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Review Article

An Imperative Role of Industry 4.0 in Revolutionizing Horticulture Sector

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Abstract *- According to the Food and Agricultural Organization, horticulture production needs to be improved by 60% to provide for the increasing population's need for nutrition by 2030. Limited studies have discussed digitalization in horticulture with sustainability aspects and have yet to discuss other enabling technologies such as digital twins, augmented reality, and cloud computing. The current study presents the significance of digitalization with the IoT, AI, digital twin, augmented reality, and cloud computing. After the analysis, the study identified that the digital twin is implemented to identify climate set points, different fruit qualities, and crop management strategies. The study also observed that AI oversees weeds through computer vision. The study concludes that augmented reality estimates potential changes that may enhance the supply chain of fresh horticulture produce and allow for the timely monitoring of greenhouse operations due to ongoing uncertainties.*

Keywords *- SDGs, AI, Digitalization, Horticulture, Greenhouse, Technologies, Digital twin, Cloud computing.*

1. Introduction

The introduction of phytochemicals and minerals present in horticulture crops has received more attention as an essential component of regular diets in recent years due to the expanding awareness of their health-promoting and protective properties. Fruits, vegetables, and spices that humans directly use as foods, flowers, aesthetic or medicinal plants, and aromatic plants are all considered horticultural crops [1].

Edible horticultural crops have a strong connection with a reduced risk of getting infections, heart disease, and other chronic diseases when constantly eaten [2]. Production methods for greenhouse horticulture are getting more industrialized due to important challenges with food availability, food supply, and health. Greenhouses are now becoming high-tech industries with extensive use of technology and large-scale production [3, 4]. Alternative to direct observation and labor-intensive tasks, growers may monitor and control processes through the use of digital data that is virtually real-time in modern greenhouse horticulture. Fresh fruit and vegetable losses and waste through Farm-to-consumer ratios are still high and can be up to 10 percent [5]. India is the world's leader in producing grapes per unit of land area and mango, banana, sapota, and acid lime. India ranks second to China in the middle of land and vegetable production, leading the world in cauliflower, onions, and cabbage production.

For the benefit of its people, it increases the thought that having established food security, India must now be achieving nutritional security. Fruits and vegetables are essential for achieving nutritional security [6]. The SDGs of Responsible Consumption and Production (SDG 12), Zero Hunger (SDG 2), and Industry, Innovation, and Infrastructure (SDG 9) are also supported by horticulture. Advanced technologies can profit; they have just started playing a major role in daily life, extending our perspectives and capacity to alter our surrounding environment. IoT is used in diagnosis and control, particularly in environmental and agro-industrial domains.

Additionally, it can tell the customer about the origins and characteristics. The purpose of this study paper is to be based on IoT technology, which is being applied to the agriculture sector. The successful construction of IoT technologies like sensor hardware, software application services, platforms, and routing protocols that are specialized for horticulture for agricultural contexts is required to properly build such a smart agricultural environment to keep any type of plant growing environment in top condition and horticulture environment monitoring system offers services for monitoring the environment as well as facility managing services. Additionally, this technology can increase user plantation sector productivity and convenience [7-9]. It may be applied to evaluate field factors such as plant biomass, weather, and soil quality. It can also be used to measure and manage information on factors using wireless sensor networks, which can be used to measure parameters such as EC, pH, wind direction, wind speed, temperature, and humidity that have a direct effect on crops and soil. When GPS, CCTV, and environmental and soil sensors are installed outside sources, modules are used to collect picture information related to the environment and Geographical details about the location of the server system. The horticulture environment monitoring system transforms the data into a database to provide growers with the proper information and services. The network server is also customized to use solar-powered energy, which can be used in horticultural areas with sufficient electrical service. However, they can be used to select the best farmer for a given situation, identify diseases, manage equipment, etc [10]. In this study, the previous studies concentrate on information on soil moisture, humidity, and temperature in crop fields. We need to store the data, have a method for extracting information from the data over time, connect with the user, and construct a proper system. The study aims to analyze how an application development process for a controlling electronic device applies to using an application for Android smartphones, and processes for soil moisture and temperature were recorded. They also want to find a smart monitoring system that uses an integrated IP-connected micro-web server to access and locate flexible, reasonable parts or equipment for farm monitoring systems.

1.1. Research Objectives

- To identify and categorize the key Industry 4.0 technologies relevant to horticulture.
- To discuss the potential of smart farming in the horticulture Sector.
- To compare existing research findings and highlight gaps in the literature.

