Environment and Ecology 42 (4B) : 1933—1942, October—December 2024
Article DOI: https://doi.org/10.60151/envec/KSOK1056
ISSN 0970-0420

Role of Cutting-Edge Technology in Horticulture Crops for Shaping the Future Smart Farming Ecosystem: A Comprehensive Review

Mukesh Kumar, Abhishek Kumar, Sajjan Kumar, G.T. Patle, Surender Kumar, Anju Tanwar

Received 28 August 2024, Accepted 12 November 2024, Published on 16 December 2024

ABSTRACT

Agricultural automation is rapidly advancing worldwide, with crop management systems optimizing cultivation across diverse conditions. In India, where horticultural crops are economically vital despite limited land, innovative technologies like AI, blockchain, IoT, remote sensing, and hydroponics are key to meeting growing demand. Advances in AI, robotics, and machine learning now enable effective monitoring of plants, pests, and diseases. This review examines the global impact of these technologies on horticulture, including their effects on food production, associated challenges, and future prospects, along with digital tools for farm management.

Keywords Automation, Blockchain, Artificial intelligence, IoT, Vertical farming, Remote sensing.

INTRODUCTION

Horticulture stands to benefit significantly from automation and digitization. Technologies such as AI, robotics, sensor-controlled solutions, and data management systems can boost output and enhance sustainability and competitiveness in the industry (Shamshiri *et al.* 2018). With the global population expected to reach 9 billion by 2050, increasing production through expanded land, improved productivity, and reduced post-harvest losses is crucial. Horticultural crops, being highly productive, are well-positioned to meet this demand (Tiwari *et al.* 2015). In India, horticulture boosts the economy by increasing agricultural production, creating jobs, and supplying raw materials for food processing (Qingxue and Wu 2016). Despite greater fruit production, coordinating sales remains challenging due to intermediary control and exploitation, though cooperatives and improved cold chains have made strides in some regions. Agriculture faces pressure to enhance yield with a projected population of 10 billion by 2050. Climate change and environmental

Mukesh Kumar[1]*, Abhishek Kumar[2], Sajjan Kumar[3], G.T. Patle[4], Surender Kumar[5], Anju Tanwar[6]

[1,2,3,5,6]Assistant Professor, [4]Associate Professor

[1]Botany Department, Government College Bahadurgarh, Jhajjar 124507, Haryana, India

[2]Graphic Era (Deemed to be University), Dehradun 248002, India

[3]Department of Geography, Government College Bahadurgarh, Jhajjar 124507, Haryana, India

[4]College of Agricultural Engineering and Post-Harvest Technology, Central Agricultural University, Gangtok, Sikkim 737135, India

[5]Department of Botany, Pt.NRS Government College, Rohtak, India

[6]Department of Botany, Goverenment PG College, Ambala Cantt 133001, Haryana, India

Email: mukbot23@gmail.com
*Corresponding author

challenges complicate this task, but technologies like AI and IoT offer viable alternatives to land expansion by optimizing field data analysis and farming practices (Matta *et al.* 2017). Precision farming, through accurate input measurement and reduced pesticide use, promotes sustainable productivity (Bernhardt *et al.* 2021). Overall, automation and digitization are vital for advancing horticulture, as they enable efficient management and sustainability, crucial for meeting the growing global food demand. The use of these technologies, despite being in early development stages, is essential for addressing the challenges of an increasing population and limited resources (Matta and Pant 2019).

Digitization and automation

It is projected that the global population would see rapid growth and reach a total of 10 billion individuals by the year 2050. The agriculture business is under significant pressure to increase the yield per hectare and enhance crop production. In recent years, horticulture has faced ongoing threats from climate change and other environmental challenges, which have made it exceedingly challenging to achieve higher levels of productivity. Two potential answers to the food supply problem include expanding land use and implementing large-scale farming, or adopting best practices and utilizing technological support to enhance productivity. In densely crowded areas of rising nations, when extending land space is not practicable, the only viable solution is to enhance intelligence through the implementation of advanced technologies such as artificial intelligence (AI), the Internet of things (IoT), and other interventions in horticulture. Field data can be analyzed more effectively using digital technologies such as artificial intelligence and the internet of things. These technologies also enable systematic organization of farming practices with minimal human involvement. Over the years, the agricultural business has recognized the significance of precision farming. Precision farming, through accurate measurement of inputs and careful control of potentially dangerous pesticides and other substances, provides a sustainable solution that can enhance productivity.

Better insights may be produced from field data by utilizing digital technologies like artificial intelligence and the Internet of things, which also make it possible to organize farming methods cautiously with the least amount of human effort. The agricultural industry has come to understand the value of precision farming over the years. By precisely measuring inputs and minimizing the misuse of potentially harmful pesticides and other inputs, precision farming offers an environmentally friendly choice that will increase productivity.

