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Review

Horticulture 4.0: Adoption of Industry 4.0 Technologies in Horticulture for Meeting Sustainable Farming

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Abstract: The United Nations emphasized a significant agenda on reducing hunger and protein malnutrition as well as micronutrient (vitamins and minerals) malnutrition, which is estimated to affect the health of up to two billion people. The UN also recognized this need through Sustainable Development Goals (SDG 2 and SDG 12) to end hunger and foster sustainable agriculture by enhancing the production and consumption of fruits and vegetables. Previous studies only stressed the various issues in horticulture with regard to industries, but they did not emphasize the centrality of Industry 4.0 technologies for confronting the diverse issues in horticulture, from production to marketing in the context of sustainability. The current study addresses the significance and application of Industry 4.0 technologies such as the Internet of Things, cloud computing, artificial intelligence, blockchain, and big data for horticulture in enhancing traditional practices for disease detection, irrigation management, fertilizer management, maturity identification, marketing, and supply chain, soil fertility, and weather patterns at pre-harvest, harvest, and post-harvest. On the basis of analysis, the article identifies challenges and suggests a few vital recommendations for future work. In horticulture settings, robotics, drones with vision technology and AI for the detection of pests, weeds, plant diseases, and malnutrition, and edge-computing portable devices that can be developed with IoT and AI for predicting and estimating crop diseases are vital recommendations suggested in the study.

Keywords: horticulture; micronutrient; Industry 4.0; SDGs; IoT; blockchain; real-time prediction; AR; bigdata

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Citation: Singh, R.; Singh, R.; Gehlot, A.; Akram, S.V.; Priyadarshi, N.; Twala, B. Horticulture 4.0: Adoption of Industry 4.0 Technologies in Horticulture for Meeting Sustainable Farming. *Appl. Sci.* **2022**, *12*, 12557. https://doi.org/10.3390/app122412557

Academic Editors: José Miguel Molina Martínez, Ginés García-Mateos, Dolores Parras-Burgos and Georgios Papadakis

Received: 14 September 2022
Accepted: 9 November 2022
Published: 8 December 2022

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1. Introduction

According to the Food and Agriculture Organization and World Health Organization State of Food Security and Nutrition in the World (SOFI) report,45 million children die from the deadliest form of malnutrition under the age of five [1]. A chronic deficiency of essential nutrients in their nutrition has also resulted in delayed development and growth in two billion children under the age of five. This indicates that there is a need to have more emphasis on overcoming food insecurity and malnutrition due to climate extremes and economic disruption. Even the SDGs (SDG 2 and SDG 12) of the UN emphasize eradicating hunger and enhancing food security with responsible consumption and production toward sustainability [2,3]. Healthy micronutrients for overcoming malnutrition can be achieved with sustainable farming of fruits and vegetables, i.e., horticulture [4]. India is currently the world's second-largest producer of fruits and vegetables, trailing only China. Horticulture comprises fruits, root and tuber crops, mushrooms, vegetables, spices, aromatic plants,

flowers, bamboo, coconut, cashew, and cocoa. Different strategies such as technology promotion, research, post-harvest management, and marketing are key for the growth of horticulture. Improving horticulture production, increasing farmer income, improving nutritional security, and improving productivity by using quality germplasm, planting material, and micro irrigation to save water are the key vision of India for the promotion of holistic horticulture growth.

Horticulture crops significantly contribute to the Indian economy by enhancing farm output, generating employment, and providing raw materials to various food-processing businesses [5]. The amount of land allotted for horticulture is minimal, but the demand for the production of horticulture is high. Therefore, meeting the demand with minimum resources is a bit challenging, as sustainable practices need to be adopted to meet a sustainable environment [6]. It has also been observed that the export rate of Asian countries such as India has increased in the past few years; however, there are a few challenges such as meeting quality standards set by international countries and payment for exports. The main challenge in fruits and vegetables is the short lifetime after plucking. Additionally, given that the majority of horticulture cultivation is processed in rural areas, it has been determined that horticulture has to be promoted in urban areas.

1.1. Problem Statement

Ref. [7] discussed the main problems that are present in horticulture, including the decline of fertile soil, global warming, rising land prices, shortage of water, and lost opportunity of low-cost labor, all of which portray serious threats to growth of horticulture. For horticultural crops, abiotic stresses like an inundation, temperature extremes, salinity, pH, and drought are major obstacles. As an outcome of global warming, there will be less precipitation all in all, and the snow cover will melt faster, resulting in extreme drought. These circumstances lead to several stress-related problems, including the deficit of fertile soil, flooding, increased evapotranspiration, low soil-oxygen levels, decreased production, leachate of nutrients, and slow planting. Alongside increasing temperatures, global warming had also contributed to record-breaking cold weather. Land salinity and irrigation-water salinity are also significant concerns for horticultural production. Along with these problems, previous studies also discussed that sustainable pest-management methods need to be adopted to protect against pathogens and pest resistance. The absence of markets to accumulate production, the substantial percentage of middlemen, the absence of marketing institutions safeguarding farmers' interests, the imperfect pricing system, and the absence of transparency in market-information systems, especially in the export market, is the main marketing problems for horticultural produce.

1.2. Motivation, Novelty, and Contribution of the Study

As discussed above, the traditional approaches lack appropriate monitoring of pest control, water management, soil management, light control, and temperature control, as these parameters are crucial for the effective production of horticulture with a sustainability aspect. The previous study found that the different issues in this group highlight the necessity for more environmentally sound processes, in addition to a rise in the utilization of automated systems and accurate processes. Industry 4.0 technology has proven its capability in various applications through the fusion of advanced technologies such as the Internet of Things, artificial intelligence, blockchain, robotics, digital twins, and big data. The amalgamation of Industry 4.0 and horticulture provides the opportunity to transform industrial agriculture into the next generation, namely Horticulture 4.0. Moreover, Industry 4.0 is capable of achieving sustainable and intelligent ecosystem with real-time management of farming, automation, intelligent decisions, real-time processing, and analysis [8]. It has proved that Industry 4.0 technologies have already delivered exceptional results in greenhouse farming for a sustainable food supply chain with the integration of hardware and software algorithms and giving rise to higher yields using fewer resources and less water. Although many studies have addressed Industry 4.0 technologies individually for fruits

and vegetables, they are limited studies that merely address multiple Industry 4.0 digital technologies as single concepts for discussing their significance in horticulture. Based on the aforementioned information, this study analyzed the value and applications of Industry 4.0 technologies in horticulture for real-time monitoring of fruit-and-vegetable conditions in various environmental settings, intelligent and predictive analytics for fruit-and-vegetable growth and disease estimation, and virtual horticulture plants. The contribution of the study is as follows:

- The significance of using Industry 4.0 technologies for horticulture is discussed in the study for sustainability.
- We also discuss the significance and applications of the Internet of Things, cloud computing, artificial intelligence, blockchain, and big data for horticulture for enhancing traditional practices for disease detection, irrigation management, fertilizer management, maturity identification, marketing, and the supply chain, soil fertility, and weather patterns at pre-harvest, harvest, and post-harvest
- Finally, the article discusses the challenges and suggests recommendations for the wide adoption of any future enhancement in the vicinity of horticulture. In horticulture settings, robotics, drones with vision technology and AI for the detection of pests, weeds, plant diseases, and malnutrition, and edge-computing portable devices that can be developed with IoT and AI for predicting and estimating the disease of crops are vital recommendations suggested in the study.

1.3. Methodology of the Study

In this section, the methodology of the study is presented. Based on the limitations identified in previous studies, this study framed a research question that was employed to carry out the review. The research question was, "What is the progress and significance of Industry 4.0 technology integration in horticulture?" This research question constructed various keywords with Boolean function operators in the Scopus and Web of Science databases. The following strings were considered for obtaining publications: "horticulture AND Industry 4.0", "horticulture AND sustainability", "Industry 4.0 for fruits and vegetables", "Industry 4.0 AND digitalization", "horticulture AND digitalization", "horticulture AND IoT", "IoT AND fruits and vegetables", "disease detection AND horticulture crop", "blockchain AND horticulture", "artificial intelligence AND horticulture", "quality assessment AND artificial intelligence", "big data AND horticulture", "blockchain AND marketing of fruits and vegetables", "blockchain AND energy", "crop monitoring AND horticulture", and "soil fertility AND horticulture." During the search for articles, there was al ack of articles that merely emphasized the integration of Industry 4.0 for horticulture. Therefore, we considered a few conference articles and other supportive articles in this study. Based on the obtained articles, the study categorized four different sub-sections in which the progress and significance of the previous studies that implemented Industry 4.0 for enhancing horticulture from production to marketing are assessed. After analyzing the studies, few limitations were identified and vital recommendations for future work were suggested.

1.4. Comparative Analysis

Table 1 provides a comparative analysis of the different studies that focused on horticulture that are analyzed within the proposed study. In most previous studies, it was identified that the study only focused on some key areas in horticulture, like yield monitoring, pesticide monitoring, and quality assessment. A recent study emphasized the different issues in horticulture from the perspective of industries. Along with this, [9] reviewed the different critical parameters that are required for automation with IoT for vertical gardens. Ref. [10] carried out a review on the significance of deep-learning models in horticulture for various applications. Ref. [11] discussed the implementation of digital twins in horticulture. However, there is a possibility of emphasizing the importance of multiple Industry 4.0 technologies for addressing the different issues of horticulture from production to market-

ing. The current study focused on discussing the different Industry 4.0 technologies for overcoming the different issues of horticulture within the context of sustainability. This study highlights the significance and application of Industry 4.0 for horticulture. Based on the limitations identified, this study also discusses vital recommendations for future work.

Table 1. Comparative analysis of the previous studies with the current study.

