khatri *et al.*, 2024)^[4].

Role of Machine Learning and Deep Learning Techniques

These AI-integrated systems are based on the advanced deep learning and machine learning algorithms that convert raw sensor data into valuable information. (Miller *et al.*, 2025)^[8]. Convolutional neural networks (CNNs) have been extensively applied in analyzing image data in smartphones, drones and fixed cameras with diagnostic accuracy of up to 95%. (Raj & Prahadeeswaran, 2025)^[12]. At the same time, object recognition systems such as YOLOv8 have been applied to specific symptoms such as leaf miner damage on tomato plants or cassava leaf diseases, with an accuracy rate of 87-93 percent depending on the information and conditions. (Yin *et al.*, 2025)^[16]. More layers transformer-based models, originally developed in natural language processing, are currently being adapted to process large genomic and environmental data. understanding of the factors that cause crop stress and disease. (Raj & Prahadeeswaran, 2025)^[12]. They are supplemented with traditional machine learning models that include decision trees, support vector machines, and ensemble models, which play a complementary role in these deep learning strategies. circumstances in which data volumes are either smaller or more diverse (Ali *et al.*, 2024)^[1]. To attain the degree of diagnostic accuracy needed for precision agriculture, which would provide both economic and environmental benefits, it is essential to keep improving and perfecting these algorithms (Raj & Prahadeeswaran, 2025)^[12].

Technological Infrastructure and IoT Integration

The complex technological infrastructure supporting the cutting-edge analytical capabilities of AI-integrated diagnostic systems includes cloud-based analytics, communication protocols, and sensor networks (Raj & Prahadeeswaran, 2025)^[12]. IoT sensors placed in agricultural fields continuously gather data on environmental variables like soil moisture, temperature, and humidity, as well as plant physiological signals. like acoustic signatures and VOC emissions (Ali *et al.*, 2024)^[1]. These sensors are frequently connected via wireless networks that feed data into central cloud platforms or, more and more, into edge devices, where local processing can produce close to instantaneous insights (Miller *et al.*, 2025)^[8]. The need for consistent data protocols and better connection in rural areas continues to be a problem, despite these improvements (Miller *et al.*, 2025)^[8].

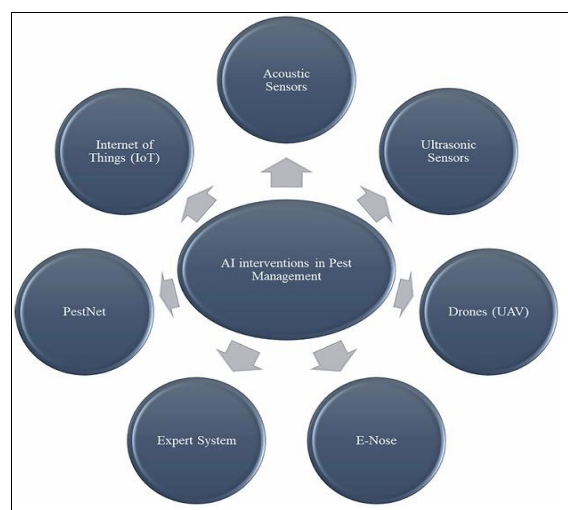


Fig 3: Different interventions of Artificial Intelligence in the field of pest management (Vidya Madhuri *et al.*, 2025)^[14]

Conclusion

The integration of Artificial Intelligence (AI) into agricultural pest and disease control is a revolutionary advancement that is changing the field. sustainable agriculture of the future. The behavior of AI-driven, data-focused technologies that deliver precision, effectiveness, and may not require chemicals, human labor or response is gradually replacing the previous style of pest management. and flexibility. This review has revealed that the use of advanced AI technology in the form of deep learning, machine learning algorithm and computer vision achieved a significant early-detection and real-time-detection, predictive outbreak, and target intervention increases. (Aziz *et al.*, 2025)^[2], (Paul *et al.*, 2024)^[10].

Incorporation of AI technologies with remote sensing, UAVs, field sensors of the IoT and mobile applications enjoys the possibility to gather and analyze information in time and allow farmers to make unbiased and timely decisions. (Miller *et al.*, 2025)^[8]. Predicted analytics, in other words, have shown that correct prediction of pests and diseases can be made with the assistance of historical and environmental data to act prior to the eventuality, to minimize the effects of the surrounding and at the expense of losses. (Jafar *et al.*, 2024)^[3], (Yang *et al.*, 2024)^[15]. In addition, mobile based diagnostic programs and automated decision support systems (DSS) have played a critical role in democratizing access to expert advice by bringing the benefits of AI to smallholder/low-resource farmers. (Raj & Prahadeeswaran, 2025)^[12], (Manoj M U *et al.*, 2024)^[6].

Species classification of pests, loss or symptom identification and provision of the best mitigation measures has particularly been successful with deep learning models such as CNNs, YOLOv8 and hybrids such as CNN-LSTM. (Yin *et al.*, 2025)^[16], (Aziz *et al.*, 2025)^[2]. These inventions are completely aligned with the strategy of Integrated Pest Management (IPM) which emphasizes on accurate environmentally friendly remedies as opposed to medicalizing the masses of people with chemicals. (Leybourne *et al.*, 2025)^[5], (Aziz *et al.*, 2025)^[2]. Not to mention, AI-controlled robots and computerized systems can minimize the necessity of pesticides and manual work, as well as, render the process of working in the field more accurate and efficient. (Sargunar Thomas *et al.*, 2023)^[13]. Despite all these developments there are still certain giant leaps. The quality and variety of data, definite available data standards, user friendly products and proper internet connectivity specifically in rural areas are the keys to having effective AI systems (Khatri *et al.*, 2024)^[4], (Miller *et al.*, 2025)^[8]. Other aspects like the models developed by AI will not necessarily work with other crops, or regions, lack of enough data in certain areas, and social or economic barriers which should be overcome also exist so that these services can be implemented in a fair and widespread way. (Ali *et al.*, 2024)^[11].

In conclusion, today AI has become a to change the stagnant agricultural practices of managing pests and diseases by enhancing detection, prevention and control. The resilient and productive agricultural systems offered by its leading with digital technology and environmental friendly farming methods makes it possible to have ecologically sustainable agricultural systems. As these increasingly global challenges emerge, including climate change, pest resistance and food security, cross-cutting research, policy advocacy and practical implementation of AI-combined systems will be vitally necessary in terms of informing the next generation of intelligent and sustainable agriculture.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper

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