2. Problem Statement

They range from more in-depth concerns about production methods and techniques to more general issues regarding overproduction and down-selling price, ecological issues and correlated minimum standards, labour supply, and information sources. Prototypes are a helpful tool for scientists to research these types of difficulties. To better understand how crops interact with soil, greenhouse, insects, and diseases, models have been developed. To determine factors at the level of complete nurseries and even entire nations, these sub-systems' simplified models have been integrated. These studies are important for developing knowledge as to how systems operate, the knowledge that can be used to advise manufacturers, growers, organizations, and policymakers. Examples include yield-gap analysis and regional and nursery-level investigations into the effectiveness of the economy and environment [11]. Lack of Production techniques, non-availability of the reason for the specific design of the protected structure of various Agro-climatic conditions, well Poor availability of quality seeds of Horticultural crops, Not availability of disease and Resistant Varieties, Not availability of Heat and Drought Resistant Varieties, Poor Availability of skilled labor, Lack of trained skilled and professional manpower for designing & maintenance for the protected structure, Lack of demand-driven cultivation without proper marketing strategies, Non-availability of virus free healthy planting material and Increasing threat of soil problems like root-knot nematodes, etc.

3. Methodology of Study

The study's methodology is discussed in this section. Based on the issues found in previous studies, this study developed A demand for research that was utilized to investigate the review. What is the state of Industry 4.0 technology inclusion in horticulture, and how important is it? This research question produced a wide range of keywords for the Scopus as well as the Web of Science databases by using Data type function operators. For securing articles, the following set of keywords were taken into consideration. Digitalization and Industry 4.0 for fruits and vegetables, fruits and vegetable monitoring, horticulture, fruits and vegetables, disease detection and fruits crops, artificial intelligence a disease identification in fruits, big data and horticulture, and soil fertility and fruits and vegetable crops are some of the terms used in this article. The worldwide horticulture industry is currently dealing with a number of unyielding issues, including a lack of workers, climate change, wasteful resource use, and increasing demand from customers for high-quality products. Even though traditional methods have helped produce food for decades, they frequently fail to achieve the productivity and ecological targets of today. For horticulture, Industry 4.0 which is defined by smart technologies like IoT, AI, cloud computing, and augmented reality - offers transformational possibilities. Even with increased attention, there is still a great deal of research to be done on how these technologies can be successfully scaled across a variety of conditions and incorporated into horticultural systems. The current study presents the significance of digitalization with the IoT, AI, digital twin, augmented reality, and cloud computing in horticulture systems.

Out of 219 papers reviewed in the field of Industry 4.0 revolutionizing the horticulture sector, only 70 papers have been implemented.

4. Integration of Technologies for Fruits and Vegetables

In this section, we have discussed the different studies on different technologies in monitoring fruits and vegetables as part of digitalization.

Although the emergence of Industry 4.0 technologies has been widely acknowledged for revolutionizing the agricultural sector, a more comprehensive review is necessary to contextualize their specific role in horticulture. Most existing studies focus on digitalization in broad agricultural contexts, with limited emphasis on horticulture-specific challenges such as crop diversity, seasonality, and labor intensity. This review addresses this gap by consolidating current findings and examining how using Industry 4.0 technology can enhance environmental sustainability, resource efficiency, and operational precision within horticulture.

4.1. Internet of Things (IoT)

Farmers can substantially minimize the use of pesticides by properly identifying crop pests with IoT-based smart devices such as sensor systems, drones, and robots, as shown in Figure 1. Today, utilizing IoT to control pests provides disease prediction, modeling, and real-time monitoring, making it more efficient than traditional pest control methods [12]. Automatic traps controlled by IoT may record, count, and even describe insect species before uploading the data to the cloud for thorough study [13]. This IoT-based pest monitoring system can help restore a natural climate while reducing overall costs [14]. With the goal of tracking environmental parameters in vegetable greenhouses in real-time and reducing the impact of climate disasters on vegetable growth, previous studies produced a technology platform that includes environmental data collection, transmission, disaster warning, remote control, and information movement through the use of Internet of Things technology [15]. Climate changes and unpredictability become more common due to climate change. Crop damage and decreased plant quantity and quality are common problems for farmers. A critical challenge is developing a monitoring system that can assist farmers in growing crops. An IoT board with electronic sensors is used to monitor the cultivation process. The information collected is expected to be used in our future study on developing intelligent automated indoor micro-climate horticulture crops using machine learning models. An IoT board with electronic sensors is used to control the cultivation process. A database includes the sensor readings that were collected. The Indonesian Meteorological Agency's data, which contains meteorological information and daily at the cultivation location, is also integrated into the database [16]. To ensure that the greenhouse automation system operates as expected in a modern greenhouse, multiple measurement stations are required to track down the local climate parameters in various regions of a large-scale greenhouse [18]. One of the areas that has lately attained the most popularity is the Internet of Things, where smart devices and sensors change socially, as well as the dissemination of information. The application of WSNs, which collect information from all the sensors in a network and are characterized by a large range of communication and low power consumption, is one of the important concepts in IoT [19]. With very little labor required, new IoT-based fertilizing systems help with the monitoring procedures of spatial patterns of fertilizer requirements [20]. It's also believed that embracing future IoT technology can modify the drip irrigation that is in place currently. Implementing IoT-based techniques, such as Crop Water Stress Index (CWSI)-based irrigation management, is expected to significantly improve agricultural efficiency. CWSI computation requires crop canopy development along with different times and air temperatures [21]. Horticulture has widely adopted the Internet of Things (IoT) for real-time monitoring of crops and the growing environment [71]. Networks of sensors collect data on soil moisture, temperature, air humidity, light, and nutrients, which are transmitted via wireless networks to cloud platforms or local computers for analysis [72]. All field sensors are linked in a Wireless Sensor-Based (WSB) monitoring system designed to record measured data. This data is then transported to a processing facility where the necessary intelligent computer software is used to collect and analyze the farm data. Table 1 details the objective and application of IoT implementation for fruit and vegetable monitoring.