Ref	Objective	Findings
[8]	The study carried out a review to analyze the critical parameters that are significant for automation in vertical gardens through IoT.	One of the study's key findings is that the majority of studies used 6–20 tiers (40%) when integrating VGs, with lettuce representing the most dominant crop (28.6%).
[9]	A brief overview of deep-learning approaches is provided in which deep-learning technologies are used in the horticultural domain.	Large datasets need to be built by collecting real-condition imaging data of plants to create robust models.
[10]	The study carried out a review to provide insight into the implementation of digital twins in horticulture.	There is a dominant focus on the cultivation process at the greenhouse level, among others, for climate control, energy management, and lighting.
[12]	Yield monitoring of annual and perennial crops of horticulture	The study contends that many commercial strategies for mapping horticultural crop yield are necessary. It was also discovered that integrating multiple technologies can provide better and more accurate results.
[13]	To determine the pesticide-residue levels in widely consumed fruits and vegetables throughout Kuwait	The results conclude that there is a high presence of pesticides in fruits and vegetables.
[14]	The Delphi Technique was utilized to recognize the most significant challenges facing the horticulture industry.	A framework was proposed for assisting researchers in identifying the key issues in horticulture within the COVID-19 context.
[15]	A real-time monitoring system was constructed to evaluate the quality losses that a perishable product can suffer during transportation and storage.	Conceptual shelf-life was minimized while stored or transported at an incorrect temperature.

The following describes how the study is structured: Section 2 discusses an overview of Horticulture 4.0 and Industry 4.0 technologies, Section 3 addresses the intervention of Industry 4.0 technologies in horticulture, and Section 4 covers the discussion and recommendations.

2. Overview of Horticulture and Industry 4.0

High temperatures have two main effects on crop production: they inhibit vegetative growth and have a detrimental effect on fruit production. Prolonged transpiration along with subjection to extreme temperatures limits vegetable crops that are susceptible to considerable transpiration deficits [16,17]. Another problem is that the maximum time for the fruit set is proportional to humidity levels. Extremely high temperatures can occur. The obvious limitation encountered by cold temperatures is the freezing of plant tissues. Rapidly pushing freezing temperatures at a phase of rapid growth might cause damage to a variety of plant tissues [18,19]. Some plants can adapt to cold temperatures provided there is sufficient time and the appropriate circumstances, whereas others cannot. Changes in regional precipitation patterns may cause an increase in drought conditions in many different parts of the world as atmospheric CO_2 levels to rise [20]. Although the current belief is that leaf photosynthetic responds to high CO_2 as well as soil-water deficiency, the connections between CO_2 enrichment and drought stress remain unexplored [21]. These are the few problems that have been addressed by previous studies in the area of horticulture. Below, we discuss the significance of Industry 4.0 technologies and their importance in enhancing practices in horticulture. Industry 4.0, often known as the Fourth Industrial Revolution, is the phenomenon that results from the impact of the IoT on information and communication technology. With the help of technologies like the integration of cyber-

physical systems (CPS), IoT, and the real-time interaction between machinery, software, and people, it aims to revolutionize the industry through smart factories that will enable greater flexibility in production needs, efficient resource allocation, and process integration from device monitoring to final delivery [22].

Figure 1 depicts the technologies that can be intervened in horticulture, such as artificial intelligence (AI), blockchain, big data, the Internet of things (IoT), and cloud computing, in industry 4.0. Figure 1 illustrates the implementation and application area in which Industry 4.0 can be adopted for horticulture. In horticulture, there are different stages, including pre-harvesting, harvest, and post-harvest. Industry 4.0 technologies cover the following parameters for horticulture: automation of actuators, disease detection, irrigation management, fertilizer management, maturity identification, marketing and supply chain, soil fertility, and weather patterns. Along with these applications, Industry 4.0 integration in horticulture enables quality assessment and grading of horticulture products. The quality assessment of horticulture products is different in the three stages. The following are aspects through which the quality and grading of a horticulture product are decided, and they are typical cultivar ripeness, absence of defects and blemishes, a non-harmful number of pesticide residues, freshness, and other chemicals. Therefore, the quality assessment and grading of horticulture products mainly rely on the parameters discussed above. The monitoring of each parameter and utilizing the data generated from different wireless sources with Industry 4.0 technologies boost the performance of the horticulture industry for the future.

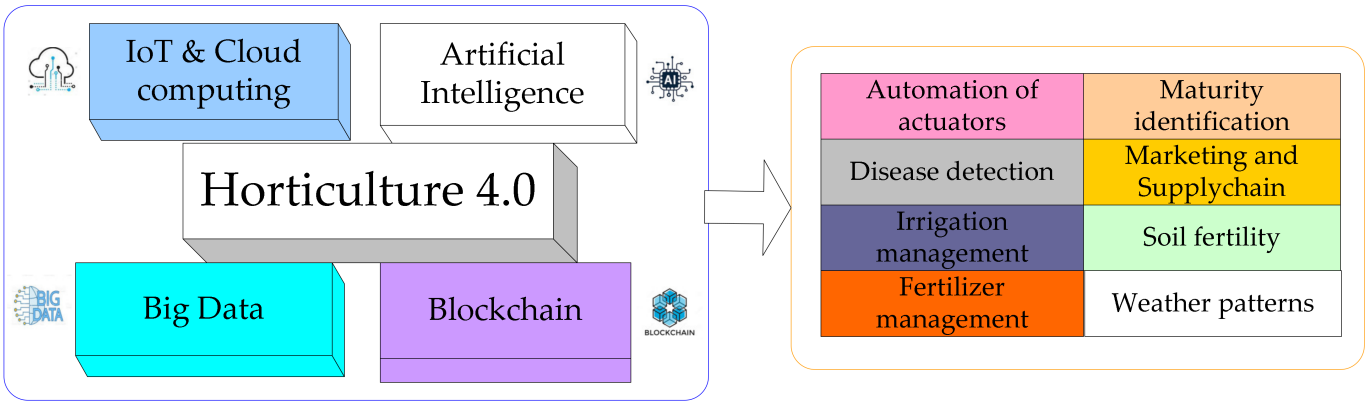


Figure 1. Horticulture 4.0.

Overview of Technologies and TheirFunctions

IoT is the primary technology that enables the provision of real-time information that is required for other technologies to implement their functions. IoT is an open network of intelligent devices that may self-organize; exchange information, data, and resources; and respond and act according to circumstances and environmental changes [22]. Fundamentally, IoT comprises the following layers in its architecture: perception layer, access layer, network layer, middleware layer, and application layer [23]. The perception layer is a key layer in which sensors, actuators, and identification technologies empower the transmission of real-time information and also enable control of things from remote locations through internet connectivity. The network layer empowers the transmission of packets of data with the assistance of communication protocols that are embedded in the architecture. Wireless fidelity (Wi-Fi), Bluetooth, and Zigbee are widely used communication protocols to establish a wireless sensor network and connect it with the internet to form the IoT [24].

The limitations of these communication protocols are the short transmission range and high-power consumption. In view of the IoT, most IoT devices are resource-constrained (work on battery power), so it demands communication protocols that consume less energy and transmit to a long range. A low-power–wide-area network (LPWAN) enables these challenges to be overcome, as it meets the requirements of the IoT [25]. Long-range (LoRa),

Sigfox, and narrowband (NB-IoT) are LPWAN communication technologies. As part of the application layer, a cloud server is suitable for visualization, real-time monitoring, and applying further analytics on the data available in it.AI is the science of enabling computers to accomplish intelligent tasks that could only be completed by humans.

AI is a multidisciplinary technology capable of combining machine learning, cognition, human-computer interaction, emotion recognition, data storage, and decision-making [26]. The bottleneck of AI was overcome with the advancement of processing power, and the development of deep learning and enhanced learning based on huge data progressed. With the constant advancement of GPUs has come the successful development of customized processors and increased computer capacity; this has established the groundwork for AI's rapid progress. Artificial neural networks (ANNs), decision-support systems (DSSs), genetic algorithms (Gas), support-vector machines, and computer vision are some of the AI techniques that are widely applied in the field of agriculture for the management of soil, crops, disease, and weeds [27]. Big data is defined as data sets that are too massive or complicated to be acquired, maintained, and processed in a low-latency manner by conventional database systems [28]. Big data has characteristics such as high volume, high velocity, and high variety. Big-data analytics can ultimately enable better and faster decision-making, model, and forecast future outcomes, and improve business intelligence [29]. A distributed, unchangeable database called blockchain makes it simpler to track assets and record transactions in a corporate network [30]. Distributed ledger technology, immutable records, and smart contracts are the key elements of blockchain. Each transaction is logged as a "block" of data as it occurs. Each block is linked to the ones that come before and after it. Transactions are linked in an irreversible chain

Horticulture is utilizing the IoT to collect data from field planting and horticultural facilities for production, management, and service. Robots, drones, remote sensors, and computer imagery are used in horticulture as part of the IoT to monitor crops, survey, and map fields, as well as to provide data to farmers for logical farm-management strategies that will reduce both time and cost [31]. AI is facilitating various sectors in agriculture to enhance productiveness and performance and to overcome traditionally demanding situations in each field. The intervention of AI in horticulture is helping farmers to improve their farming efficiency and reduce hostile environmental impacts [32]. Blockchain horticulture empowers information to be traced throughout the food supply chain to improve food safety. The ability of blockchain to store and manage data creates traceability, which is utilized to enhance the creation and deployment of innovations for intelligent farming and index-based horticultural insurance. Improved quality control and food safety are advantages of applying blockchain to gardening. Increased supply-chain traceability of farmers' productivity will lead to more equitable payments for farmers [33].

Farmers can learn in-depth information about topics like rainfall patterns, water cycles, fertilizer requirements, and more thanks to large datasets. Companies can utilize this information to choose which crops to produce and when to harvest them in order to maximize their profits [34]. Data on horticulture are gathered, examined, and stored using cloud computing. Farmers can better understand crop conditions by using cloud-connected wireless sensors to collect data from the field and machine-learning algorithms to analyze that real-time information [35]. Precision horticultural farming heavily relies on augmented reality. Farmers can use augmented reality in horticulture to boost production, reduce crop waste, and teach other farmers [36].