The development of horticulture technology

Field data can be analyzed more effectively using digital technologies such as artificial intelligence and the Internet of Things (Katal *et al.* 2013). These technologies also enable the careful organization of farming operations with minimal human intervention. Over the years, the agricultural business has recognized the significance of precision farming (Wazid *et al.* 2017). Precision farming, through accurate measurement of inputs and effective reduction of the abuse of potentially hazardous pesticides and other inputs, provides an ecologically conscious option that will enhance output. Digitization in horticulture enables real-time analysis, leading to improved land management, water management, spraying, and field monitoring. By harnessing state-of-the-art digital technology, the agriculture sector can achieve numerous advantages such as reduced input costs and waste, implementation of sustainable methods, and greater production to meet the growing global need for food (Bernhardt *et al.* 2021).

Overview of technologies and their functions

Horticulture is leveraging advanced technologies such as cloud computing, blockchain, big data, and the Internet of Things (IoT) for automation, disease detection, supply chain optimization, fertilizer management, irrigation control, maturity identification, and weather pattern analysis. The IoT, a network of smart devices, provides real-time information, essential for other technologies. AI, integrating machine learning, cognition, emotion recognition, data storage, and human-computer interaction, has advanced with increased computer power and specialized processors, enabling deep learning and improved data utilization (Arya and Gangwar 2021). AI techniques like artificial neural networks, decision-support systems, genetic algorithms, support-vector machines, and computer vision are used in agriculture for soil management, crop management, disease detection, and weed control (Caiming and Lu 2021). IoT collects data for production, management, and service from horticultural facilities, using robots, drones, remote sensors, and computer imagery for efficient farm management, reducing costs and saving time (Alireza and Ludena 2013). Blockchain enhances food safety by facilitating traceability, improving quality control, and ensuring fair remuneration for farmers (Zhiguo *et al.* 2010). Extensive databases provide detailed data on precipitation patterns, hydrological cycles, and fertilizer needs, helping firms optimize crop selection and harvest timing (Coble *et al.* 2018). Cloud computing aggregates and analyzes horticulture data, with machine learning algorithms enhancing crop condition understanding (Ruthie 2019). Augmented reality aids precision farming, improving productivity, reducing waste, and sharing information among farmers (Kamilaris *et al.* 2019). Advanced technologies like sensors, robotics, aerial and satellite photography, and GPS enhance the agricultural value chain, increasing profitability, efficiency, safety, and sustainability. Hydroponics, a soilless cultivation technique, aligns with these advancements, leveraging AI, plant biology, and indoor vertical farming to play a crucial role in future food production (Hati and Singh 2021, Pant *et al.* 2009).

Artificial intelligence in horticulture

Artificial Intelligence (AI), a field coined by John McCarthy in 1950, focuses on replicating human behavior through machines (Manaware 2020). AI enhances horticulture by cultivating nutritious crops, organizing data for farmers, reducing workload, and improving the food supply chain. Integrated with the Internet of Things (IoT), AI reduces costs, particularly labor, which accounts for about 30% of greenhouse production expenses in the Netherlands (Pekkeriet *et al.* 2015). Technological advancements like machine learning improve profitability and operational efficiency by automating tasks across production, post-harvest, quality evaluation, storage, and packaging (Nturambirwe and Opara 2020, Sousa-Gallagher *et al*. 2016). Current AI applications in horticulture include advanced pest management and fruit harvesting. Digital systems automate pest monitoring through auditory and optical detection, using microphones and digitized traps (Böckmann *et al.* 2021), and integrate with pest control guidelines accessible via mobile apps (Sinn *et al.* 2021). Specialized systems like SPLAT manage pheromone release for pest control. In fruit harvesting, robots equipped with cameras and air jets differentiate between fruit and foliage, ensuring non-damaging collection (Kumar *et al.* 2023). AI also aids in forecasting environmental changes, optimizing crop production, and reducing postharvest losses. For example, neural networks predict frost and optimize growth conditions (Robinson and Mort 1997, Sahni *et al.* 2021), while image processing and hyperspectral imaging improve fruit counting and moisture content prediction (Lomte *et al.* 2019, Siregar *et al.* 2017).

The internet of things (IoT) intervention in horticulture

It is widely acknowledged that all pests and illnesses are harmful to plants and can completely destroy horticulture. The internet of things system was created to reduce the frequency of pesticide and fungicide applications while also predicting when pests may arise (Kumar *et al.* 2022). Fruit identification is performed by combining color, shape, and texture—the three fundamental features of an object—via soft computing technology. This approach decreases the dimensions of the feature vector. As a result, with less training data, integrated and normalized picture features achieve greater classification accuracy. To mitigate the effects of climatic disasters on vegetable production, researchers created an IoT-based technology platform for real-time environmental data collecting (Rajpoot *et al*. 2024), disaster warning, transmission, remote control, and information push in vegetable greenhouses (Khan *et al.* 2020). Machine-learning algorithms for intelligent, automated indoor microclimate horticulture crops are expected to be taught using data collected by an IoT board (Bhujel *et al.* 2020). In the early days of the internet of things, when devices were simpler, very little data were captured. It was only used to transmit basic alarm signals with minimal processing. Artificial intelligence algorithms had no place there. Data analysis became important as IoT systems became more complex and sophisticated, resulting in large volumes of data, or big data. Artificial intelligence (AI) algorithms can process data and extract meaningful insights, leading to better decision-making. Machine learning, natural language processing, machine vision, artificial neural networks (ANN), and other new concepts and approaches have made problem solving and automation easier (Jha *et al.* 2019).

