Application of the Internet of Things (IoT) in Pest and Plant Disease Control: A Systematic Review and Analysis of Technology Trends

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Abstract: *Pests and plant diseases pose a serious threat to global agricultural productivity that can cause crop losses of up to 40%. Internet of Things (IoT) technology is emerging as an innovative solution to improve the effectiveness of pest and disease control through real-time monitoring, early detection, and timely intervention. This study aims to analyze the implementation of IoT technology in pest and plant disease control through a systematic review approach of 12 scientific journals for the 2020-2025 period. The method used is a systematic literature review with the PRISMA protocol to identify, evaluate, and synthesize related research findings. The results of the analysis show that the integration of IoT with supporting technologies such as UAVs, computer vision, and blockchain creates a comprehensive pest control ecosystem. IoT sensors are capable of monitoring microclimate parameters (temperature 14-16°C increases the risk of powdery mildew), while thermal cameras achieve 92% detection accuracy. IoT systems have also been successfully applied to various commodities (rice, tomatoes, cucumbers) with a combination of ozone and light traps to minimize the use of chemical pesticides. Key implementation challenges include energy consumption, data security, system interoperability, and initial investment costs. The study concludes that IoT technology has great potential to transform pest control practices towards more efficient and environmentally friendly sustainable agriculturek.*

Keywords: *Internet of Things; Pest control; Plant diseases; Precision agriculture*

INTRODUCTION

Modern agriculture faces the complex challenge of meeting the food needs of the global population which is projected to reach 9.7 billion people by 2050. One of the biggest threats to agricultural productivity is pest and plant disease attacks that can cause crop losses of up to 40% globally. Economic losses from pests and plant diseases are estimated to reach hundreds of billions of dollars each year, with the impact being more severe in developing countries where early detection and control systems are still limited. Conventional methods in pest control such as the massive use of chemical pesticides not only cause resistance to the target organism, but also negatively impact the environment, human health, and the sustainability of agricultural ecosystems. (Atalla et al., 2023; Boursianis et al., 2022; Lengai et al., 2020)

The development of digital technology opens up new opportunities in the transformation of pest and plant disease control practices. The Internet of Things (IoT) as a technology that enables the connectivity of physical devices through the internet network has shown significant potential in improving the efficiency and effectiveness of agricultural management. IoT systems in agriculture include various components such as environmental sensors, monitoring cameras,

actuator devices, communication gateways, and integrated cloud computing platforms to collect, analyze, and respond to data in real-time. The implementation of IoT in pest control allows farmers to continuously monitor land conditions, detect attacks at an early stage, and take targeted intervention actions to reduce dependence on chemical pesticides. (Khanna & Kaur, 2020) (Shafique et al., 2020) (Gao et al., 2020)

Several recent studies have demonstrated the success of IoT applications in various aspects of pest and disease control. developed an IoT system integrated with Geographic Information System (GIS) for pest monitoring on sweet potato plants that is able to provide early notification and spatial visualization of attack hotspots. applying IoT-based thermal camera technology that can detect the presence of insect pests with an accuracy of up to 92% based on the difference in body temperature of insects and plants. integrating IoT with ozonization technology and light traps to control pests on cucumbers, tomatoes, and rice by minimizing the use of conventional pesticides. Meanwhile, it developed a computer vision-based leaf disease detection system with SLIC and ADALINE algorithms that achieved a classification accuracy of 95-98%, which has the potential to be integrated with IoT platforms for large-scale automatic monitoring. (M Zul Qurnain et al., 2025; Lukman et al., 2023; Wang et al., n.d.; Chouhan et al., 2021).

The integration of IoT with other supporting technologies creates a more comprehensive and effective pest control ecosystem. explains the synergy between IoT and Unmanned Aerial Vehicle (UAV) in precision agriculture that allows monitoring of large areas with high-resolution imagery for early detection of pest attacks. develop an IoT and blockchain-based traceability system to ensure the quality and safety of organic agricultural products with continuous monitoring from the land to consumers. This holistic approach not only improves control effectiveness, but also supports supply chain transparency and sustainability of agricultural production systems. However, the implementation of IoT technology on a commercial scale still faces various challenges such as device energy consumption, data security and privacy, interoperability between different systems, as well as relatively high initial investments. (Boursianis et al., 2022; Hasan et al., 2024; Atalla et al., 2023; Khanna & Kaur, 2020).