3. Intervention of Industry 4.0 in Horticulture

In this section, we discuss the various Industry 4.0 technologies in horticulture intending to transform into Horticulture 4.0.

3.1. IoT Intervention in Horticulture

The potential of pests and plant diseases is inseparably associated in particular with-specific weather characteristics. Previous research concluded that humidity and rainfall

have a significant impact on pathogen spread and propagation [37]. Pests and diseases are more inclined to spread as a result of the wind. According to the information presented above, pests and diseases are prevalent in crops, and monitoring of the related parameters can be achieved with the IoT. An intelligent monitoring system was proposed on the basis of the IoT with a global packet for radio service (GPRS) and Zigbee communication protocol for pest warning, planting works, and production-quality checks of apples with the assistance of soil sensors, meteorological sensors, and cameras [38]. The feasibility, yield, and irrigation water-use efficiency of an IoT-based precision-irrigation system with LoRaWAN technology on fresh-market tomato production was analyzed [39]. ET, Watermark 200SS-5 soil-metric potential sensors, MP40, and a decision-support system were used to design and test four irrigation-scheduling treatments. A study was conducted with the integration of a camera module, and the images collected were used to analyze the water-management system as well as detect plant disease within a green environment [40].

Researchers established a technology platform using the IoT for environmental data acquisition, disaster warning, transmission, remote control, and an information push in vegetable greenhouses in real-time and lessen the influence of climate catastrophes on vegetable development [41]. The data collected by an IoT board are expected to be utilized to train machine-learning models for the development of intelligent automated indoor microclimate horticulture crops [42]. A database contains the results of the sensor analysis and it is also linked with data from the Indonesian Weather Agency, which contains daily meteorological data from the cultivation location [43]. To ensure the proper operation of the greenhouse automation system, multiple measuring stations are needed in a modern greenhouse to identify the local climate parameters in various areas of a large-scale greenhouse [44]. The IoT paradigm is allowing the scientific community to establish integrated settings where data could be automatically transferred among many distinctive networks to provide consumers with specific relevant information [45]. The security of the foods supplied can be ensured by utilizing the provenance data that are kept throughout the supply chain of vegetables, including during planting, harvesting, government oversight, testing, transportation, customs clearance, warehousing, repackaging, and internal testing [46,47].

Every kind of pest and disease is believed to be harmful to plants and to have a serious unfavorable effect on horticulture. To decrease the frequent use of pesticides and fungicides and to anticipate when pests will arise, the IoT system was created [48]. Soft-computing technologies are used to identify fruits by combining the three essential characteristics of an object—color, shape, and texture. This method reduces the dimensions of the feature vector. As a result, the combined and normalized image features produce better classification accuracy with fewer training data [49]. Real-time supply-chain monitoring can give stakeholders insight into perishable food to better manage to price and take appropriate action to uphold quality requirements [50]. Farmers confront a variety of challenges when growing vegetables, including issues with seeds, managing pests and diseases, commodity costs, and product marketing. Farmers can use the internet and the concept of mobile cloud computing to access information and engage in an interactive dialogue about vegetable production through mobile learning [51]. A framework for papaya grading based on the Artificial Bee Colony algorithm was proposed to classify papaya fruits from digital photographs [52,53].

Figure 2 illustrates an architecture that was implemented by previous studies for monitoring different parameters in horticulture. As discussed in Section 2, one of the key components of the IoT is sensors. Sensors such as temperature, soil moisture, humidity, light intensity, pH, NPK, and water level are crucial for obtaining important information about the soil and environment. Along with these sensors, the camera module is used to obtain data from the horticulture field. The sensors remain the same for the indoor and outdoor environments of horticulture cultivation. Data on the soil and environment are mapped to obtain better productivity by smart controlling of irrigation and fertilizer. Based on the soil data, the crop-yield analysis is analyzed, and fertilizers can be used as needed. All of these sensors send the soil and environment data to the computing unit,

at which point the data-sensor processor communicates with the cloud server through a wireless-communication protocol and gateway. In the cloud server, the data are visualized on the graphical user interface.

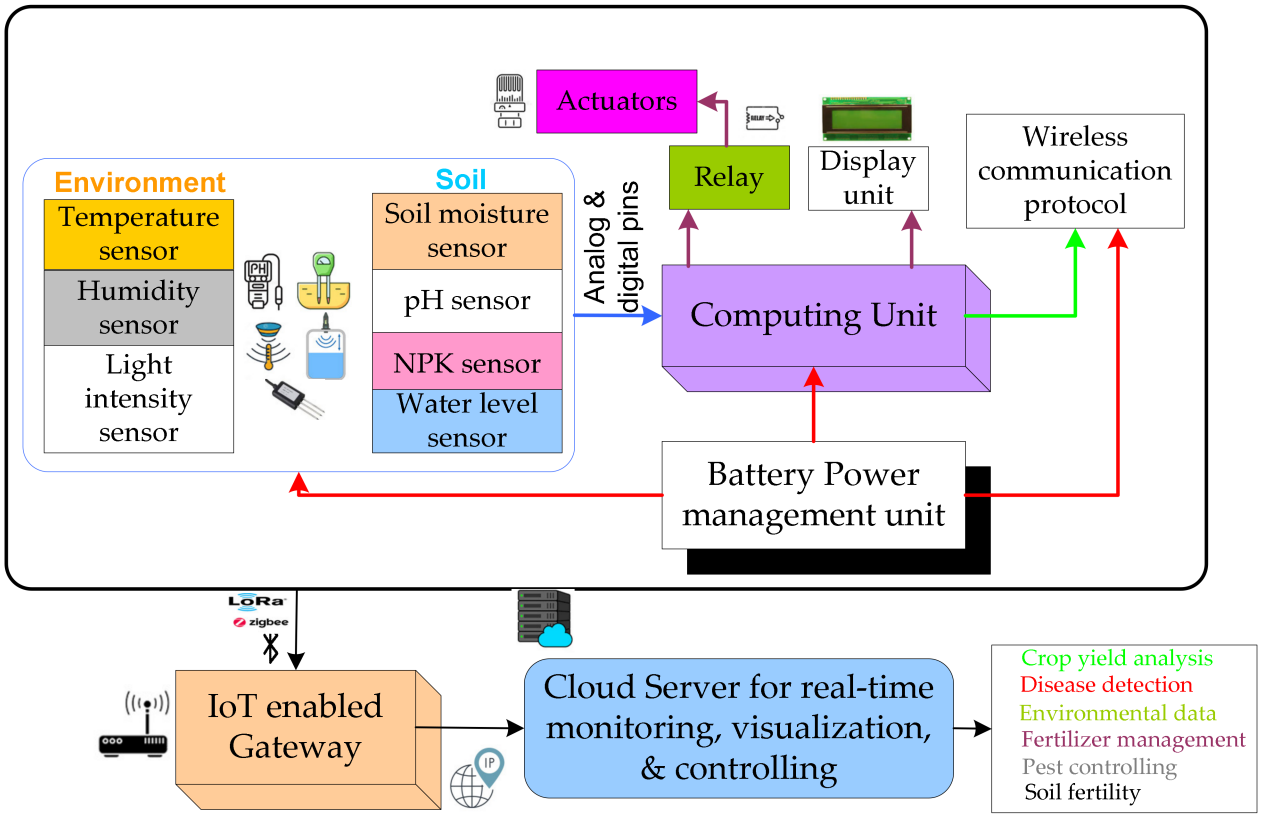


Figure 2. IoT for horticulture.

3.2. AI in Horticulture

Fresh and wholesome food is essential for feeding the expanding world population, and greenhouses and indoor agricultural techniques play a crucial role in this. In the past two decades, hyperspectral imaging research has developed, and in the decades to come, its use in horticulture is expected to grow. There are still challenges to the applicability. The automated detection of pests and diseases in plants empowers the effective monitoring of scalable fruit-and-vegetable crops. The detection of pests and diseases at the right time enhances pest- and disease-management systems [54]. The previous study concluded that AI algorithms can be implemented in horticulture for distinct applications, including fruit detection, pest, disease detection, weed detection, plant-stress detection, and yield prediction through the spectroscopy-and-camera system [55]. A study was implemented to identify common pests and diseases in apple fruit using sparse coding. Computer-vision techniques can identify pest- and disease-damaged fruits and provide data to assist in the detection and treatment of diseases and pests in the early stages [56]. Soil-organic-carbon (SOC) monitoring is a crucial characteristic of soil quality because it directly determines soil fertility and enables sustainable soil-nutrient management [57]. To improve SOC prediction, artificial neural networks (ANN), cubist regression, support-vector machines (SVM), multiple linear regression (MLR), and random forests (RF) were applied to the data of soil-nutrient indicators, total catchment area, and the topographic-wetness index.

Automatic detection of plant pests and diseases can aid in the monitoring of large farms and gardens. The application of AI in the drying process of fruits and vegetables has received a lot of attention because it can generate better-dried fruit-and-vegetable products when combined with an efficient physical field [58,59].An IoT-based tool can determine whether a climacteric fruit has been artificially ripened or not. To determine whether

the fruit is ripened artificially or naturally, machine-learning algorithms are applied [60]. We discuss these techniques and discuss the significance of combining computer-vision techniques with an autonomous robotic system that uses the deep-learning concept of artificial intelligence [61]. In order to reduce food waste, one study used sensors and analyzed gases produced by certain food products to detect rotten food at an early stage and boost accuracy. To forecast how frequently food will degrade, the researchers used machine learning, the IoT, and sensors. To assess the freshness of food, this study used ML and IoT. The implementation of vision-based hardware in robots enables the realization of intelligent spraying, crop-yield prediction and price forecasting, predictive insights, and disease diagnosis (Figure 3). In addition, during the supply chain, the AI-based IoT system enables the indoor environment conditions to be adjusted on the basis of external climatic conditions and travel time to avoid the spoilage of fruit and vegetables.

