

AI - Robotics in Plant Biotechnology: Transforming Crop Improvement and Sustainable Agriculture.

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Abstract

Artificial Intelligence (AI) and robotics in plant biotechnology are transforming modern agriculture by enhancing crop improvement and promoting sustainable farming systems. Recent systematic reviews indicate rapid growth in AI-driven agricultural robotics research between 2015 and 2025 (Hamrani et al., 2025). The integration of AI tools with biotechnological innovations such as genome editing, synthetic biology, and molecular breeding has accelerated trait development and precision farming (Li et al., 2025; Zhang et al., 2025). AI-IoT-enabled sensing systems further enhance disease detection and crop management (Ibrahim et al., 2025). These technologies reduce labor dependency, improve breeding accuracy, and optimize resource utilization, contributing to global food security and environmental sustainability.

Keywords

Plant Biotechnology, Robotics, Artificial Intelligence, Smart Agriculture, Genome Editing, Crop Improvement, Sustainable Agriculture, Machine Learning, Deep Learning, IoT, Big Data.

Introduction

Agriculture plays a vital role in sustaining human life by providing essential resources such as food, fiber, and other necessities. AI-powered autonomous farming is significantly transforming the agricultural landscape by enhancing efficiency, sustainability, and

productivity through technologies such as artificial intelligence, robotics, sensors, and data analytics (Chen, 2025).

Recent research highlights a substantial increase in the application of AI and robotics in agriculture, particularly in precision farming and specialty crops (Hamrani et al., 2025; Barbosa Júnior et al., 2024). Agricultural crops include fruits, vegetables, tree nuts, horticulture and nursery crops, floriculture, and medicinal plants. Many tasks such as planting, spraying, and harvesting are still labor-intensive and expensive.

Plant biotechnology involves genetic engineering, molecular breeding, genome editing, and tissue culture to enhance traits such as drought tolerance, disease resistance, and improved nutritional quality. The integration of AI with biotechnology enables predictive modeling of gene–trait associations, accelerating crop improvement programs (Li et al., 2025; Zhang et al., 2025).

AI robotic platforms combined with high-throughput phenotyping systems allow real-time monitoring of plant morphology and physiological responses (Pan et al., 2024). These systems utilize sensors, imaging technologies, computer vision, and deep learning algorithms (Artificial Intelligence in Life Sciences, 2023).

Robotics in plant biotechnology represents a transformative shift toward smart, data-driven agriculture, enhancing efficiency, accuracy, and sustainability (Gupta et al., 2024). Robotics technology is not only crop improvement but also contributing to global food security and Environmental conservation. As research continues to evolve, robotics will become an essential component of next-generation agricultural systems.