Table 1. Previous studies of IoT for fruit and vegetable monitoring

Ref	Objective	Application
12	Help farmers with all aspects of agricultural production, including planting, harvesting, packaging, and shipping.	Analyze the IoT trends in agriculture and the research challenges.
13	Automated irrigation systems	Effective soil and weather monitoring.
14	To supervise crop fields and automation in irrigation	This system will be more useful in areas where water is scarce.
15	Investigate the research problems and IoT developments in agriculture.	Promotes the fast development of agricultural modernization.

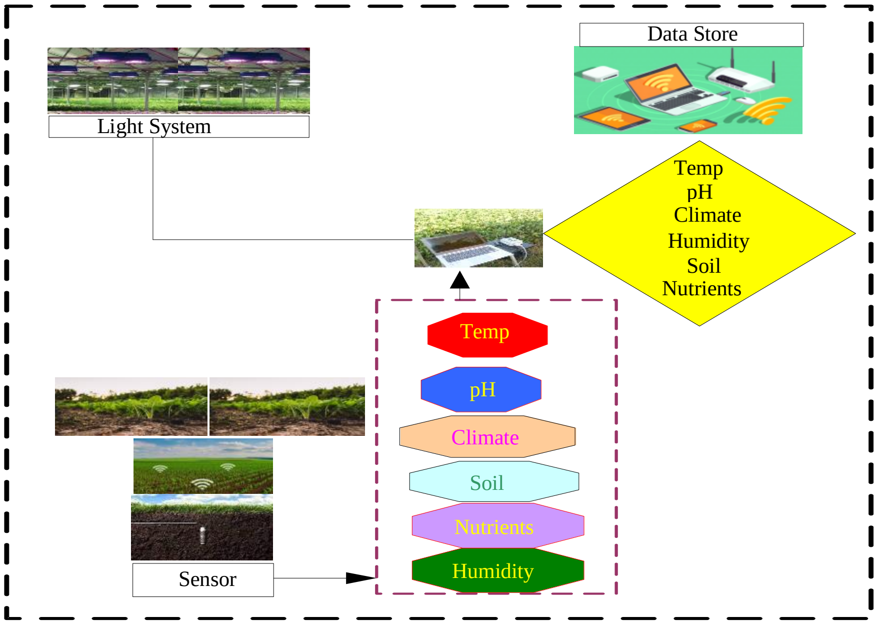

Fig. 1 IoT for digitalization of horticulture

In order to give users a richer experience and to provide important, relevant data about the environment in consideration to which they are interacting, the scientific community is now allowed to develop integrated environments using the IoT concept. The special vegetable farming and delivery system, which is centered on health benefits, greatly benefits from these characteristics [22]. Vegetables' whole supply chain can be tracked and used to guarantee the nutritional value of the foods delivered, from growing and harvesting through governmental authority, evaluation, shipping, tax analysis, distribution, packing, and internal evaluation [23].

People can determine fruits and vegetables by quantity using their cellphones and internet access, provide food ideas, and begin creating and revising fresh dishes depending on the abundance of produce [24]. When curbing diseases and pests, pesticides and fungicides - which damage ecological systems and reduce crop quality and yield - must be used. The IoT system has been created to lessen the continual use of chemical pesticides and fungicides and to anticipate when the pests are likely to arrive in order to lower the presence of pests [25].

4.2. Artificial Intelligence (AI)

A low-cost IoT-powered phenotyping tool was created to look at the dynamic interaction among genotype, phenotype, and environment. Growing healthy, wholesome food for the expanding world's inhabitants necessitates conservatories and interior agricultural techniques. As shown in Figure 2, the accessibility of IoT information may be efficiently used with AI's help to gain superior insight. The operation's major goal was to boost net profit by utilizing AI techniques to control the greenhouse's surroundings and harvest. They employed innovative algorithms and sensor feedback to determine crop management approaches and climatic set points [26]. A lot of interest has been paid to the application of AI in the air drying of vegetable and fruit products since, when combined with it, it may provide superior goods manufactured from dried fruits and vegetables [27].