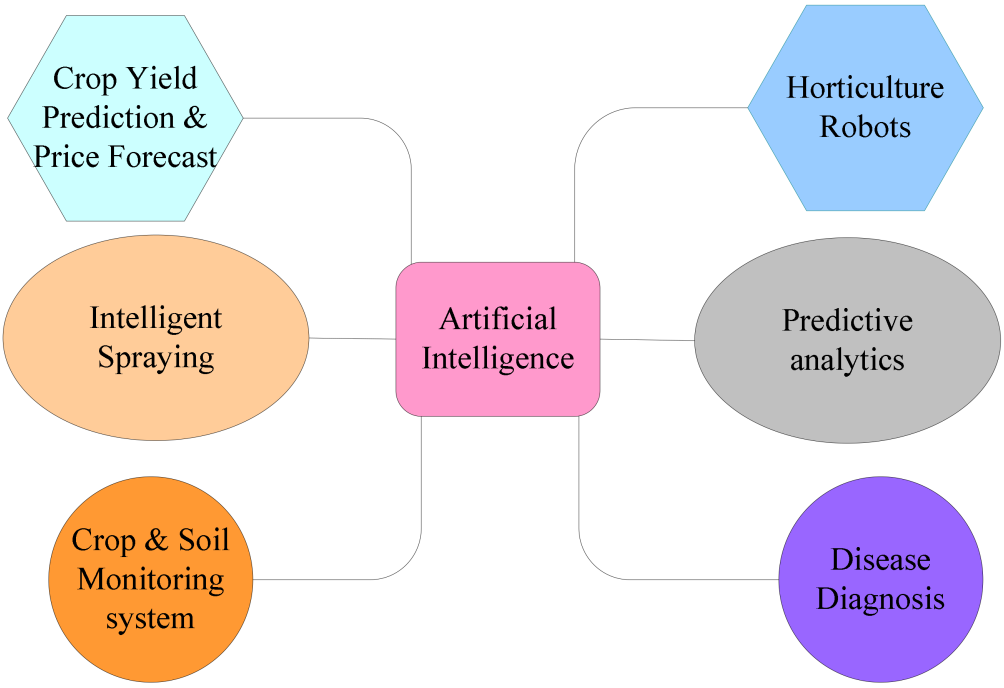


Figure 3. AI in horticulture and farming.

Table 2 illustrates the different studies that implement AI for horticulture crops for disease detection, quality assessment, and grading. The table provides the different algorithms that have been implemented for feature selection, feature extraction, classification, and regression for identifying defects, bruising quality assessment, and grading of the fruit. Different studies have used different feature-selection and feature-extraction techniques such as random frog, random forest, linear discriminant analysis-based fully convolutional networks, competitive adaptive reweighted sampling–successive projection algorithms, uninformative variable elimination, successive projection algorithm, gray histograms, and gray-level co-occurrence matrices. Classification and regression techniques include least-squares support-vector machines, support vector machines, convolutional neural networks, logistic regression, random forest, multilayer perceptron, linear discriminant analysis, k-nearest neighbors, and backpropagation in the neural network.

Table 2. AI for horticulture crops.

Ref	Function	Feature Selection/Extraction	Classification/Regression
[62]	A classification model is created to separate hard and soft blueberries.	Random frog	Least-squares support-vector machine, active learning algorithms
[63]	To accurately identify internal bruising in blueberries	Random forest, linear discriminant analysis-based fully convolutional networks	Support-vector machine
[64]	Detection of internal mechanical damage of blueberry	Customized convolutional neural networks	Convolutional neural networks, logistic regression, random forest, multilayer perceptron
[65]	Accurate assessment of bruising damage	Relief	Linear discriminant analysis, random forest, support vector machine, k-nearest neighbors
[66]	Assessment of strawberry ripeness using hyperspectral imaging	Competitive adaptive reweighted sampling–successive projection algorithm, Uninformative variable elimination, the successive projection algorithm	Random forest, support vector machine, partial least-squares regression, support-vector regression, random forest regression
[67]	Detection and analysis of decaying blueberries	Gray histogram, gray-level co-occurrence matrix	Backpropagation in neural network

Table 3 illustrates AI implementation in horticulture with accuracy and data-acquisition parameters. The previous studies illustrate that AI has been implemented for multiple applications such as quality assessment of fruit by evaluating moisture levels in the fruits. Following these studies, AI was used to forecast the yield of fruits such as bananas and blueberries. A few studies implemented AI for the detection and segmentation of apple fruits and branches in orchards through fused convolutional features, ResNet-101, clustering-RCNN, and CNN. The accuracy of different classifiers is illustrated in the table, and SVM, KNN, and DT achieved 100%. During the classification of tomato diseases, CNN achieved 99.18% accuracy on the dataset formed from 14,828 images. In the detection of citrus fruits, the CNN applied to the UAV images achieved 96.24% accuracy.

Table 3. AI implementation for horticulture with accuracy and data-acquisition sources.

Ref	Objective	Data Acquisition Source	Algorithm	Accuracy
[68]	Quality assessment of fruits through moisture content	Non-invasive sensing	SVM, KNN, and DT	100% for days 1 and 4 by three classifiers with 80% moisture content
[69]	Forecasted banana-harvest yields	Agrarian-reform beneficiary (ARB) cooperative of Dapco in Davao del Norte, Philippines	Long–short-term memory	Single and multiple LSTM layers with 43.5% and 44.95% error rates.
[70]	A data-processing pipeline is built to count blueberries, assess maturity, and assess compactness.	Four southern highbush blueberry cultivars	Mask R-CNN	Detection: 90.6% and segmentation: 90.4%
[71]	Classification of the different tomato diseases	The dataset contains 14,828 images of tomatoes leave infected with nine diseases.	CNN	99.18%
[72]	An apple monitoring system was developed with an edge-detection network.	Spherical video camera and two personal computers	Fused convolutional features	F1 score: 53.1% (FCF)
[73]	Detection and segmentation of apples in an orchard	Vision sensor	ResNet-101	F1 score: 0.832 for the detection of apples
[74]	Fruit detection in apple orchards	Not mentioned	Clustering-RCNN	0.853
[75]	Detection of citrus fruits	Unmanned aerial vehicle images	CNN	96.24

3.3. Blockchain

Blockchain is a distributed-ledger technology with the advantage of being tamper-resistant to information. It is anticipated to be able to address the issue of resource allocation for transactions among numerous unreliable parties in the supply chain for fresh fruit [76]. One potential method for supply-chain traceability in the pineapple industry is blockchain technology. The fruit-chain protocol that was introduced has identical consistency and liveliness qualities as assuming an honest majority of computer power [77] and is roughly fair with an overwhelming probability. Although blockchain might be viewed as a viable option for food-chain traceability, it was determined that [78] the goal of the investigation was to learn more about blockchain technology and its potential applications in the retail industry. Additionally, potential blockchain uses that might help the retail sector and the wider industry are foreseen. The study also underlined the crucial role that blockchain technology plays in the retail sector for fruit as well as the connections between these aspects [79].

Figure 4 shows blockchain technology in horticulture. The blockchain enables a distributed network to be established among the different entities in the supply chain for real-time monitoring and tracking of the activities from any location that is immutable and transparent. Blockchain empowers digital and secure trading to be created by incorporating smart contracts between entities. In addition, blockchain enables the realization of secured transactions of the export of fruits and vegetables in the international market. The quality and standards of the fruits and vegetables that are set by international bodies can be protected with secured hash cryptography.

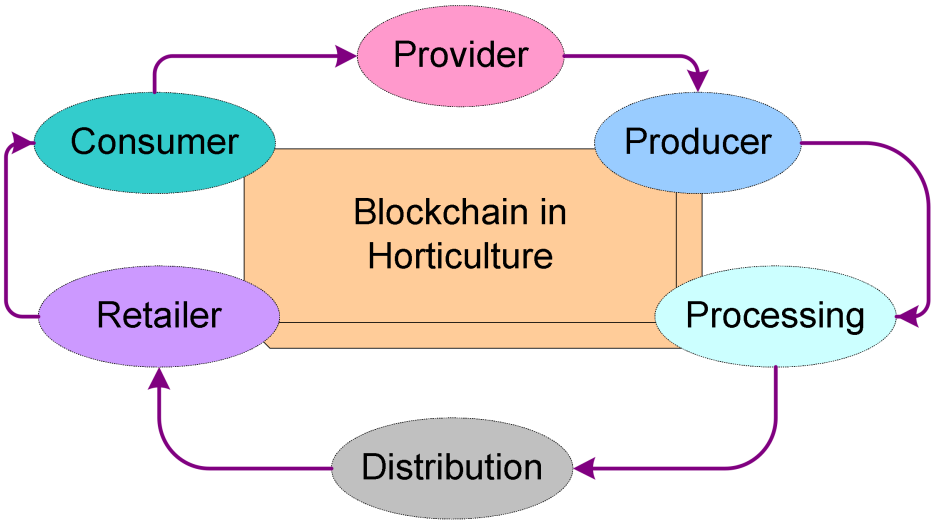


Figure 4. Blockchain technology in horticulture.