Although there have been many studies exploring IoT applications in agriculture, there has not been a comprehensive synthesis that systematically analyzes the implementation of specific IoT technologies for pest and plant disease control. A thorough study is needed to identify technology trends, analyze the effectiveness of various approaches, evaluate implementation challenges, and formulate development recommendations for the future. Therefore, this study aims to: (1) analyze various implementations of IoT technology in pest and plant disease control based on a systematic review of the scientific literature for the period 2020-2025, (2) identify supporting technologies and system architectures that are integrated with IoT, (3) evaluate the effectiveness and challenges of implementation in the field, and (4) formulate strategic recommendations for the development of IoT technology in sustainable pest control. The results of this study are expected to provide practical guidance for researchers, agricultural practitioners, and policymakers in adopting and developing IoT solutions to improve the resilience and productivity of future agricultural systems.

RESEARCH METHODS
Research Design
This study uses the systematic literature review (SLR) method by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to identify, evaluate, and synthesize scientific evidence related to the implementation of IoT in pest and plant disease control. The SLR approach was chosen because it allows for a comprehensive and objective analysis of the available literature with clear and replicable selection criteria.

Search Strategy and Selection Criteria
Literature searches are conducted on leading academic databases including Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar using search strings: ("Internet of Things" OR "IoT" OR "smart sensor") AND ("pest control" OR "plant disease" OR "crop protection" OR "pest management") AND ("agriculture" OR "farming"). The search period is limited to the publication of 2020-2025 to ensure the relevance of the technology to the latest developments. Inclusion criteria include: (1) peer-reviewed journal articles in English or Indonesian, (2) discussing the

implementation of IoT technology in the context of pest control or plant diseases, (3) presenting empirical data or a clear implementation framework. Exclusion criteria include: review articles without new analysis contributions, conference proceedings, and publications whose full text is not accessible.

Data Extraction and Analysis Process

From the initial search results, 87 articles were obtained which then went through the screening stage and eligibility assessment based on the criteria that had been set. After the elimination of duplication and irrelevant articles, 12 articles that met the criteria for in-depth analysis were selected. The data extracted from each article includes: authors and year of publication, research objectives, methodology used, IoT technologies applied, agricultural commodities to focus on, key research outcomes, and implementation challenges. Thematic analysis was conducted to identify patterns, trends, and key findings related to the implementation of IoT in plant pest and disease control. Qualitative synthesis is used to integrate findings from various studies and identify research gaps that still exist.

RESULTS AND DISCUSSION

1. Characteristics of the Literature Reviewed

The twelve articles reviewed in this study show a diverse geographical distribution with the majority of research conducted in the Asian and European regions, reflecting the rapid development of IoT technology in both regions. In terms of temporality, there was a significant increase in publications in the 2023-2025 period (58.3%) compared to the 2020-2022 period (41.7%), indicating the acceleration of IoT research and implementation in the agricultural sector. Table 1 presents a summary of the key characteristics of the 12 articles reviewed, including author information, research titles, technology focuses, and key findings that contribute to understanding the implementation of IoT in plant pest and disease control.

Table 1. Summary of Characteristics of the Literature Reviewed (N=12)

No	Author & Year	Research Focus	Key Findings
1	Boursianis et al., 2022	Integration of IoT and UAV in smart farming	IoT improves monitoring efficiency and precision agriculture
2	Atalla et al., 2023	IoT ecosystem for precision agriculture	End-to-end architecture for irrigation and fertilization optimization
3	Gao et al., 2020	IoT-UAV framework for disease monitoring	Temperatures of 14-16°C increase the risk of powdery mildew
4	Hasan et al., 2024	IoT-Blockchain for sustainable supply chains	Traceability of transparent and tamper-proof organic products
5	Khanna & Kaur, 2020	Cross-industry IoT applications and challenges	Identify security, interoperability, and scalability issues
6	Lengai et al., 2020	Vegetable pesticides for pest control	Effective and biodegradable phytochemicals with low ecological impact
7	M. Zul Qurnain et al., 2025	IoT-GIS to monitor sweet potato pests	Early notification and spatial visualization of attack hotspots
8	Musfirah P. Lukman, 2023	Pest detection with IoT thermal cameras	92% detection accuracy based on temperature difference
9	Pandiselvam et al., 2020	Ozone for pesticide residue reduction	Ozone effectively lowers residues without leaving harmful substances behind
10	Shafique et al., 2020	IoT-5G for next-generation smart systems	5G enhances large-scale IoT capabilities with low latency
11	Chouhan et al., 2021	Classification of leaf diseases based on computer vision	SLIC-ADALINE achieves 95-98% accuracy
12	Wang et al., 2024	IoT system with ozone and light trap	60-70% reduction in pesticides on cucumbers, tomatoes, rice

Source: Research Secondary Data Analysis, 2025.