One of the various dietary items that may be ingested to support one's health is fruits. Fruit offers a range of nutrients necessary for optimum wellness, making fruit eating crucial. A device powered by the Internet of Things that can determine how much climacteric fruit has undergone mechanical processing. Machine learning algorithms are used to assess if the fruit has been ripened by nature or unnaturally [28].

The importance of using computer vision techniques in conjunction with unmanned machinery that uses the deep computing theory of AI was examined in earlier works that analyzed these techniques [29]. As IoT technology is receiving a greater spotlight, more horticulture applications have started using it to autonomously handle and track horticultural plantations with the least amount of human participation [30].

For the purpose of predicting crop conditions such as humidity, temperature, and soil moisture, IoT technology enables users to capture, track, and interpret a vast quantity of data [31]. Algorithms identify patterns, such as declining soil moisture, to automate actions, although data heterogeneity remains challenging [73, 74]. The goal and method of using AI for fruit and vegetable observation are outlined in detail in Table 2.

Table 2. Previous studies of AI for fruit and vegetable monitoring

Ref	Objective	Application
26	Detection and forecasting during the processing of berries.	AI-based advanced detection methods for processing berries.
27	To assist the efficient physical field in the drying of fruits and vegetables.	Reduce the problems of high nutrient loss, uneven drying, and high energy consumption.
28	Evaluate for the presence of artificial ripening in climacteric fruit.	The device has accuracy and recall of 0.93 and 0.92 for spotting artificial ripening.
29	Developing more about modern post-processing systems	Addressing the issues that arise throughout the assessment, quality-checking, and fruit-sorting processes for date palms.

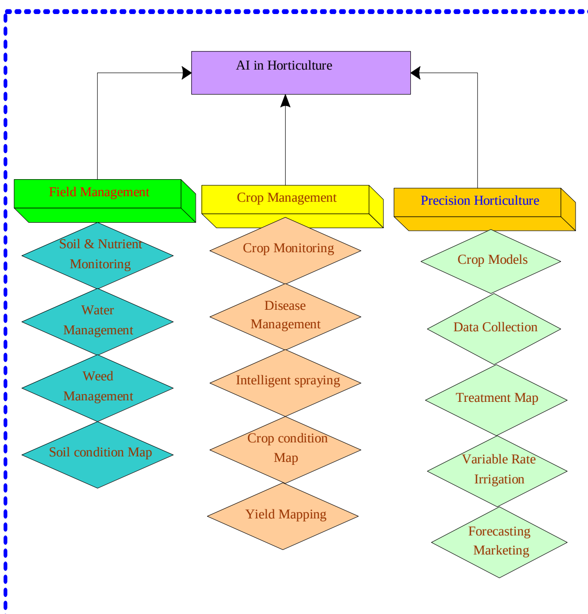

Fig. 2 AI in horticulture crops

By using machine vision and apple, peach, and pear independence, farmers may use AI to manage weeds. With the use of artificial intelligence (AI), knowledge about the weed is gathered, motivating farmers to the application of chemical combinations precisely where the weeds are. As a result, compared to the usual amount of chemicals that are synthetically administered, AI minimizes the usage of herbicides in the field [32]. Agribusiness robots with artificial intelligence assist farmers in developing more efficient weed-control strategies for their crops. This additionally helps in resolving workplace problems. Crops can be harvested more rapidly and in greater quantities by computers with artificial intelligence built into them than humans. It is easy to identify the weeds and smother them with PC vision. As a result, producers are using AI to find progressively effective ways to protect their harvests from weeds [33]. Pests are among farmers' worst enemies since they obliterate crops throughout the area before their harvest and storage for human consumption. In addition to the benefits farmers receive from their crops, the grains designed for human use have been eaten by beetles, grasshoppers, and other typical insects. But, owing to AI in agriculture, growers now have an instrument against such pests. Pests, one of the most harmful challengers of farmers, damage crops wherever before they are collected and stored for human use. Both the advantages that farmers derive from their crops and the grains designed for human consumption are being consumed by beetles, grasshoppers, and other common insects.

However, producers now have a weapon against such pests thanks to AI in horticulture. Artificial Intelligence (AI) may be employed in farming to lessen the ecological problems brought on by disadvantageous farming practices, including excessive pesticide usage, incorrect irrigation that results in water loss, and fertilizer contamination of water. Implementing AI might benefit each of the aforementioned respects [34]. Numerous Artificial Intelligence (AI) platforms have already been created and put forth by researchers for various fields [35]. The key to increasing yields and assuring production consistency has been using seeds with high vigor, fast development, and seedling growth rates that typically assure appearance even under fluctuating horticultural circumstances [36]. Given that profitability and production are the primary goals of all types of agriculture, forecasting algorithms are among the increasingly popular AI tools for farmers. Before projecting production, factors such as the kind of soil, soil nutrient accessibility, agricultural knowledge, and meteorological conditions are taken into account [37].