Consumers are driving an entirely different transformation in food procurement as a consequence of the growth in global food catastrophes that are triggering health insecurity. Consumers have called for transparency, traceability, and attentiveness along the entire fruit supply chain. The importance of the supply chain in this industry is increased by the fact that the products are perishable and have a limited shelf life. Yields are impacted by inconsistent delivery and a lack of fertilizers and insecticides as a result of dependence on middlemen, market instability, and other factors. Increased costs for input and transportation, post-harvest losses, and problems with safety and quality dominating supply-chain losses are key challenges involved in the fruit supply chain. Blockchain integration in the fruit supply chain (Figure 5) allows for post-harvest and inventory management streamlining, increasing operational effectiveness and lowering losses. End-to-end traceability with QR codes on the fruits presents the final customer with an honest and reliable narrative. A fair price for the producers is ensured by the grouping and collaboration of all stakeholders on a single platform, which fosters confidence and transparency. Real-time data collection

allows for simple tracking and tracing, which helps with recall management. In addition to this, blockchain is used for monitoring the pre-harvest process for yield and quality. Post-harvest management for monitoring the crucial phases to prevent losses and boost output, monitoring a set of procedures for confirming sustainable practices, and digital records that cannot be altered and display accurate information are necessary to meet legal requirements.

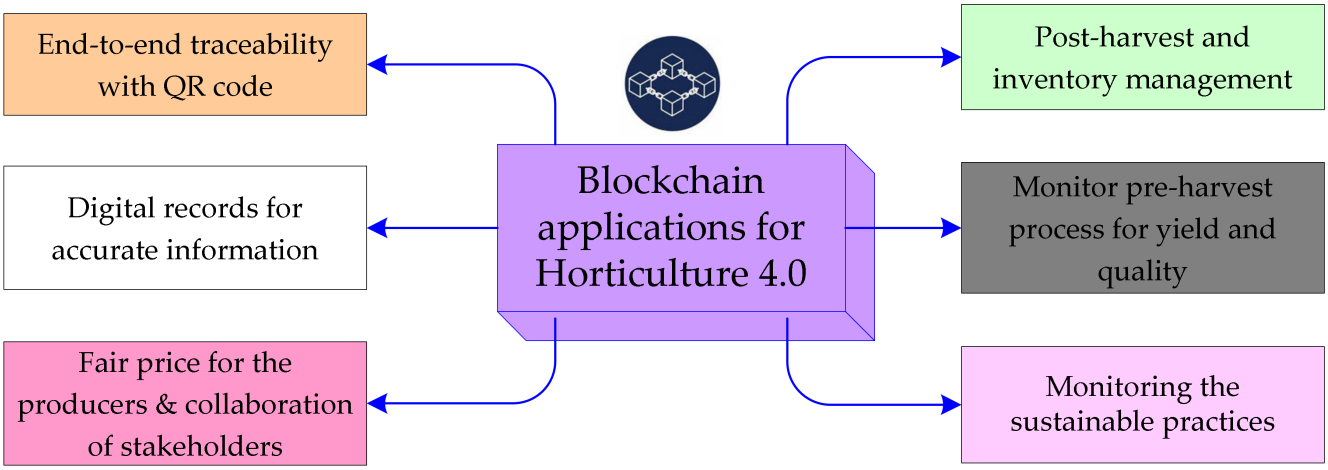


Figure 5. Applications of blockchain for Horticulture 4.0.

3.4. Big Data in Horticulture

A multi-sensor network system was established to accumulate smaller ecological statistical data on vegetable-growing regions. Researchers were able to identify the critical components pushing pest spread using multidimensional information such as environment, soil, meteorology of vegetable fields, and ultimately the vegetable-pest warning system premised on multidimensional big data [80]. The distinctive nutrition-based vegetable-production and -distribution system utilizes the inventive big-data framework and its multiple benefits to provide a healthful food recommendation to the end customer as well as various predictive analyses to boost system efficacy [45]. The new ICT horticulture project will heavily rely on big-data methodologies; therefore, it is important to understand how to manage them and how they could affect everyday business [81] Big-data intervention in horticulture is presented in Figure 6. Because fruits and vegetables are produced in such large quantities, the sensor data that are available and can be used in horticulture are now considered big data. The big data can be transmitted to the cloud server and made available in a distribution box and control box through wireless-communication protocols.

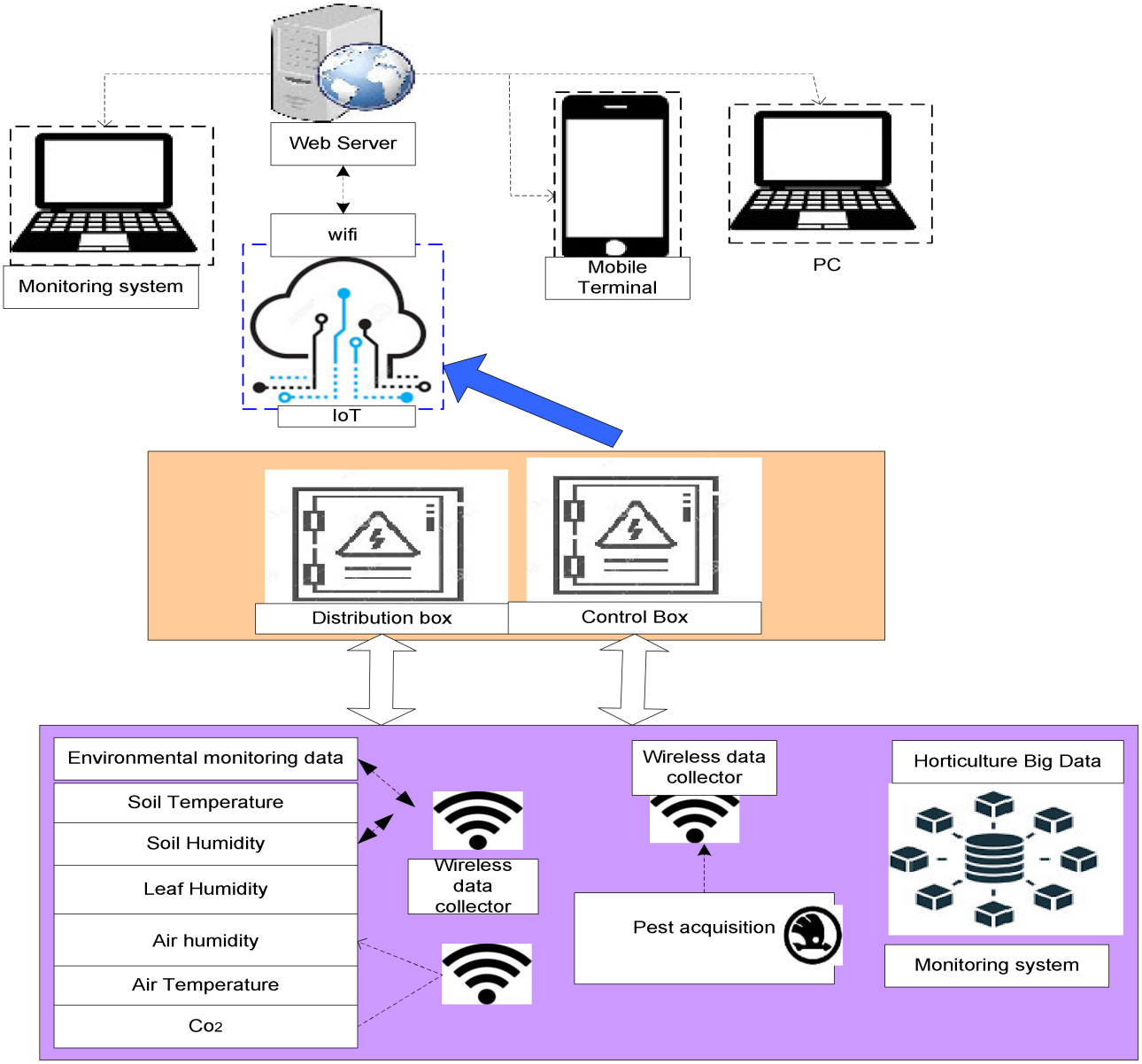


Figure 6. Big-data overview in horticulture.

4. Results

In this section, the results identified from the analysis of previous studies based on Industry 4.0 integration for horticulture monitoring are discussed.

- The IoT is predominantly used in horticulture to monitor various pests and diseases that are harmful to plants and have a serious negative impact on horticulture. The Internet of Things system was configured to minimize the frequency with which pesticides and fungicides are used and to predict when pests will appear. Along with this, IoT and cloud computing are employed to identify fruits by combining an object's three essential characteristics—color, shape, and texture. Farmers face a variety of challenges when growing vegetables, including seed issues, pest-and-disease management, commodity costs, and product marketing. Farmers can access information and engage in an interactive process about vegetable production through the internet and the concept of the mobile cloud.
- AI in horticulture enables the detection of diseases, quality assessment, and grading of horticulture crops. Linear discriminant analysis-based fully convolutional networks, random forest, competitive adaptive reweighted sampling–successive projection al-

gorithm, uninformative variable elimination, successive projection algorithm, and gray-level co-occurrence matrix have been used for feature extraction and selection. Least-squares support-vector machine, support-vector machine, convolutional neural networks, logistic regression, random forest, multilayer perceptron, and k-nearest neighbors are the key techniques used for classification and regression.

- Yields are impacted by inconsistent delivery and a lack of fertilizers and insecticides as a result of dependence on middlemen, market instability, and other factors. Increased input and transportation costs, post-harvest losses, and safety and quality issues dominate supply-chain losses. However, the incorporation of blockchain improves pre-harvest and post-harvest management through real-time tracing and secure transactions in the distributed network.