IoT in agricultural automation

Innovative farm machinery is advancing with the development of autonomous tractors and fruit harvesters employing deep learning-based computer vision algorithms. IoT technology further enhances farming efficiency, particularly in fertilizer application. An NPK sensor, utilizing LED, light-dependent resistors, and resistors, measures potassium, phosphorus, and nitrogen levels through colorimetric and photo-conductivity principles. Additionally, the Central Institute of Agricultural Engineering (CIAE) in Bhopal has developed a low-cost Single Photon Avalanche Diode (SPAD) to assess chlorophyll content in leaves, aiding in nitrogen requirement evaluation. Cloud services like Google Cloud Platforms offer scalable connectivity for delivering fertilizer recommendations (Lavanya *et al.* 2020). Weed and pest control benefit from IoT-based intelligent monitoring systems that use soil and meteorological sensors, cameras, and communication technologies such as GPRS and Zigbee to provide pest warnings and monitor operations (Salgado-Salazar *et al.* 2018). Drones also play a crucial role, equipped with CPUs, sensors (e.g., laser, radar, camera), and communication systems, for tasks such as crop surveillance, field watering, and pesticide application (El Hoummaidi *et al*. 2021, Mogili and Deepak 2018). They employ AI and vision-based technologies to detect weeds, monitor plant growth, and evaluate crop quality, thus reducing product damage and loss during storage and transit (Tripicchio *et al.* 2015, Gharibi *et al.* 2016, Ganai *et al*. 2022).

Blockchain

Artificial intelligence (AI) benefits horticulture by supporting farmers in enhancing output while limiting negative environmental effects (Verma *et al.* 2024). Food safety can be improved by implementing blockchain horticulture to track information across the food supply chain. The traceability provided by blockchain's ability to store and manage data facilitates the development and deployment of innovations for index-based horticulture insurance and intelligent farming. Blockchain technology in gardening can improve food safety and quality control. Improved production tracking across the supply chain will result in more equitable pay for farmers. Blockchain technology is one potential way to supply chain traceability in the pineapple industry. The fruit-chain protocol, which was introduced, is fair with a high probability and has the same consistency and liveliness as anticipating the true majority of computer power (Zhang *et al.* 2022).

Blockchain technology can help the food and horticulture industries in reducing known risks and maintaining overall affordability. Blockchain technology enables the interconnection of various horticultural companies and the visualization of data on decentralized database networks, including the entire process from production to supply. Big data offers farmers comprehensive data on water cycles, fertilizer needs, rainfall patterns, and other relevant factors. This enables individuals to make well-informed decisions regarding the optimal timing for harvesting and the selection of plants to cultivate in order to maximize their financial gain (Abbas *et al.* 2017).

Remote sensing in horticulture

Satellite remote sensing has become a crucial technology for crop monitoring on various scales since the 1970s (Macdonald and Hall 1980). While "agricultural monitoring" encompasses livestock, horticulture, and aquaculture, "crop monitoring" primarily focuses on staple crops, involving activities like agroclimatic studies, crop condition assessments, and yield forecasting. Remote sensing for crop monitoring emphasizes growth status and yield, covering areas such as crop mapping (Orynbaikyzy *et al.* 2019), condition evaluations (Virnodkar *et al.* 2020, Zhang *et al.* 2019), yield projections (Schauberger *et al.* 2020, Elavarasan *et al.* 2018, Klompenburg *et al.* 2020), drought monitoring (Jiao *et al.* 2021, Khanal *et al*., 2019), and precision agriculture (Maes and Steppe 2019). A remote sensing system consists of a power supply, transmission line, target, and satellite sensor, which together measure and record data about distant regions (Singh *et al.* 2014).

Indian researchers have significantly advanced digital image processing and software development in remote sensing applications. These advancements support agriculture through watershed development, land resource mapping, fishing spot forecasting, precision agriculture, crop systems analysis, agricultural water management, and drought assessment (Ray *et al.* 2020). In fruit crops, remote sensing has greatly enhanced orchard mapping and area estimation. For example, Sharma and Panigrahy (2007) used high-resolution data from India's IRS satellite, P6, to create a block-by-block database of apple plantations in Shimla, achieving over 90% accuracy. Remote sensing data from Landsat and AWIFS have improved precision in fertilizer application, revealing that 89.82% of apple orchards are between 1500-2000 meters elevation. Abiotic stress detection has also benefited from remote sensing used to monitor the Photochemical Reflectance Index (PRI) and crown temperature in peach orchards, distinguishing between stressed and well-irrigated plants.