4.3. Cloud Computing

Soft computing approaches are utilized to recognize the fruit by integrating the three basic characteristics that constitute an object: shade, design, and material. This technique minimizes the feature vector's size. In the end, normalizing properties of the pictures, together with increased proficiency in classification, are produced with a smaller amount of training information [38]. Food security is a key component of satisfying the nutritional needs of the increasing population. For instance, the Food and Agriculture Department (FAO) of the United States estimates that yearly losses following harvest amount to 1.3 billion tonnes, or 33% of production. Real-time distribution network surveillance provides consumers with information about perishable food items so they may better manage pricing and take the necessary steps to uphold quality standards [39]. Farmers face challenges while cultivating vegetables, including seed issues, controlling insects and diseases, product expenses, and product advertising. Farmers need a mobile educational system that provides knowledge and interactive discussion about vegetable production over the internet for enhanced communication [40]. Soft computation is a rapid, trustworthy, and fair assessment technique that has gained popularity in a wide range of industries. Image processing, which involves the gathering of physical data, may be used to assess the quality of fruit. Past research examined these techniques and outlined a structure for papaya grading using the Artificial Bee Colony methodology when analyzing papaya fruits from photographic images [41]. Fruit and vegetable diversity affects the market for exported goods and how quality is rated. The monetary worth of vegetable and fruit products is an important perceptual attribute influencing consumer choices and decisions. This characteristic helps identify exterior issues in vegetables and fruits using shape, shades, and smell. Many techniques provided in this suggested study, especially for quality inspection, also address extrinsic fruit problems [42], which has an opportunity to be extremely important in the digital transformation of horticulture and has applications in many other sectors.

Due to the advancement of cloud computing in the horticulture business, there is potential for implementing horticultural apps to create business opportunities in rural regions. For detecting temperature, humidity, soil moisture, and other parameters, various data-gathering techniques, Radio-Frequency Identification (RFID) sensors, and wireless sensor networks may be effectively linked with cloud computing applications [43]. In addition, cloud computing offers a sizeable capacity for storage appropriate for the extra protection of this enormous quantity of data and information pertinent to agriculture (Figure 3), and it also provides an appropriate platform for decision support, information acquisition, and knowledge sharing among the global horticulture community [44]. A survey on smart irrigation systems for horticulture was conducted to advance our understanding of IoT-based horticulture advancement utilizing cloud computing [45]. A cloud-based connection to the internet of tracking solutions for horticulture. A UV sensor, heat detector, Relative Humidity (RH) instrument, and soil moisture sensor are examples of sensor devices that may be used to oversee greenhouses and polyhouses and monitor various environmental variables. Every thirty seconds, the sensors gather data from the horticulture area and utilize cloud computing and the IoT to store it online [46]. Conventional approaches are increasingly being transformed into Smart Horticultural Services for end users using IoT technology to boost yield. The monitoring process has simplified and becomes much quicker in recent years with the use of cloud computing and IoT, allowing for the invention of smart farm equipment and the effective management of farmer-related difficulties. Agri-System processes input data, which may comprise, among other things, pH value assessment, humidity prediction, and warmth of the apiculture region/ sector. Utilizing big data analysis, cloud computing, IoT, detectors, mobile computing, etc., multitasking may be accomplished [47]. Technologies that use cloud computing IoT to track horticulture in the modern day anticipate that creating a comprehensive information system will accelerate the spread of present-day horticulture. The goal and implementation of cloud computing for monitoring fruits and vegetables are presented in detail in Table 3.