5. Discussion and Recommendation

In this section, based on the discussion of the analysis above, we discuss the recommendations for applications in horticulture as part of future work. A few vital recommendations are as follows:

- When considering long-term benefits like improved production and automation, the use of the IoT in horticulture is strongly advised and very successful. The Internet of Drones enables horticulture operations to be improved. The Internet of Drones is an architecture intended to focus on providing UAVs, also commonly known as drones, with coordinated connectivity to controlled airspace. Drones for horticulture are used to monitor fields, plant crops, irrigate fields, spray pesticides, and also to assess the health of plants [82,83]. Moreover, drones with vision-based technology and AI empower the detection of weeds and identify the stages of the growth of plants in pre-harvest, harvest, and post-harvest. Drones can be used to monitor the quality assessment and grading of horticulture crops to minimize the damage and loss of the product during transportation and storage.
- Robotics leverage AI technology to improve harvest quality and precision. In horticulture settings, robotics with vision technology and AI for the detection of pests, plant diseases, and malnutrition. Before choosing which herbicide to apply in a region, AI can detect and target weeds through the visuals obtained from the camera module inserted into robots. A wide range of issues in the farming sector can be resolved by using an amalgamation of robots and AI approaches [84]. In addition to this, currently, different robots with AI technology are used for weed removal and plucking, sorting, and packaging of fruits [85].
- Globally, horticulture supply chains have an exciting opportunity to improve transactional efficiency, reduce resistance, and promote traceability thanks to blockchain technology [80]. Blockchain technology can help the horticulture and food industry deal with and control known risks while maintaining affordability across the ecosystem. Blockchain in horticulture enables the linking of various horticultural entities for the visualization of data from production to supply on distributed-ledger networks. Granular information on rainfall patterns, water cycles, fertilizer requirements, and more are made available to farmers through big data. This enables them to make wise decisions, such as which plants to sow for greater profitability and when to harvest. Making the proper choices ultimately increase crop output. The fundamental goal of precision horticulture is to guarantee profitability, efficacy, and sustainability [86].
- In horticulture, edge computing is employed for different activities. Edge computing can be utilized to analyze the data at the edge of a network for better monitoring and productivity. Mobile edge computing (MEC) is an architecture that provides cloud-computing services at the edge of networks leveraging mobile base stations [87,88]. Currently, different study areas have implemented edge-computing-based portable devices in order to predict what is useful for the user in enhancing their practices [89,90]. In the scenario of horticulture, an edge-computing-based portable device can be developed with IoT and AI for predicting and estimating disease in a crop. Based on the

analysis and prediction, it can also communicate to the user on the cloud server and the respective horticulture authorities to suggest a solution in real-time.

- Figure 7 illustrates a hybrid architecture that is implemented in horticulture with the amalgamation of the IoT, cloud computing, AI/ML, blockchain, and big data. This architecture enables a smart and intelligent ecosystem to be achieved in horticulture with multiple features such as blockchain-assisted marketing, prediction of international markets, and the quality of fruits and vegetables based on real-time environmental data. The generated output and sensor data can then be distributed in the peer-to-peer network of any location.

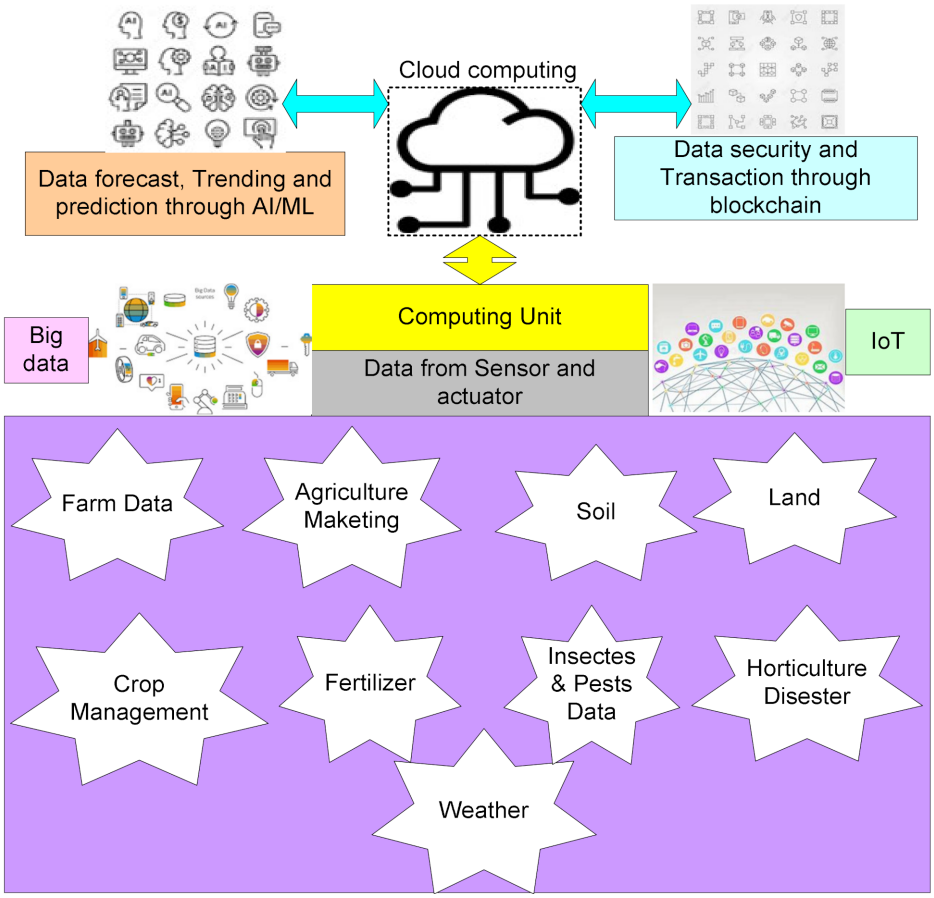


Figure 7. Hybrid architecture for Horticulture 4.0.

6. Conclusions

Horticulture is the field of cultivation of fruits and vegetables. It ensures production and consumption by minimizing malnutrition in the current scenario addressed by United Nations. Recently, Industry 4.0 technologies have delivered the ability of digitalization and realize the SDGs set by the United Nations. The previous studies did not highlight the significance and application of Industry 4.0 for distinct issues of horticulture. Based on this limitation, the current study addressed the significance and application of Industry 4.0 technologies such as the Internet of Things, cloud computing, artificial intelligence, blockchain, and big data for horticulture to enhance traditional practices of disease detection, irrigation management, fertilizer management, maturity identification, marketing, and supply chain, soil fertility, and weather patterns at pre-harvest, harvest, and post-harvest.

The findings of the study are as follows: in horticulture, the IoT is primarily used to monitor various pests and diseases that are harmful to plants and have a serious negative impact on horticulture. In addition, IoT and cloud computing is used to identify fruits by combining three essential characteristics of an object: color, shape, and texture.AI in horticulture has enabled the detection of diseases, quality assessment, and crop grading.

For feature extraction and selection, we used fully convolutional networks, a random forest, and a competitive adaptive reweighted sampling–successive projection algorithm based on linear discriminant analysis. The key techniques used for classification and regression are the least-squares support-vector machine, support-vector machine, convolutional neural networks, logistic regression, multilayer perceptron, and k-nearest neighbors. Inconsistent delivery and a lack of fertilizers and insecticides as an outcome of dependence on middlemen, market instability, and other factors have a negative impact on yields. Increased input and transportation costs, post-harvest losses, and safety and quality issues that dominate supply-chain losses can be overcome with blockchain during-harvest and post-harvest management. Finally, the study suggested vital recommendations for future works, such as robotics; drones with vision technology and AI for the detection of pests, weeds, plant diseases, and malnutrition; and edge computing portable devices developed with the IoT and AI for predicting and estimating disease in crops.

Author Contributions: Conceptualization, R.S. (Rajesh Singh) and R.S. (Rajat Singh); methodology, A.G.; formal analysis, S.V.A.; data curation, S.V.A.; writing—original draft preparation, R.S. (Rajat Singh); writing—review and editing, N.P. and B.T.; visualization, R.S. (Rajesh Singh) and A.G.; funding acquisition, N.P. and B.T. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by Tshwane University of Technology, South Africa.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. UN Report: Global Hunger Numbers Rose to as Many as 828 Million in 2021. Available online: https://www.fao.org/newsroom/detail/un-report-global-hunger-SOFI-2022-FAO/en (accessed on 6 September 2022).
2. Goal 2: Zero Hunger-United Nations Sustainable Development. Available online: https://www.un.org/sustainabledevelopment/hunger/ (accessed on 6 September 2022).
3. Goal 12. Department of Economic and Social Affairs. Available online: https://sdgs.un.org/goals/goal12 (accessed on 6 September 2022).
4. Keatinge, J.D.H.; Virchow, D.; Schreinemachers, P. Horticulture for sustainable development: Evidence for impact of international vegetable research and development. In Proceedings of the International Symposia on Tropical and Temperate Horticulture-ISTTH2016 1205, Cairns, Australia, 20 November 2016; pp. 179–190.
5. Qingxue, L.; Wu, H. Research on vegetable growth monitoring platform based on facility agricultural IoT. In *International Conference on Geo-Informatics in Resource Management and Sustainable Ecosystem*; Springer: Singapore, 2016.
6. Cappelli, I.; Fort, A.; Pozzebon, A.; Tani, M.; Trivellin, N.; Vignoli, V.; Bruzzi, M. Autonomous IoT Monitoring Matching Spectral Artificial Light Manipulation for Horticulture. *Sensors* **2022**, *22*, 4046. [CrossRef]
7. Lamm, K.; Powell, A.; Lombardini, L. Identifying Critical Issues in the Horticulture Industry: A Delphi Analysis during the COVID-19 Pandemic. *Horticulturae* **2021**, *7*, 416. [CrossRef]
8. Bhavana, H.; Bhagwan, A. Review on: Role of robotics in horticulture. *J. Pharm. Phytochem.* **2021**, *10*, 306–309.
9. Yang, B.; Xu, Y. Applications of deep-learning approaches in horticultural research: A review. *Hortic. Res.* **2021**, *8*, 123. [CrossRef]
10. Ariesen-Verschuur, N.; Verdouw, C.; Tekinerdogan, B. Digital Twins in greenhouse horticulture: A review. *Comput. Electron. Agric.* **2022**, *199*, 107183. [CrossRef]
11. Halgamuge, M.N.; Bojovschi, A.; Fisher, P.M.; Le, T.C.; Adeloju, S.; Murphy, S. Internet of Things and autonomous control for vertical cultivation walls towards smart food growing: A review. *Urban For. Urban Green* **2021**, *61*, 127094. [CrossRef]
12. Longchamps, L.; Tisseyre, B.; Taylor, J.; Sagoo, L.; Momin, A.; Fountas, S.; Manfrini, L.; Ampatzidis, Y.; Schueller, J.K.; Khosla, R. Yield sensing technologies for perennial and annual horticultural crops: A review. *Precis. Agric.* **2022**, 1–42. [CrossRef]
13. Jallow, M.F.A.; Awadh, D.G.; Albaho, M.S.; Devi, V.Y.; Ahmad, N. Monitoring of Pesticide Residues in Commonly Used Fruits and Vegetables in Kuwait. *Int. J. Environ. Res. Public Health* **2017**, *14*, 833. [CrossRef]
14. Bulgari, R.; Petrini, A.; Cocetta, G.; Nicoletto, C.; Ertani, A.; Sambo, P.; Ferrante, A.; Nicola, S. The Impact of COVID-19 on Horticulture: Critical Issues and Opportunities Derived from an Unexpected Occurrence. *Horticulturae* **2021**, *7*, 124. [CrossRef]
15. Rehman, M.U.; Rather, G.H.; Gull, Y.; Mir, M.R.; Mir, M.M.; Waida, U.I.; Hakeem, K.R. Effect of climate change on horticultural crops. In *Crop Production and Global Environmental Issues*; Springer: Cham, Switzerland; pp. 211–239.