Pest detection has become more cost-effective with remote sensing by measuring leaf and canopy reflectance in peach orchards to identify spider mite damage. Disease incidence detection has improved with multispectral imaging, helping to differentiate healthy from diseased trees (Sindhuja *et al.* 2013, Usha and Singh 2013). Remote sensing also aids in crop area estimation and canopy measurement, crucial for market planning and input application. It can forecast crop size and yield with over 90% accuracy (Nageswara Rao *et al.* 2004), estimate mature mango orchards, and differentiate mulberry from other crops. Accurate canopy cover estimation, related to NDVI, is essential for proper input application (Smart *et al.* 1990). Despite challenges in yield estimation for fruit trees and vegetables, remote sensing has been applied to tomato processing yields, cabbage characteristics and citrus orchard yield mapping (Whitney *et al.* 2002, Zaman *et al.* 2006).

Nuclear technology in horticulture

While nuclear technology is widely known for its role in power production, its influence on non-energy applications is often overlooked (Bagher *et al.* 2014). Beyond energy and weaponry, nuclear technology significantly advances horticultural practices by improving water quality, boosting crop yield, and managing pests and diseases. In horticulture, nuclear technology employs physical mutagens such as electromagnetic radiation (gamma rays from radioactive cobalt-60, X-rays, UV light) and particle radiation (thermal and fast neutrons, alpha and beta particles). Ionising radiation induces chromosomal breaks, facilitating DNA strand cross-linking and nucleotide alterations (Oladosu *et al.* 2016). Srivastava *et al.* (2007) studied the effects of gamma radiation from cobalt-60 on Gladiolus plants, observing notable changes compared to the control group. Gamma radiation affected plant height, leaf size, and overall

Table 1. Effect of radiations of horticultural fruits.

Fruit	Cultivar	Year	Mutagens	Improved fruit traits
Apple	Golden haidegg, Mcintosh	1966 1970	Gamma rays	Fruit size
Mango	Rosica	1966	Spontaneous	Large and good quality
Orange	Xuegen 9-12-1	1983	Gamma rays	Seedless
	Eureka 22	1987	X-rays	Fruit quality
Peach	Magnif	1968	Gamma rays	Large, red skin
Loquat	Shiro-mogi	1981	Gamma rays	Fruit size
Banana	Novaria	1993	Gamma rays	Earliness
Papaya	Pusa nanha	1986	Gamma rays	Dwarfness
Plum	Spurdente-ferco	1988	Gamma rays	Earliness
Pomegranate	Karabakh	1979	Gamma rays	Fruit quality
Sweet cherry	Lapins	1983	X- rays	Larger size

structure, as well as flowering patterns, resulting in variations in flower size, color, shape, and symmetry. Additionally, various radioisotopes such as Zn-65, S-35, and Rb-86 have been used in research to study plant growth and nutrient absorption (Chaurasia *et al.* 2023).

Seed breeding technique: The production of radiation resulted in the advancement of more productive seed varieties. An illustrious instance of a crop that has achieved prosperity is "miracle" rice, which has significantly enhanced the expense of rice production. Radiation-induced mutation technologies have become a significant element of plant breeding strategies. The following are several notable cultivars and varieties that possess distinct quality traits. These were developed and released from various research sites, as indicated in Table 1.

Vertical farming techniques

Vertical farming refers to the cultivation and advancement of crops in areas characterized by steep slopes and vertical structures. The primary global challenge at present is providing sustenance for the rapidly growing population, which is on the verge of a significant increase. Vertical farms come in many sizes and designs, ranging from small, wall-mounted, or two-story systems to large, multi-story complexes. Vertical farms only employ one of three soilless systems, namely hydroponics, aeroponics, or aquaponics, to provide nutrients to their plants. There are three types of farming system commonly used nowadays : Hydroponics, Aeroponics and Aquaponics.

Hydroponics, as defined by Niu and Masabni (2022), is a soil-less cultivation method where plants grow in a water-based environment, receiving essential nutrients through a nutrient-rich solution. Various inert media such as perlite, gravel, and mineral wool can be used, or roots can be submerged in a mineral solution (Sardare and Admane 2013, Jain *et al.* 2024). The primary hydroponic systems include the Drip System, which utilizes a container and pump to deliver a fertilizer solution to plants in a soilless medium, allowing for recirculation or discharge of excess solution and enabling the cultivation of various plant varieties (Rouphael and Cola 2005). The Ebb and Flow system works on a flood and drain principle, filling and emptying a grow tray with nutrient-rich fluid, although it requires filtration to address issues like mildew and algae (Nielsen *et al.* 2006). Deep Water Culture (DWC) involves suspending plant roots in nutrient-rich water with air supplied through an air stone, necessitating careful monitoring of salinity, pH, and oxygen levels to prevent mould and algae growth, and is particularly effective for fruit-bearing plants like tomatoes and cucumbers (Domingues *et al.* 2012). The Wick System, the simplest of all, employs capillary action to transport nutrients from a reservoir to plants through a nylon wick in a porous medium like cocopeat or vermiculite, making it suitable for small plants, herbs, and spices (Sharma and Bansuli 2024). The Nutrient Film Technique (NFT) involves growing plants in channels with a continuous flow of fertilizer solution, keeping roots moist rather than submerged; maintaining the power supply and pump system is crucial to avoid system failures (Khan *et al.* 2020, Aires 2018, Solanki *et al.* 2017)

Aeroponics, an advanced variant of hydroponics, involves spraying a fertilizer solution directly onto plant roots exposed to air, which enhances nutrient absorption through constant oxygen contact. This method uses various nozzles and a computerized system to maintain static pressure between 60 to 90 Psi, with the nutrient pump activated briefly every few minutes by a timer Although aeroponics is costly, it holds promise for space crop production (Lakhiar *et al.* 2018).