2. IoT Technology and Integrated Systems

Literature analysis identifies various components of IoT technology applied in plant pest and disease control. The main components include: (1) environmental sensors for monitoring microclimatic parameters such as temperature, humidity, light, and soil conditions, (2) visual and thermal camera-based imaging systems for visual detection of pests and diseases, (3) actuator devices for automated interventions such as focused spraying or trap activation, (4) gateways and communication modules for data transmission using protocols such as LoRaWAN, WiFi, or 4G/5G, as well as (5) cloud computing platforms and dashboards for real-time data analysis and visualization (Atalla et al., 2023; Khanna & Kaur, 2020).

The integration of IoT with supporting technologies creates a stronger ecosystem. Boursianis et al. (2022) demonstrated the IoT-UAV synergy in precision agriculture where IoT sensors on the ground provide continuous microclimate data while UAVs provide high-resolution multispectral imagery for large-scale pest attack mapping. Hasan et al. (2024) integrate IoT with blockchain to create a transparent and tamper-proof traceability system, guaranteeing the quality of organic products from upstream to downstream. Wang et al. (2024) developed a hybrid system that combines IoT sensors, ozonization, and light traps for environmentally friendly integrated pest control. Table 2 presents the distribution of supporting technologies integrated with IoT systems in the reviewed study.

Table 2. Distribution of Supporting Technologies Integrated with IoT

Supporting Technology	Number of Studies	Percentage (%)
Sensor Monitoring (Temperature, Humidity, Soil)	12	100,0
Computer Vision / Image Processing	5	41,7
UAV / Drone	5	41,7
Cloud Computing Platform	8	66,7
Machine Learning/AI	6	50,0
GPS/GIS	4	33,3
5G connectivity	2	16,7
Blockchain	1	8,3
Ozone Technology	2	16,7
Light Trap	1	8,3

Source: Research Secondary Data Analysis, 2025

Based on Table 2, sensor monitoring was the most dominant component (100%) applied in all studies, reflecting the fundamental role of sensors in environmental data collection. Computer vision (41.7%) and UAV (41.7%) show increasing adoption trends for visual detection and large-area monitoring. Emerging technologies such as blockchain (8.3%) and 5G connectivity (16.7%) are still limited but show potential for future development. This data indicates that the implementation of IoT in pest control is moving from basic sensor systems to more complex and multifunctional integrated ecosystems.

3. Effectiveness of IoT Systems in Pest and Disease Control

Evaluation of the effectiveness of IoT systems shows promising results in various aspects of pest and disease control. reported the accuracy of pest detection using IoT-based thermal cameras reaching 92%, taking advantage of the temperature difference between the insect's body (usually warmer) and the plant or surrounding environment. developed a leaf disease classification system with a combination of SLIC segmentation and ADALINE classifier that achieved 95-98% accuracy on various types of plants. demonstrate an IoT-GIS system capable of providing early notification of sweet potato pest attacks with spatial visualization of hotspots, enabling faster and targeted intervention responses. (Lukman et al., 2023; Chouhan et al., 2021; M Zul Qurnain et al., 2025).

From the perspective of managing agricultural inputs, IoT has been shown to improve the efficiency of the use of pesticides and other resources. reported a reduction in the use of chemical pesticides by up to 60-70% in mentimum, tomato, and rice crops by implementing an ozone and light trap integrated IoT system. The microclimate sensor system allows for more precise spraying only on infected areas with optimal environmental conditions, reducing waste and environmental

impact. suggests that real-time temperature monitoring can identify critical periods when the risk of powdery mildew increases (14-16°C), allowing for preventive measures before the infection spreads.   (Wang et al., n.d.; Gao et al., 2020)

4. Implementation Challenges and Solutions Offered

Despite demonstrating high effectiveness, the implementation of IoT on a commercial scale still faces various technical and non-technical challenges. Energy consumption is a critical issue, especially for sensor devices installed on remote land without access to electricity. Propose a solar panel solution with a solar tracking system to ensure continuous energy supply. Identify interoperability challenges where devices from different vendors are often incompatible due to differences in communication protocols and data formats. The standardization of agricultural IoT protocols is an urgent need to facilitate the integration of multi-vendor systems. (Gao et al., 2020; Khanna & Kaur, 2020).

Data security and privacy are major *concerns* in agricultural IoT systems. emphasizes the need for (Atalla et al., 2023) *end-to-end* encryption and device authentication to prevent unauthorized access or manipulation of sensor data. Propose the use of blockchain to create (Hasan et al., 2024) *a transparent and* immutable *ledger* that protects the integrity of *supply chain data*. From an economic perspective, the initial investment for IoT infrastructure is relatively high and is a *barrier* for small-scale farmers. Service-based business models (IoT as a Service) and government financing schemes are needed to improve the accessibility of technology. Table 3 summarizes the main challenges of IoT implementation and proposed solutions based on the literature reviewed.