16. Eftekhari, M.S. Impacts of Climate Change on Agriculture and Horticulture. In *Climate Change*; Bandh, S.A., Ed.; Springer: Cham, Switzerland, 2022. [CrossRef]
17. Saran, P.L.; Singh, S.; Solanki, V.; Choudhary, R.; Manivel, P. Evaluation of Asparagus adscendens accessions for root yield and shatavarin IV content in India. *Turk. J. Agric. For.* **2021**, *45*, 8. [CrossRef]
18. Zulfiqar, F. Effect of seed priming on horticultural crops. *Sci. Hortic.* **2021**, *286*, 110197. [CrossRef]
19. Grygorieva, O.; Klymenko, S.; Kuklina, A.; Vinogradova, Y.; Vergun, O.; Sedlackova, V.H.; Brindza, J. Evaluation of Lonicera caerulea L. genotypes based on morphological characteristics offruits germplasm collection. *Turk. J. Agric. For.* **2021**, *45*, 14. [CrossRef]
20. Mall, M.; Kumar, R.; Akhtar, M.Q. Horticultural crops and abiotic stress challenges. In *Stress Tolerance in Horticultural Crops*; Woodhead Publishing: Sawston, UK, 2021; pp. 1–19.
21. Alireza, A.; Dennis, R.; Ludena, A. Big data application to the vegetable production and distribution system. In Proceedings of the 2014 IEEE 10th International Colloquium on Signal Processing and Its Applications, Kuala Lumpur, Malaysia, 7–9 March 2014.
22. Kaburuan, E.R.; Jayadi, R. A design of IoT-based monitoring system for intelligence indoor micro-climate horticulture farming in Indonesia. *Procedia Comput. Sci.* **2019**, *157*, 459–464. [CrossRef]
23. Alem, Č.; Hadžialić, M. Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues. *Comput. Netw.* **2018**, *144*, 17–39.
24. Mohammad Nuruzzaman, B.; Rahman, M.; Billah, M.; Saha, D. Internet of things (IoT): A review of its enabling technologies in healthcare applications, standards protocols, security, and market opportunities. *IEEE Internet Things J.* **2021**, *8*, 10474–10498.
25. Kais, M.; Bajic, E.; Chaxel, F.; Meyer, F. A comparative study of LPWAN technologies for large-scale IoT deployment. *ICT Express* **2019**, *5*, 1–7.
26. Arya, P.S.; Gangwar, M. A Proposed Architecture: Detecting Freshness of Vegetables using Internet of Things (IoT) & Deep Learning Prediction Algorithm. In Proceedings of the 2021 3rd International Conference on Advances in Computing, Communication Control and Networking (ICAC3N), Greater Noida, India, 17–18 December 2021; pp. 718–723. [CrossRef]
27. Caiming, Z.; Lu, Y. Study on artificial intelligence: The state of the art and future prospects. *J. Ind. Inf. Integr.* **2021**, *23*, 100224.
28. Sagiroglu, S.; Sinanc, D. Big data: A review. In Proceedings of the 2013 International Conference on Collaboration Technologies and Systems (CTS), San Diego, CA, USA, 20–24 May 2013; pp. 42–47. [CrossRef]
29. Yosra, H.; Boulila, W.; Farah, I.R.; Romdhani, I.; Hussain, A. Big data and IoT-based applications in smart environments: A systematic review. *Comput. Sci. Rev.* **2021**, *39*, 100318.
30. Mohd, J.; Haleem, A.; Singh, R.P.; Khan, S.; Suman, R. Blockchain technology applications for Industry 4.0: A literature-based review. *Blockchain Res. Appl.* **2021**, *2*, 100027.
31. Alireza, A.; Ludena, R.D.A. Big Data approach to a novel nutrition-based vegetable production and distribution system. In Proceedings of the 2013 IEEE International Conference on Computational Intelligence and Cybernetics (CYBERNETICSCOM), Yogyakarta, Indonesia, 3–4 December 2013.
32. Kumar, P.C.; Bhatnagar, R. Social internet of things in agriculture: An overview and future scope. In *Toward Social Internet of Things (SIoT): Enabling Technologies, Architectures and Applications*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 317–334.
33. Sun, Z.; Hui, X.; Wensheng, W. An architecture for the agricultural machinery intelligent scheduling in cross-regional work based on cloud computing and internet of things. In *International Conference on Computer and Computing Technologies in Agriculture*; Springer: Berlin/Heidelberg, Germany, 2010.
34. Coble, K.H.; Mishra, A.K.; Ferrell, S.; Griffin, T. Big data in agriculture: A challenge for the future. *Appl. Econ. Perspect. Policy* **2018**, *40*, 79–96. [CrossRef]
35. Ruthie, M. Big data in agriculture and nutrition. *Agric. Improv. Nutr. Seizing Momentum* **2019**, *142*, 1–15.
36. Kamilaris, A.; Fonts, A.; Prenafeta-Boldύ, F.X. The rise of blockchain technology in agriculture and food supply chains. *Trends Food Sci. Technol.* **2019**, *91*, 640–652. [CrossRef]
37. Codeluppi, G.; Cilfone, A.; Davoli, L.; Ferrari, G. VegIoT garden: A modular IoT management platform for urban vegetable gardens. In Proceedings of the 2019 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), Portici, Italy, 24–26 October 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 121–126.
38. Salgado-Salazar, C.; Shiskoff, N.; Daughtrey, M.; Palmer, C.L.; Crouch, J.A. Downy mildew: A serious disease threat to rose health worldwide. *Plant Dis.* **2018**, *102*, 1873–1882. [CrossRef] [PubMed]
39. Feng, C.; Wu, H.R.; Zhu, H.J.; Sun, X. The design and realization of apple orchard intelligent monitoring system based on internet of things technology. In *Advanced Materials Research*; Trans Tech Publications Ltd.: Bäch, Switzerland, 2012; Volume 546, pp. 898–902.
40. Zhang, H.; He, L.; Di Gioia, F.; Choi, D.D.; Heinemann, P. Internet of things (IoT)-based precision irrigation with LoRaWAN technology applied to vegetable production. In *2021 ASABE Annual International Virtual Meeting*; American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA, 2021; p. 1.
41. Khan, F.A.; Ibrahim, A.A.; Zeki, A.M. Environmental monitoring and disease detection of plants in smart greenhouse using internet of things. *J. Phys. Commun.* **2020**, *4*, 055008. [CrossRef]
42. Bhujel, A.; Basak, J.K.; Khan, F.; Arulmozhi, E.; Jaihuni, M.; Sihalath, T.; Lee, D.; Park, J.; Kim, H.T. Sensor Systems for Greenhouse Microclimate Monitoring and Control: A Review. *J. Biosyst. Eng.* **2020**, *45*, 341–361. [CrossRef]