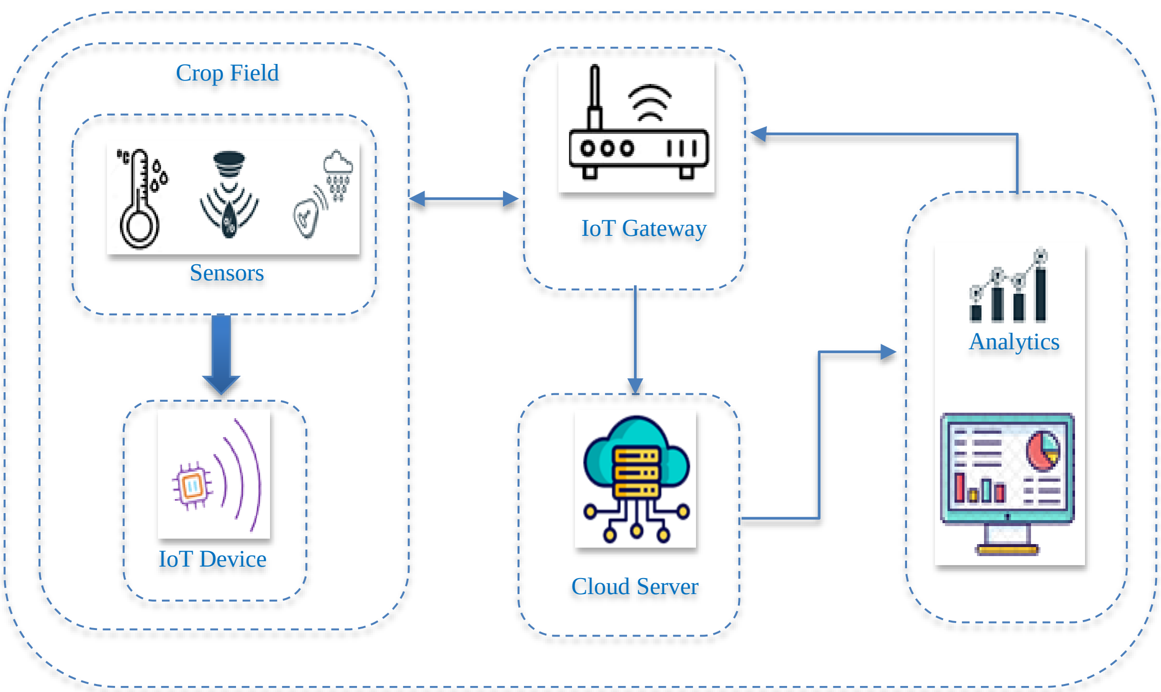

Fig. 3 Cloud computing in horticulture

Table 3. Previous studies of cloud computing for fruit and vegetable monitoring

S.No	Objective	Application
38	The analysis of various fruit disease detection methods is the main objective of our work.	Various computer vision techniques for fruit sorting.
39	Design a mobile learning platform that describes vegetable production and allows interactive communication.	Easily accessible to better the situation
41	A framework for Carica papaya grading involves using the Artificial Bee Colony algorithm (ABC) to identify papaya fruits from digital photos.	The accuracy of the suggested optimization methods for the various papaya fruit picture datasets is 94.04%.
42	Based on morphology, colour, and texture, identify external problems in fruits and vegetables.	Different quality screening algorithms proposed, including external fruit problems

4.4. Augmented Reality

There is a huge possibility for children with disabilities schooling since augmented reality makes it possible to integrate virtual and real worlds together. Figure 4 details and highlights the uses of augmented reality. To educate children with disabilities about the different elements of local fruits and vegetables [48], classify fruits by combining augmented reality with a conventional neural network. A smartphone is necessary for this application in the following way: This programmer will scan actual fruit and then offer data regarding the quality of the fruit and three-dimensional images for fruit quality evaluations. So that growers can quickly distinguish between fruits of various grades [49]. The usage of an augmented reality-based model that could show 3D items and attractively portray data collected using gauge monitors was advised in order to deliver nutritional data on mobile devices. Although it only offers minimal nutritional information on the amino acids, fatty acids, and polysaccharides of a limited number of fruits, AR could potentially be used to present details on horticultural pursuits and to promote the establishment of crops [50]. In a greenhouse, while growing grapes, when gardening, and when landscaping [51, 52]. Research points to the application of augmented reality for insect, plant, and weed identification [53, 54, 55]. A farmer has employed augmented reality to collect soil samples [56]. With augmented reality, virtual worlds take the role of tangible items.

