ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(9): 909-911
www.agriculturaljournals.com
Received: 16-06-2025
Accepted: 18-07-2025

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Recent trends in farm machineries for horticulture

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DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i9l.843

Abstract
Horticultural mechanization has emerged as a crucial driver of productivity, quality enhancement, and sustainability. Unlike broadacre agriculture, horticultural crops require highly specialized machinery due to smaller plot sizes, intensive cultural operations, and delicate produce. Over the last decade, but especially in the period 2020-2025, significant technological progress has been recorded in precision farming, automation, robotics, electrification, protected cultivation machinery, and post-harvest processing. Digital tools such as artificial intelligence (AI), Internet of Things (IoT), and cloud-based decision support systems are accelerating adoption. This review synthesizes recent trends, examines adoption constraints, identifies research gaps, and proposes future directions to foster wider use of modern farm machineries in horticulture.

Keywords: Horticultural mechanization, precision agriculture, agricultural robotics, electrification, post-harvest mechanization, protected cultivation

Introduction

Horticultural crops — fruits, vegetables, floricultural and plantation crops — contribute substantially to nutritional security and income generation. India is the second largest producer of fruits and vegetables globally, with production exceeding 355 million tonnes in 2022-23 (NHB, 2023). However, production is highly labour-intensive; operations such as planting, weeding, pruning, spraying, harvesting, grading and packaging demand precision and skill. Rising labour costs, seasonal shortages, and consumer demand for uniform, high-quality produce are intensifying the need for mechanization.

In contrast to field crops, horticultural mechanization faces unique challenges: smaller farm holdings, high-value but delicate produce, diverse crop morphology, and the need for gentle handling. Recent years have witnessed rapid advances in robotics, sensor-based systems, renewable-energy-powered equipment, and post-harvest machines. Integration of digital technologies such as IoT and AI further strengthens mechanization outcomes.

This article reviews recent trends in horticultural mechanization with focus on precision agriculture, automation and robotics, electrification, machines for protected cultivation, post-harvest innovations, and digital integration, followed by identification of research gaps and policy priorities.

Precision Agriculture in Horticulture

Precision farming technologies are being increasingly customized for horticulture.

- **Sensors and monitoring devices:** Soil moisture sensors, canopy reflectance sensors, and low-cost IoT-enabled devices help optimize irrigation and fertigation.
- **Variable rate application (VRA):** Nutrients and pesticides are delivered based on crop and canopy variability, reducing wastage.
- **GNSS/RTK-based systems**: These allow accurate row planting, orchard mapping, and autonomous navigation in narrow inter-row spaces.
- **Decision support systems (DSS):** Integrated platforms now combine weather forecasts, soil data, and plant growth models to guide orchard management.

For example, precision spraying systems using ultrasonic sensors achieved up to 30% reduction in pesticide use in vineyards (Pallottino *et al.*, 2021) [4]. Similar studies in apple and citrus orchards confirm higher input efficiency.

Automation and Robotics

Robotic harvesters

Fruit harvesting is labour-intensive and time-sensitive. Robotic harvesters equipped with machine vision, depth cameras, and soft grippers are being developed for apples, strawberries, tomatoes, and citrus. Commercial prototypes like the Octinion strawberry harvester (Belgium) and FFRobotics apple picker (USA) demonstrate progress, although speed and cost remain bottlenecks.

Unmanned Ground Vehicles (UGVs)

Small-scale UGVs fitted with weeding tools, sprayers, or load carriers are increasingly used in high-value crops. Researchers at Wageningen University developed a robotic lettuce harvester, while Indian prototypes of robotic weeders for vegetables show promise in labour substitution.

Drones in horticulture

Drones are applied for

- Aerial spraying of micronutrients and pesticides in vineyards and mango orchards.
- Remote sensing for canopy stress detection.
- Pollination support in greenhouse crops.

Challenges

Robotic adoption is slowed by canopy complexity, variability in fruit maturity, energy constraints, and high initial investment.

Electrification and Renewable Energy Integration

Electrification is a major trend across agriculture, with horticulture as an early adopter due to smaller machines and confined operations.

- Battery-powered sprayers and weeders are widely available for small farmers.
- Electric tractors (e.g., Monarch Tractor, Sonalika Tiger Electric) are being trialed in orchards.
- Solar-powered cold rooms and dryers help reduce post-harvest losses in perishable horticultural crops.

Studies suggest that electric motors are 30-40% more energy-efficient compared to diesel counterparts for small-scale machinery (Mohanraj *et al.*, 2022) [2]. Challenges include battery replacement costs and charging infrastructure.

Mechanization for Protected Cultivation and High-Density Orchards

Protected cultivation area in India exceeds 1.5 lakh hectares. Mechanization within greenhouses and polyhouses requires compact, modular equipment.

- Mobile platforms for spraying, harvesting, and pruning are now used in cucumber and capsicum cultivation.
- Robotic pruners in apple and grapevine systems increase uniformity and reduce labour cost.
- Automated fertigation units with pH and EC sensors deliver precise nutrient solutions.

High-density orchards (apple, guava, mango) are benefiting from compact tractors, mechanical pruners, and platform harvesters designed for narrow alleys.

Post-Harvest Mechanization

Post-harvest losses in fruits and vegetables in India are estimated at 15-25% (FAO, 2021). Mechanization is critical to reducing this loss.

- Grading and sorting machines use vision sensors to classify fruits by size, colour, and quality.
- On-farm pack houses with conveyor belts, washing, waxing, and packaging lines are expanding under government schemes.
- Solar-powered cold storage units improve shelf life for smallholders.
- Mechanical dryers enhance processing for chilies, ginger, and onion.

Research is now focusing on affordable and modular post-harvest units for small-scale farmers.

Digitalization and AI Integration

Digital platforms are transforming horticultural machinery usage:

- IoT-enabled devices collect real-time field data.
- AI models are applied for disease detection, yield forecasting, and maturity indexing.
- Blockchain-based traceability is being piloted in grape export chains.

Startups in India (e.g., Fasal, CropIn) are integrating IoT with machinery operations to optimize inputs.

Socio-Economic Aspects and Barriers to Adoption

Despite technological availability, adoption remains limited. Barriers include:

- High upfront cost and limited credit.
- Lack of after-sales service in rural areas.
- Knowledge gaps among farmers.
- Fragmented landholding.

Custom Hiring Centers (CHCs) and Farmer Producer Organizations (FPOs) are emerging as effective business models to improve access.

Research Gaps and Future Directions

- Affordable and rugged robotic harvesters adaptable to diverse crops.
- Development of compact electric tractors and implements for small farms.
- Sensor networks with offline functionality for low-connectivity areas.
- Modular post-harvest mechanization units tailored for micro-enterprises.
- Life-cycle assessments of horticultural machinery for sustainability benchmarking.
- Policy support for financing, subsidies, and training.

Conclusion

Farm mechanization in horticulture is at a transformative stage. Precision agriculture, automation, electrification, and post-harvest innovations hold immense promise. However, adoption hinges on affordability, service ecosystems, and context-specific design. Future research must focus on developing scalable, cost-effective, and sustainable technologies that suit small and medium horticultural holdings while integrating digital tools for efficiency.

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