Aquaponics combines fish and plant cultivation, utilizing nutrient-rich fish waste to nourish plants in vertical farms, which in turn clean the water for reuse in fish ponds. While aquaponics is used in some small-scale vertical farms, most vertical farming focuses on fast-growing vegetables to enhance efficiency. Standardized aquaponic systems could increase the adoption of these self-sustaining setups. Palande *et al.* (2018) developed a fully automated hydroponic system that is cost-effective and easy to operate, incorporating IoT for remote monitoring. Titan Smartponics exemplifies such automation, offering benefits like control over growth factors, adaptability to plant needs, and independence from external conditions.

Challenges and opportunities

The agricultural economy can be revolutionized by technology, but farmers' limited technical knowledge in running technology-driven equipment poses a significant barrier to this advancement. By prioritizing the needs of the farmers during the development of the systems, we can efficiently tackle the problem. When designing digital products, designers should focus on the user interface. One possible way to overcome this challenge is by providing solutions in local languages. The cost and quality of equipment and sensors pose a significant obstacle for small-scale farmers in embracing new technologies. Given the various nature of IoT devices, ensuring compatibility is of utmost importance. Therefore, it is necessary to have efficient device synchronization in order to enhance performance. This task is difficult because it involves multiple manufacturers and equipment. Due to the continuous increase in data generated by IoT devices, horizontal scaling will eventually become indispensable. Notwithstanding the numerous obstacles, they possess the capacity to automate and enhance horticulture in the future. These technologies possess the capacity to fundamentally transform agricultural practices. In the coming years, the advancement of 5G technology will be crucial for enhancing the capabilities of the Internet of Things.

CONCLUSION

Precision farming, which produces more crops of higher quality while using fewer resources, is made easier by farming technology that uses artificial intelligence. AI could help lower the cost of farming by managing labor costs, making good use of pesticides and fertilizers, and reducing crop losses by picking crops at the right time and when they are fully grown. Additionally, technological advances should not stop young people from moving to cities, but instead should inspire tech-savvy individuals to choose gardening as a career. The technology information center found that people were adopting technology at amazing rates, but there were also some big problems. For example, it was hard to figure out how to measure a farmer's productivity and yield in relation to extension efforts, and each town only got one suggestion, no matter how healthy the soil was. Also, the crop sub-sector got too much attention, leaving the forests, fisheries, livestock, and natural resources management sub-sectors out in the cold (Giovannucci *et al.* 2002). In this system, farmers also depend on the knowledge of extension workers in each village, who may not always be up to date. The uses that remote sensing and GIS could have are quickly becoming clear. Some of these are figuring out the amount of biomass in a crop, the factors of the soil (like its moisture and nutrient content), the number of green fruits, estimating the crop's yield, the damage caused by biotic and abiotic stressors, and so on. Horticultural supply chains have a great chance to make transactions more efficient, reduce friction, and make it easier to track goods around the world thanks to blockchain technology (Zhang *et al.* 2018). Blockchain technology can help the gardening and food industries deal with known risks and keep prices low for everyone. If you work in gardening, blockchain technology lets you link different businesses and see data on distributed ledger networks, from growing plants to delivering them. To reach this goal, artists and engineers need to find a middle ground where they can talk to each other and understand what the other needs. Technologists need to meet the needs of food producers by making products, services, and methods much better so that food production in cities and places near cities is efficient and sustainable. Producers need to know how to use technology most effectively and push for new ideas that meet the real needs of the food supply and value chains.

REFERENCES

Abbas N, Zhang Y, Taherkordi A, Skeie T (2017) Mobile edge computing: A survey. *IEEE Internet of Things Journal* 5 (1) : 450-465. http://10.1109/JIOT.2017.2750180

Aires A (2018) Hydroponic Production Systems: Impact on Nutritional Status and Bioactive Compounds of Fresh Vegetables. *Vegetables - Importance of Quality Vegetables to Human Health* pp 55.

Alireza A, Ludena RDA (2013) Big Data approach to a novel nutrition-based vegetable production and distribution system. *IEEE International Conference on Computational Intelligence and Cybernetics (CYBERNETICSCOM)* IEEE : 131-135.