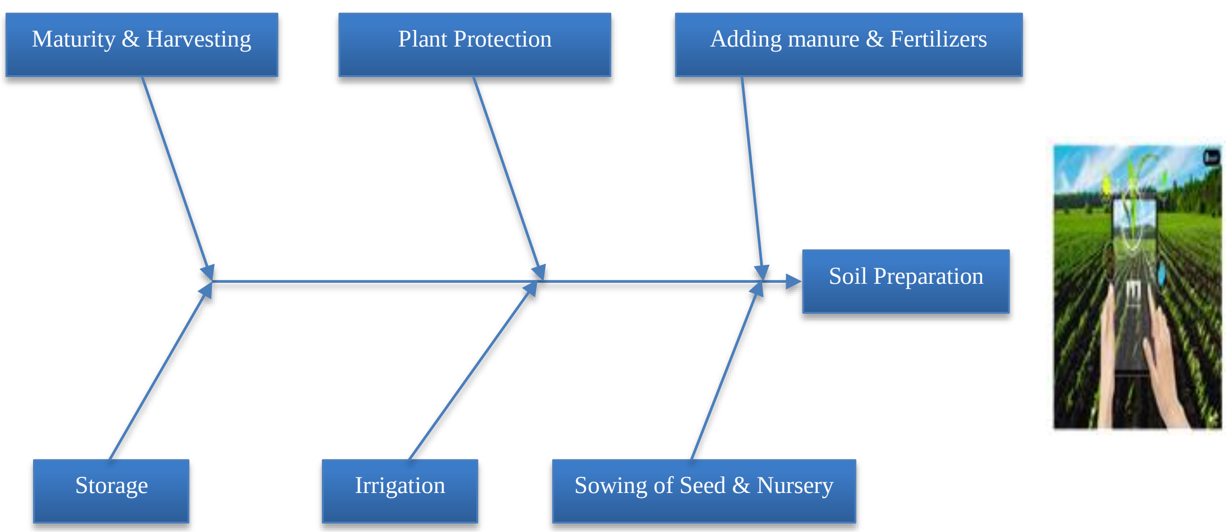

Fig. 4 Augmented reality in horticulture

An augmented reality system that uses computer vision techniques to recognize vegetation compared to their foliage and enables us to connect them online is collaborative and productive, positively affecting results in a transferred, commonplace, and readily available form of relationship with the natural environment [57]. In this article, we provide a novel idea for collecting color photos of soil maps using a drone, followed by using augmented reality goggles to assist farmers in collecting samples that indicate management zones utilizing the segmentation approach and point of sampling selection. For instance, for farmers to be eligible for financial assistance under the Agro-based Cooperation Programmer in Finland, they must take soil tests at an appropriate rate and consistency [58]. The goal and use of augmented reality deployment for fruit and vegetable surveillance are presented in detail in Table 4.

Table 4. Previous studies of augmented reality for fruit and vegetable monitoring

Ref	Objective	Application
48.	Components of local produce, both fruits and vegetables.	Developing a link between real and digital information.
49.	Classify fruit with augmented reality and a traditional neural network in combination.	Using a smartphone in the following manner: This application will provide information on fruit quality and three-dimensional images to compare fruit quality after real fruit has been scanned.
50.	Horticultural mobile augmented reality framework.	Technology for collecting and storing information.
51.	Create a smart Garden support system.	Visualise farming operation guidance using computer animation and overlay it over a field.

Table 5. Previous studies of digital twins for fruit and vegetable monitoring

Ref	Objective	Application
60.	In this study, 95 shipments were analyzed for four fruits all through the cold chain (cucumber, eggplant, strawberry, and raspberry).	The capacity of the digital twin to analyze various scenarios.
65.	Planning and control are made possible when Digital Twins are used as the primary tool for farm management.	Digital information is available in real time instead of depending on direct observation.
66.	A component, product, or system's complete physical and functional description is referred to as a "digital twin.	Modeling and simulation are common system development techniques.

4.5. Digital Twin

The advent of digital twins might signal the start of a new age in data-driven and intelligent greenhouse horticulture. A digital twin is a tool that continuously reproduces the situations and behaviors of a measurement in a computer-generated environment. Figure 5 shows how various technologies may be used to create a digital twin of any program. According to studies, they are equipped to deal with the developing labor scarcity in greenhouse horticulture and vastly improve production and sustainability [59]. Determining how much the suggested changes will improve the local horticulture distribution system might be challenging. This study allows for comparing and evaluating the effectiveness of different approaches for maintaining fresh food quality along the refrigeration chain. We took advantage of physics-based digital twins for appropriate items. The digital twin simulates freshly picked produce and uses information regarding observed room temperature to examine temperature distribution throughout the fruit and link it with production decrease [60]. Introducing digital twins might significantly improve the greenhouse [61-63]. Vertical collaboration and process standardization of greenhouse manufacturing techniques are offered to increase energy savings, production productivity, and output without jeopardizing product quality or durability. To support the co-optimization of the manufacturing process, utilization of energy, and labor expenditures, the Digital Twins take crucial factors into account, such as production targets, grade scoring, warming up, artificial illumination, utility costs (gas and electricity), and predictions for the weather [64].

Digital twins can be used as the primary farm management tool to remove physical motions from planning and control. As an outcome, farmers are eliminating the need to oversee operations through local human labor and close monitoring. Instead, it may accomplish this distantly by using digital data that is (nearly) real-time [65]. The state and activity of a real-life object during its existence in an online setting are simulated by a digital twin. Digitalized items in greenhouse horticulture might include everything from a greenhouse or the chain's worth to specific plants' genetics. Given the concept's relative freshness, smart greenhouse horticulture may be seen as a progression of the Digital Twin idea [66]. Although greenhouse horticulture is at an important phase in developing the Digital Twin concept, there are already applications that are not classified as Digital Twins [67].