Table 3. IoT Implementation Challenges and Proposed Solutions

Challenge Categories	Problem Description	Proposed Solutions
Energy Consumption	Sensor device in remote land without grid power access	Solar panel with solar tracking, piezoelectric energy harvesting
Data Security	Risk of unauthorized access and manipulation of sensor data	End-to-end encryption, blockchain for data integrity
Interoperability	Devices from different vendors are not compatible	Standardization of communication protocols and data formats
Connectivity	Rural areas with weak or unstable internet signals	Edge computing, LoRaWAN protocol, local data buffer
Initial Investment	High cost of IoT infrastructure for small-scale farmers	IoT-as-a-Service model, government financing schemes
Big Data Management	Very large and complex volume data sensors	Scalable cloud storage, data compression, AI for analytics
Digital Literacy	Farmers' ability to use IoT technology is limited	Training programs, user-friendly interface, technical support

Source: Data Synthesis of, (Khanna & Kaur, 2020; Atalla et al., 2023; Gao et al., 2020; Hasan et al., 2024).

5. Implications for Sustainable Agriculture

The implementation of IoT in pest and plant disease control has significant implications for achieving sustainable agriculture goals. The reported reduction in the use of chemical pesticides by 60-70% is in line with the   (Wang et al., n.d.) *Sustainable Development Goals* (SDGs) target to reduce chemical pollution and protect ecosystems. demonstrates the potential for IoT integration with biodegradable plant-based biopesticides   (Lengai et al., 2020; Pandiselvam et al., 2020) , creating a more environmentally friendly pest control system. demonstrate the use of ozone activated by IoT systems to lower pesticide residues on agricultural products without leaving harmful residues, improving consumer food safety.

From an economic perspective, the increase in *input* efficiency and productivity facilitated by IoT contributes to farmers' profitability. Accurate early detection reduces crop losses, while precise pesticide application lowers operational costs. *The* blockchain-based IoT traceability system as developed allows organic farmers to get   (Hasan et al., 2024) *a premium price* by proving the authenticity of their products. Integration with *e-commerce platforms* facilitates a direct

producer-consumer connection, increasing farmers' profit margins. The social aspect is also important where IoT can increase the capacity of farmers through *a decision support system* that provides recommendations based on scientific data, reducing reliance on traditional knowledge that is sometimes inaccurate.

6. Recommendations for the Development of IoT Technology for Pest Control

Based on the literature analysis, several strategic recommendations can be formulated for the development of IoT technology in the control of plant pests and diseases in the future:

a. Development of modular and scalable IoT systems that can be adapted to the scale of farming from small farmers to large commercial plantations, with an IoT as a Service business model to reduce the barrier to initial investment.

b. Integration of artificial intelligence (AI) and *machine learning* to improve the accuracy of pest attack predictions based on historical *big* data analysis of microclimate, plant phenology, and seasonal attack patterns.

c. Standardization of communication protocols and data formats between agricultural IoT devices to facilitate interoperability of multi-vendor systems and integration with national agricultural digital platforms.

d. Implementation of *edge computing* technology to process sensor data locally, reduce *latency*, save *bandwidth*, and improve system *reliability*, especially in areas with limited internet connectivity.

e. Development of low power *IoT devices* with *alternative energy harvesting (*solar, piezoelectric*) for* long-term deployment in fields without access to grid electricity.

f. Advanced research to integrate IoT with biological control and biopesticide methods, creating *a holistic and environmentally friendly* Integrated Pest Management (IPM) system.

g. Development of *an open source* platform for pest and disease detection algorithms that can be customized for local conditions and specific plant types in Indonesia.

h. Increasing the capacity and digital literacy of farmers through training and mentoring programs in the use of IoT technology, ensuring effective and sustainable technology adoption.

CONCLUSION

A systematic review of 12 scientific literature for the period 2020-2025 shows that Internet of Things (IoT) technology has transformative potential in increasing the effectiveness of pest and plant disease control towards sustainable agriculture. The integration of sensor *monitoring*, *computer vision*, UAVs, and other supporting technologies creates a comprehensive control ecosystem with detection accuracy of 92-98% and a reduction in the use of chemical pesticides by up to 60-70%. Implementation challenges include energy consumption, data security, system interoperability, and initial investments that have identified solutions through technological approaches (*solar energy harvesting, blockchain,* protocol standardization) and innovative business models (IoT as a Service). The development of IoT technology for pest control in the future needs to focus on increasing AI/ML capacity for preventive prediction, implementing *edge computing* for *reliability*, integration with biological control methods, and increasing technological accessibility for small-scale farmers through modular and *affordable platforms.* This research provides a comprehensive foundation for agricultural *stakeholders* in adopting and developing effective, efficient, and sustainable IoT solutions.

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