Arya PS, Gangwar MA (2021) Proposed architecture: Detecting freshness of vegetables using Internet of Things (IoT) & deep learning prediction algorithm. *3rd International Conference on Advances in Computing, Communication*

Control and Networking (ICAC3N) IEEE : 718-723.
Bagher AM, Nahid A, Mohsen M, Vahid M (2014) Nuclear techniques in agriculture and genetics. *American Journal of Bioscience* 2(3): 102-105.
Bernhardt H, Bozkurt M, Brunsch R, Colangelo E, Herrmann A, Horstmann J, Westerkamp C (2021) Challenges for agriculture through industry 4.0. *Agronomy* 11 (10) : 1935.
Bhujel A, Basak JK, Khan F, Arulmozhi E, Jaihuni M, Sihalath T, Lee D, Park J, Kim HT (2020) Sensor systems for greenhouse microclimate monitoring and control: A review. *Journal of Biosystems Engineering* 45: 341–361.
Böckmann E, Pfaff A, Schirrmann M, Pflanz M (2021) Rapid and low-cost insect detection for analyzing species trapped on yellow sticky traps. *Scientific Reports* 11(1) : 10419.
Caiming Z, Lu Y (2021) Study on artificial intelligence: The state of the art and future prospects. *Journal of Indutrsial Information Integration* 23 : 100224.
Chaurasia J, Tripathi VK, Tripathi R (2023) Nuclear technology in horticulture: Boosting productivity, controlling pests, conserving Water. *Asian Journal of Agricultural and Horticultural Research* 10 (4) : 178-182.
Coble KH, Mishra AK, Ferrell S, Griffin T (2018) Big data in agriculture: A challenge for the future. *Applied Economics Perspectives and Policy.* 40 : 79–96.
Domingues DS, Takahashi HW, Camara CAP, Nixdorf SL (2012) Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. *Computers and Electronics in Agriculture* 84 : 53-61.
Elavarasan D, Vincent DR, Sharma V, Zomaya AY, Srinivasan K (2018) Forecasting yield by integrating agrarian factors and machine learning models: A survey. *Computers and Electronics in Agriculture* 155: 257-282.
El Hoummaidi L, Larabi A, Alam K (2021) Using unmanned aerial systems and deep learning for agriculture mapping in Dubai. *Heliyon* 7 : (10) : In press.
Ganai PT, Bag A, Sable A, Abdullah KH, Bhatia S, Pant B (2022) A detailed investigation of implementation of internet of things (IoT) in cyber security in healthcare sector. *In 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE) IEEE,* pp 1571-1575.
Gharibi M, Boutaba R, Waslander SL (2016) Internet of Drones *IEEE Access* 4 : 1148 – 1162.
Giovannucci E, Rimm E, Liu Y, Stampfer M, Willet WA (2002) A prospective study of tomato products, lycopene and prostate cancer risk. *Journal of the National Cancer Institute* 94 (5) : 391 - 398.
Hati AJ, Singh RR (2021) Smart indoor farms: Leveraging technological advancements to power a sustainable agricultural revolution. *Agric Engineering*. 3 : 47.
Jain S, Pratap B, Sonkar A, Hassanzai RG (2024) Mitigating fruit cracking and premature dropping in bael (*Aegle marmelos*) cv. NB-9 under subtropical conditions: Evaluating the effects of bio-formulations and boric acid. *Journal of Advances in Biology & Biotechnology* 27 (5) : 940-947.
Jha K, Doshi A, Patel P, Shah M (2019) A comprehensive review on automation in agriculture using artificial intelligence. *Artificial Intelligence in Agriculture* 2 : 1-12.
Jiao W, Wang L, McCabe MF (2021) Multi-sensor remote sensing for drought characterization: Current status, opportunities and a roadmap for the future. *Remote Sensing of Environment* 256 : 112313.
Kamilaris A, Fonts A, Prenafeta-Bold FX (2019) The rise of block chain technology in agriculture and food supply chains. *Trends in Food Science and Technology* 91 : 640 – 652.
Katal A, Wazid M, Goudar RH (2013) Big data: Issues, challenges, tools and good practices. In 2013 *Sixth International Conference on Contemporary Computing (IC3)* IEEE, pp 404 - 409.
Khanal S, Fulton J, Shearer S (2019) An overview of current and potential applications of thermal remote sensing in precision agriculture. *Computers and Electronics in Agriculture.* 139: 22-32.
Khan FA, Ibrahim AA, Zeki AM (2020) Environmental monitoring and disease detection of plants in smart greenhouse using internet of things. *Journal of Physics Communication* 4 (5) : 055008.
Klompenburg van T, Kassahun A, Catal C (2020) Crop yield prediction using machine learning: A systematic literature review. *Computers and Electronics in Agriculture* 177 : 105709.
Kumar M, Pal Y, Gangadharan SM, Chakraborty K, Yadav CS, Kumar H, Tiwari B (2022) Apple Sweetness Measurement and fruit disease prediction using image processing techniques based on human-computer interaction for industry 4.0. *Wireless Communications and Mobile Computing* 2022 : 1–12.
Kumar V, Jakhwal R, Chaudhary N, Singh S (2023) Artificial intel ligence in horticulture crops. *Annals of Horticulture* 16(1) : 72-79.
Lakhiar IA, Gao J, Syed TN, Chandio FA, Buttar NA (2018) Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. *Journal of Plant Interactions* 13 (1) : 338–352.
Lavanya G, Rani C, Ganesh Kumar P (2020) An automated low cost IoT based fertilizer intimation system for smart agriculture. *Sustainable Computing: Informatics and Systems* 28 : 100300.
Lomte VM, Sabale S, Shirgaonkar R, Nagathan P, Pawar P (2019) Fruit counting and maturity detec tion using image processing: A survey. *International Journal of Research in Engineering Science and Management* 2 (2): 809-812.
MacDonald RB, Hall FG (1980) Global crop forecasting. *Science* 208 (4445) : 670-679.
Maes WH, Steppe K (2019) Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture. *Trends in Plant Science* 24 (2) :152-164.
Manaware D (2020) Artificial intelligence: A new way to improve Indian agriculture. *International Journal of Current Microbiology and Applied Sciences* 9 (3) :1095-1102.
Matta P, Pant B, Arora M (2017) All you want to know about Internet of Things (IoT). *In 2017 International Conference on Computing, Communication and Automation (ICCCA). IEEE,* pp 1306-1311.
Matta P, Pant B (2019) Internet of things: Genesis, challenges and applications. *Journal of Engineering Science and Technology* 14 (3) : 1717-1750.
Mogili UR, Deepak BB (2018) Review on application of drone systems in precision agriculture. *Procedia Computer Science* 133 : 502- 509.