Horticulture is characterized by diversity and unpredictability of output. It is also influenced by environmental elements, including the environment, illnesses, the condition of the soil, seasons, and climate since it involves live, perishable items. Indoor cultivation in conservatories is a technology that offers a more regulated Production environment suited for fertigation methods, water, light, and climate to meet these challenges.

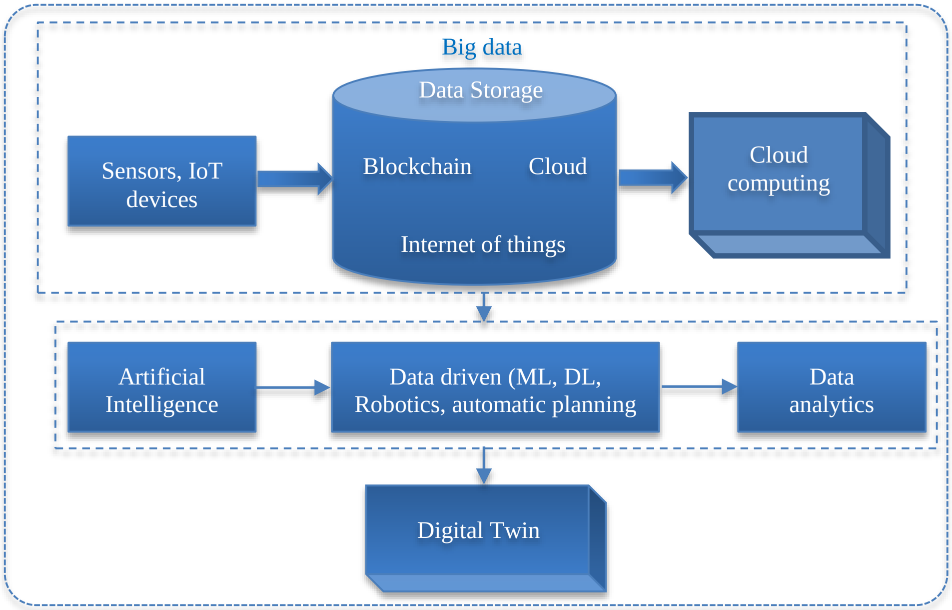

Fig. 5 Digital twins in horticulture

Given the ongoing unpredictability caused by weather-related diseases, quality deterioration, and new challenges, especially regarding energy management, growers must constantly reevaluate their agricultural tactics and reconsider the scheduling procedure centered on the on-time inspection of greenhouse operations. Digital twins may substantially enhance the correct control qualities by assisting farmers in taking rapid action in circumstances of anticipated aberrations and illustrating interventions according to real-life information [68]. Since these metrics link the digital twin to operations, monitoring the overall temperature and humidity level is a crucial part of the distribution networks for fresh horticultural goods. Different parameters related to the environment, such as ethylene, oxygen, and carbon dioxide levels or metabolic components, are of great interest [69]. These types of sensors are consistently priced higher and bigger than relative humidity or climate change indicators. The goal and use of the adoption of digital twins for fruit and vegetable surveillance are presented in detail in Table 5.

5. Recommendations

The successful adoption of Industry 4.0 technologies in horticulture hinges on technological innovation and supportive policy frameworks. As this review demonstrates, digital tools such as IoT, AI, robotics, and augmented reality offer significant benefits in terms of productivity, sustainability, and resource efficiency.

AI and IoT technologies to increase the accuracy and quality of harvests. AI and IoT combined with vision technology can be used in horticultural environments to detect pests, plant diseases, and malnutrition. AI and IoT can identify and target weeds using images from the camera module installed in robots before deciding which herbicide to use in a given area. IoT and Artificial Intelligence (AI) can be used to solve various problems in the farming industry [69].

6. Conclusion

Horticulture is an essential industry for attaining an appropriate balance of nutrients necessary for individuals to live healthy lives. With its intelligent analytics, digitization, which comes after sustainability, significantly contributes to improving the various horticultural tasks. In this paper, we go into great depth on how IoT, AI, cloud computing, augmented reality, and digital twins are being used to monitor fruits and vegetables.

Based on the debate, this study has drawn some important inferences, including using AI in earlier studies to monitor weeds using computer vision and using AR to evaluate potential changes that may boost the distribution network of horticultural products. Farmers no longer are forced to depend on on-site physical labor and close surveillance to manage procedures thanks to the use of Digital Twins.

The present study helps the researchers learn more about the application of digital technology for enhancing horticultural infrastructure. In this review, we aim to elucidate how Industry 4.0 technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), robotics, Augmented Reality (AR), and digital twins can significantly revolutionize the horticulture sector.

Collectively, these technologies provide innovative solutions to longstanding problems by enabling precision farming, automating labour and resource efficiency, and increasing productivity and sustainability.

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