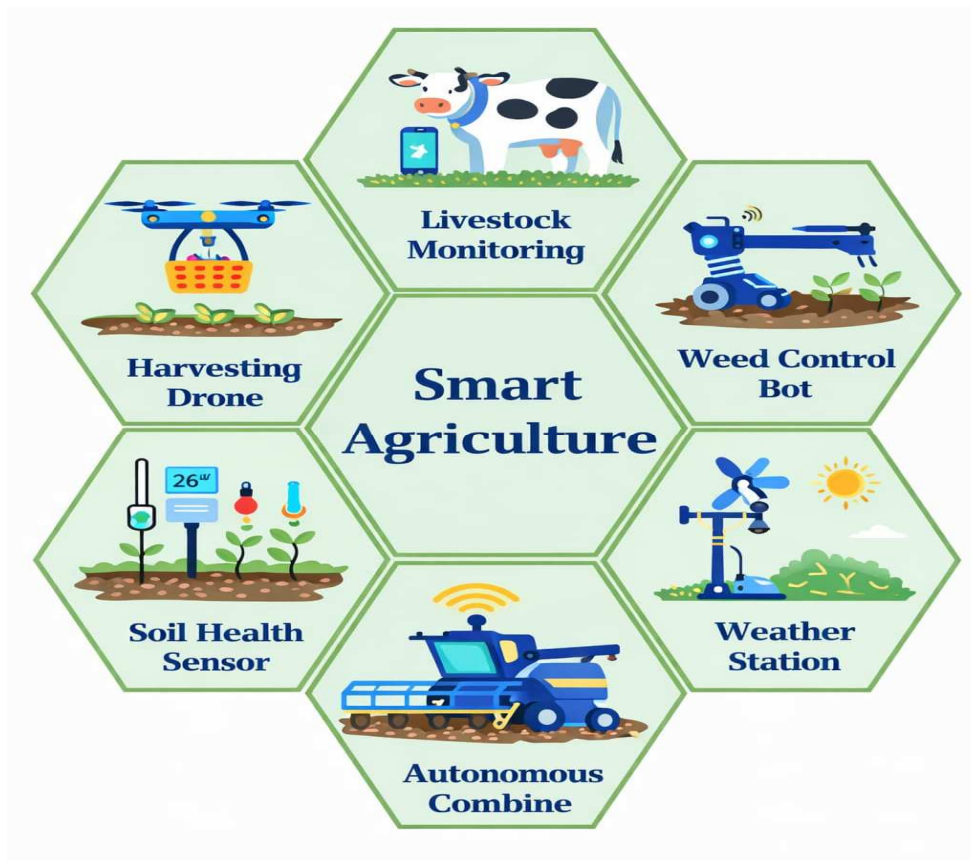
Objectives

- ❖ To analyze the role of Artificial Intelligence (AI) and robotics in modern plant biotechnology.
- ❖ To evaluate how AI-driven robotic systems enhance crop improvement strategies.
- ❖ To investigate the impact of robotic technologies on sustainable agricultural practices.

- ❖ To propose future research directions integrating AI, robotics, and biotechnology for global food security.

Methodology

Robots and automated devices are widely used in agricultural operations, including indoor farming, greenhouse management, and specialty crop production (Barbosa Júnior et al., 2024).



Weeding

Innovative robotic systems have been developed for crop and weed management in horticultural crops. Physical weed removal reduces chemical usage and promotes environmentally friendly farming (Smart Agricultural Technology, 2024).

Harvesting

AI-based robotic harvesting systems integrate hardware and software components for efficient crop picking. Machine vision techniques enable accurate fruit and boll detection.

For cotton harvesting, robotic arms based on 3D machine vision techniques have been developed at the Indian Institute of Technology Kharagpur. Advanced ground robotic systems are increasingly used in specialty crops (Barbosa Júnior et al., 2024).

Aerial Imaging Robots (Drones)

Unmanned aerial vehicles (UAVs) are widely used for crop monitoring, mapping, and environmental analysis (Pretto et al., 2019). Equipped with RGB and infrared cameras, drones capture high-resolution images for disease detection and crop health assessment (Ibrahim et al., 2025). They are automating tasks like pesticide spraying and land monitoring.

AI-powered sensor integration enables real-time monitoring of soil moisture, nutrient status, and plant stress (Agronomy, 2023). IoT-based smart irrigation systems optimize water use efficiency (Basa, 2024).

High throughput phenotyping Robots they are field and greenhouse robots equipped with sensors and cameras data on plant growth stress response.

Results and Discussion

The integration of AI technologies with biotechnological tools has significantly enhanced crop improvement outcomes. Drones are widely used in agriculture mapping environmental monitoring mapping and plant biotechnology research.

AI-based predictive models improve gene–trait association analysis and reduce the time required for target gene identification compared to conventional breeding (Li et al., 2025). The combination of synthetic biology and AI further accelerates trait engineering (Zhang et al., 2025). biotechnological tools are sustainable agriculture by way of efficient farming practices advances in geniting engineering.

AI-IoT and big data in smart agriculture systems enable automated plant disease detection and targeted treatment strategies (Ibrahim et al., 2025). High-throughput

phenotyping robots such as “Pheon-Robot” allow in-situ modeling of plant growth under field conditions (Pan et al., 2024).

Comparative analyses of robotic systems demonstrate improved sustainability, reduced chemical inputs, and enhanced productivity (Smart Agricultural Technology, 2024). Overall, AI-driven agriculture improves land-use efficiency and supports sustainable intensification (Chen, 2025).

Conclusion

Robotics and artificial intelligence provide effective solutions to modern agricultural challenges. AI improves yield outcomes, enhances operational efficiency, and reduces environmental impact. AI-enabled farming ensures precise application of water, fertilizers, and pesticides.

The integration of AI, robotics, IoT, and plant biotechnology accelerates phenotyping, optimizes breeding programs, and promotes sustainable agriculture. Continued innovation in AI-based genome editing and robotic systems will be crucial for achieving global food security and climate-resilient agriculture (Li et al., 2025; Cell, 2025).

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