rNageswara Rao PP, Ravishankar HM, Raj U, Nagajothi K (2004) Production estimation of horticultural crops using irs-1d liss-iii data. *Journal of the Indian Society of Remote Sensing*. 32: 393-398.

Nielsen CJ, Ferrin DM, Stanghellini ME (2006) Efficacy of biosurfactants in the management of phytophthora capsici on pepper in recirculating hydroponic systems. *Canadian Journal of Plant Pathology* 28 (3) :450 - 460.

Niu G, Masabni J (2022) Hydroponics. Plant Factory Basics, Applications and Advances, pp 153–166.

Nturambirwe JFI, Opara UL (2020) Machine learning applications to non destructive defect detection in horticultural products. *Biosystems Engineering* 189 : 60 - 83.

Oladosu Y, Rafii M, Abdullah N, Hussin G, Ram A, Rahim H (2016) Principle and application of plant mutagenesis in crop improvement: A review. *Biotechnology and Biotechnological Equipment* 30 (1) : 1-16.

Orynbaikyzy A, Gessner U, Conrad C (2019) Crop type classification using a combination of optical and radar remote sensing data: A review. *International Journal of Remote Sensing* 40 (17) : 6553 - 6595.

Palande V, Zaheer A, George K (2018) Fully automated hydroponic system for indoor plant growth. *Procedia Computer Science* 129 : 482- 488.

Pant B, Pant K, Pardasani KR (2009) Decision tree classifier for classification of plant and animal micro RNA's. In Computational Intelligence and Intelligent Systems: 4th International Symposium, ISICA 2009, Huangshi, China, October 23-25, Proceedings 4. Springer Berlin Heidelberg, pp 443 - 451.

Pekkeriet EJ, Van Henten EJ, Campen JB (2015) Contribution of innovative technologies to new developments in horticulture. *Acta Horticulturae* 1099 : 45 - 54.

Qingxue L, Wu H (2016) Research on vegetable growth monitoring platform based on facility agricultural IoT. In International Conference on Geo-Informatics in Resource Management and Sustainable Ecosystem. Springer.

Rajpoot NK, Singh P, Pant B (2024) Role of IoT and Cloud in Smart Healthcare Monitoring System for Efficient Resource Utilization. In Computer Science Engineering and Emerging Technologies CRC Press, pp 200-205.

Ray SS, Dadhwal VK, Parihar JS, Navalgund RR (2020) Satellite remote sensing applications for agriculture: A review in Indian context. *Vayu Mandal* 46 (2) :1 - 20.

Robinson C, Mort N (1997) A neural network system for the protection of citrus crops from frost damage. *Computers and Electronics in Agriculture* 16 (3) : 177 - 187.

Rouphael Y, Colla G (2005) Growth, yield, fruit quality and nutrient uptake of hydroponically cultivated zucchini squash as affected by irrigation systems and growing seasons. *Scientia Horticulturae* 105 (2) :177-195.

Ruthie M (2019) Big data in agriculture and nutrition. *In Agriculture for improved Nutrition: Seizing the Momentum* 142 : 1–15.

Sahni V, Srivastava S, Khan R (2021) Modelling techniques to improve the quality of food using artificial intelligence. *Journal of Food Quality* 1 : 2140010.

Salgado-Salazar C, Shiskoff N, Daughtrey M, Palmer CL, Crouch JA (2018) Downy mildew: A serious disease threat to rose health worldwide. *Plant Disease* 102 (10) : 1873- 1882.

Sardare MD, Admane SV (2013) A review on plant without soil-hydroponics. *International Journal of Research in Engineering and Technology* 2 (3) : 299 - 304.

Schauberger B, Jägermeyr J, Gornott C (2020) A systematic review of local to regional yield forecasting approaches and frequently used data resources. *European Journal of Agronomy* 120 : 126-153.

Shamshiri R, Kalantari F, Ting KC, Thorp KR, Hameed IA, Weltzien C, Ahmad D, Shad ZM (2018) Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering* 11 (1) : 1 - 22.

Sharma A, Panigrahy S (2007) Apple orchard characterization using remote sensing and GIS in Shimla district of Himachal Pradesh. In Proceedings of remote sensing and photogrammetry annual conference, pp 11-14.

Sharma S, Bansuli P (2024) Hydroponics in Vegetable Crops: A Review. Hydroponics: The Future of Sustainable Farming pp 15 - 41.

Sindhuja S, Maja JM, Buchanon S, Ehsani R (2013) Huanglongbing (citrus greening) detection using visible, near infrared and thermal imaging techniques. Sensors 13(2) : 2117 - 2130.

Singh JP, Deb D, Chaurasia RS (2014) Use of Geo-spatial technology as an evolving technology of 21st century for natural resource management in different region of India. Emerging Technology of 21st Century, New India Publishing Agency (11 May 2015), pp 449-479.

Sinn C, Pohl JP, Jahncke D, Golla B (2021) Webservices für die teilschlagspezifische Bereitstellung ökologischer und ökon omischer Kennzahlen und Basisinformationen im Pflanzenschutz. *Journal für Kulturpflanzen* 73(5-6) : 149-58.

Siregar ST, Handayani W, Saputro AH (2017) Bananas moisture content prediction system using Visual-NIR imaging. In 2017 5th International Conference on Instrumentation, Control, and Automation (ICA) IEEE, pp 89-92.

Smart RE, Dick JK, Gravett IM, Fisher BM (1990) Canopy management to improve grape yield and wine quality-principles and practices. *South African Journal of Enology and Viticulture* 11 (1) : 3 - 17.

Solanki S, Gaurav N, Bhawani G, Kumar A (2017) Challenges and possibilities in hydroponics: An Indian perspective. *International Journal of Advanced Research* 5 (11) : 177 - 182.

Sousa-Gallagher MJ, Tank A, Sousa R (2016) Emerging technologies to extend the shelf life and stability of fruits and vegetables. In The stability and shelf life of food. Woodhead Publishing, pp 399 - 430.

Srivastava P, Singh RP, Tripathi VK (2007) Response of gamma radiation on vegetative and floral characters of gladiolus. *Journal of Ornamental Horticulture* 10 (2) : 135 -136.

Tiwari A, Singh A K, Singh S, Singh B, Pal AK (2015) University-Industry based partnership for horticultural development in India-needs and challanges. *In Abst: International Conference on Issues and Challenges in Doctoral Research* 25 : 21.

Tripicchio P, Satler M, Dabisias G, Ruffaldi E, Avizzano CA (2015) Towards smart farming and sustainable agriculture with drones. In International conference on intelligent environments. IEEE, pp 140-143.

Usha K, Singh B (2013) Potential applications of remote sensing

in horticulture-A review. *Scientia Horticulturae* 153 : 71 - 83.
Verma P, Tripathi V, Pant B (2024) Blockchain-Based Secure Management of Digital Credentials for Interns. *Journal of Electrical Systems* 20 (7) : 902 - 911.
Virnodkar SS, Pachghare VK, Patil VC, Jha SK (2020) Remote sensing and machine learning for crop water stress determination in various crops: A critical review. *Precision Agriculture* 21(5) : 1121-1155.
Wazid M, Das AK, Kumar N, Rodrigues JJ (2017) Secure three-factor user authentication scheme for renewable-energy-based smart grid environment. *IEEE Transactions on Industrial Informatics* 13(6) : 3144 - 3153.
Whitney JD, Tumbo SD, Miller WM, Wheaton TA (2002) Comparison between ultrasonic and manual measurements of citrus tree canopies. In Proceedings of the ASAE Annual International Meeting, St. Joseph, MI, USA (2831).
Zaman QU, Schumann AW, Hostler HK (2006) Estimation of citrus fruit yield using ultrasonically-sensed tree size. *Applied Engineering in Agriculture* 22 (1) : 39 - 44.
Zhang C, Cai J, Xiao D, Ye Y, Chehelamirani M (2018) Research on vegetable pest warning system based on multidimensional big data. *Insects* 9 (2) : 66.
Zhang J, Huang Y, Pu R, Gonzalez-Moreno P, Yuan L, Wu K, Huang W (2019) Monitoring plant diseases and pests through remote sensing technology: A review. Computers and Electronics in Agriculture, pp 165. https://doi.org/10.1016/j.compag.2019.104943
Zhang Y, Chen L, Battino M, Farag MA, Xiao J, Simal-Gandara J, Jiang W (2022) Blockchain: An emerging novel technology to upgrade the current fresh fruit supply chain. *Trends in Food Science & Technology* 124 : 1-12.
Zhiguo S, Hui X, Wensheng W (2010) An architecture for the agricultural machinery intelligent scheduling in cross-regional work based on cloud computing and internet of things. In Computer and Computing Technologies in Agriculture IV: 4th IFIP TC 12 Conference, CCTA 2010, Nanchang, China, October 22-25, 2010, Selected Papers, Part I 4 2011 Springer Berlin Heidelberg, pp 9 -15.