43. Wayangkau, I.H.; Mekiuw, Y.; Rachmat, R.; Suwarjono, S.; Hariyanto, H. Utilization of IoT for soil moisture and temperature monitoring system for onion growth. *Emerg. Sci. J.* **2020**, *4*, 102–115. [CrossRef]
44. Alper, M.A.; Sokullu, R. An IoT-based greenhouse monitoring system with Micaz motes. *Procedia Comput. Sci.* **2017**, *113*, 603–608.
45. Dennis, A.L.R.; Ahrary, A.; Horibe, N.; Yang, W.S. IoT-security approach analysis for the novel nutrition-based vegetable production and distribution system. In Proceedings of the 3rd IIAI International Conference on Advanced Applied Informatics, IIAI-AAI 2014, Kokura Kita-ku, Japan, 31 August–4 September 2014.
46. Jie, Y.; Zhang, X.; Lu, Q.; Xin, C.; Liu, C.; Chen, Z. IOT based provenance platform for vegetables supplied to Hong Kong. In *Recent Advances in Computer Science and Information Engineering*; Springer: Berlin/Heidelberg, Germany, 2012; pp. 591–596.
47. Harish, M.P.C.S.P.; Sanghavi, K.B.P.A. Smart refrigerator and vegetable identification system using image processing and IOT. *Open Access Int. J. Sci. Eng.* **2021**, *7*, 4.
48. Kumar, M.; Pal, Y.; Gangadharan, S.M.P.; Chakraborty, K.; Yadav, C.S.; Kumar, H.; Tiwari, B. Apple Sweetness Measurement and Fruit Disease Prediction Using Image Processing Techniques Based on Human-Computer Interaction for Industry 4.0. *Wirel. Commun. Mob. Comput.* **2022**, *2022*, 1–12.
49. Rajasekar, L.; Sharmila, D. Performance analysis of soft computing techniques for the automatic classification of fruits dataset. *Soft Comput.* **2019**, *23*, 2773–2788. [CrossRef]
50. John, K.; Haw, S.; Su, N.; Mulaafer, S. Kiwi Fruit IoT Shelf Life Estimation During Transportation with Cloud Computing. In Proceedings of the 2021 IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET), Kota Kinabalu, Malaysia, 13–15 September 2021.
51. Shwetapadma, P.; Sethy, P.K. Post-Harvest Grading Of Carica Papaya Fruit Using Image Segmentation And Soft Computing. *Int. J. Adv. Res. Comput. Sci.* **2017**, *8*, 7.
52. Yaya, W.; Nugraha, E. Development Mobile Learning For Vegetable Farming In Indonesia Based On Mobile Cloud Computing. In Proceedings of the 2020 6th International Conference on Science in Information Technology (ICSITech), Palu, Indonesia, 21–22 October 2020.
53. Narendra, V.G.; Ancilla, J.P. Defects Detection in Fruits and Vegetables Using Image Processing and Soft Computing Techniques. In *International Conference on Harmony Search Algorithm*; Springer: Singapore, 2020.
54. Silke, H.; de Zwart, F.; Elings, A.; Petropoulou, A.; Righini, I. Cherry Tomato Production in Intelligent Greenhouses—Sensors and AI for Control of Climate, Irrigation, Crop Yield, and Quality. *Sensors* **2020**, *20*, 6430. [CrossRef]
55. Kingsley, J.; Isong, I.A.; Kebonye, N.M.; Ayito, E.O.; Agyeman, P.C.; Afu, S.M. Using Machine Learning Algorithms to Estimate Soil Organic Carbon Variability with Environmental Variables and Soil Nutrient Indicators in an Alluvial Soil. *Land* **2020**, *9*, 487. [CrossRef]
56. Yousef, A.-G.; Aghabara, A.; Davari, M.; Maja, J.M. Feasibility of Using Computer Vision and Artificial Intelligence Techniques in Detection of Some Apple Pests and Diseases. *Appl. Sci.* **2022**, *12*, 906. [CrossRef]
57. Diaz-Gonzalez, F.A.; Vuelvas, J.; Correa, C.A.; Vallejo, V.E.; Patino, D. Machine learning and remote sensing techniques applied to estimate soil indicators–Review. *Ecol. Indicators* **2022**, *135*, 108517. [CrossRef]
58. Maione, C.; Araujo, E.M.; Santos-Araujo, S.N.D.; Boim, A.G.F.; Barbosa, R.M.; Alleoni, L.R.F. Determining the geographical origin of lettuce with data mining applied to micronutrients and soil properties. *Sci. Agric.* **2021**, *79*, e20200011. [CrossRef]
59. Chen, J.; Zhang, M.; Xu, B.; Sun, J.; Mujumdar, A.S. Artificial intelligence assisted technologies for controlling the drying of fruits and vegetables using physical fields: A review. *Trends Food Sci. Technol.* **2020**, *105*, 251–260. [CrossRef]
60. Sreeraj, M.; Joy, J.; Kuriakose, A.; Sujith, M.R.; Unni, H. CLadron*: AI assisted device for identifying artificially ripened climacteric fruits. *Procedia Comput. Sci.* **2020**, *171*, 635–643. [CrossRef]
61. Bittu, S.; Aziz, N.A.; Siddiqi, M.A.M. AI Based Robotic Systems for the quality control of Date Palm Fruits-A Review. In Proceedings of the 2019 International Conference on Digitization (ICD), Sharjah, United Arab Emirates, 18–19 November 2019.
62. Hu, M.H.; Zhai, G.T.; Zhao, Y.; Wang, Z.D. Uses of selection strategies in both spectral and sample spaces for classifying hard and soft blueberry using near infrared data. *Sci. Rep.* **2018**, *8*, 6671. [CrossRef]
63. Zhang, M.; Jiang, Y.; Li, C.; Yang, F. Fully convolutional networks for blueberry bruising and calyx segmentation using hyperspectral transmittance imaging. *Biosyst. Eng.* **2020**, *192*, 159–175. [CrossRef]
64. Wang, Z.; Hu, M.; Zhai, G. Application of Deep Learning Architectures for Accurate and Rapid Detection of Internal Mechanical Damage of Blueberry Using Hyperspectral Transmittance Data. *Sensors* **2018**, *18*, 1126. [CrossRef]
65. Kuzy, J.; Jiang, Y.; Li, C.Y. Blueberry bruise detection by pulsed thermographic imaging. *Postharvest. Biol. Technol.* **2018**, *136*, 166–177. [CrossRef]
66. Shao, Y.Y.; Wang, Y.X.; Xuan, G.T.; Gao, Z.M.; Hu, Z.C.; Gao, C.; Wang, K.L. Assessment of strawberry ripeness using hyperspectral imaging. *Anal. Lett.* **2020**, *54*, 1547–1560. [CrossRef]
67. Qiao, S.C.; Tian, Y.W.; Song, P.; He, K.; Song, S.Y. Analysis and detection of decayed blueberry by low field nuclear magnetic resonance and imaging. *Postharvest. Biol. Technol.* **2019**, *156*, 110951. [CrossRef]
68. Ren, A.; Zahid, A.; Zoha, A.; Shah, S.A.; Imran, M.A.; Alomainy, A.; Abbasi, Q.H. Machine Learning Driven Approach Towards the Quality Assessment of Fresh Fruits Using Non-Invasive Sensing. *IEEE Sens. J.* **2020**, *20*, 2075–2083. [CrossRef]
69. Rebortera, M.A.; Fajardo, A.C. An enhanced deep learning approach in forecasting banana harvest yields. *Int. J. Adv. Comput. Sci. Appl.* **2019**, *10*, 275–280. [CrossRef]

70. Ni, X.; Li, C.; Jiang, H.; Takeda, F. Deep learning image segmentation and extraction of blueberry fruit traits associated with harvestability and yield. *Hortic. Res.* **2020**, *7*, 110. [CrossRef] [PubMed]
71. Brahimi, M.; Boukhalfa, K.; Moussaoui, A. Deep learning for tomato diseases: Classification and symptoms visualization. *Appl. Artif. Intell.* **2017**, *31*, 299–315. [CrossRef]
72. Wang, D.; Li, C.; Song, H.; Xiong, H.; Liu, C.; He, D. Deep Learning Approach for Apple Edge Detection to Remotely Monitor Apple Growth in Orchards. *IEEE Access* **2020**, *8*, 26911–26925. [CrossRef]
73. Kang, H.; Chen, C. Fruit detection and segmentation for apple harvesting using visual sensor in orchards. *Sensors* **2019**, *19*, 4599. [CrossRef]
74. Kang, H.; Chen, C. Fast implementation of real-time fruit detection in apple orchards using deep learning. *Comput. Electron. Agric.* **2020**, *168*, 105108. [CrossRef]
75. Csillik, O.; Cherbini, J.; Johnson, R.; Lyons, A.; Kelly, M. Identification of citrus trees from unmanned aerial vehicle imagery using convolutional neural networks. *Drones* **2018**, *2*, 39. [CrossRef]
76. Rafael, P.; Shi, E. Fruitchains: A fair blockchain. In Proceedings of the ACM Symposium on Principles of Distributed Computing, Washington, DC, USA, 25–27 July 2017.
77. Zhang, Y.; Chen, L.; Battino, M.; Farag, M.A.; Xiao, J.; Simal-Gandara, J.; Jiang, W. Blockchain: An emerging novel technology to upgrade the current fresh fruit supply chain. *Trends Food Sci. Technol.* **2022**, *124*, 1–22. [CrossRef]
78. Arsenii, S. Traceability technology: Fruits and vegetables trader case study. In Proceedings of the International Conference on Digital Technologies in Logistics and Infrastructure (ICDTLI 2019), St. Petersburg, Russia, 4–5 April 2019; Atlantis Press: Hong Kong, China, 2019.
79. Sharif, K.I.M.; Hassan, M.G.; Miraz, M.H.; Zulkifly, E.; Udin, Z.M.; Omar, M. Factors Affecting Blockchain in Fruit Retail Market: An Unveiling Myth of Blockchain. In *Intelligent Manufacturing and Mechatronics*; Springer: Singapore, 2021; pp. 1095–1106.
80. Zhang, C.; Cai, J.; Xiao, D.; Ye, Y.; Chehelamirani, M. Research on vegetable pest warning system based on multidimensional big data. *Insects* **2018**, *9*, 66. [CrossRef] [PubMed]
81. Puri, V.; Nayyar, A.; Raja, L. Agriculture drones: A modern breakthrough in precision agriculture. *J. Stat. Manag. Syst.* **2017**, *20*, 507–518. [CrossRef]
82. Tripicchio, P.; Satler, M.; Dabisias, G.; Ruffaldi, E.; Avizzano, C.A. Towards smart farming and sustainable agriculture with drones. In Proceedings of the 2015 International Conference on Intelligent Environments, Prague, Czech Republic, 15–17 July 2015; pp. 140–143.
83. Gharibi, M.; Boutaba, R.; Waslander, S.L. Internet of Drones. *IEEE Access* **2016**, *4*, 1148–1162. [CrossRef]
84. Rajan, K.; Saffiotti, A. Towards a science of integrated AI and Robotics. *Artif. Intell.* **2017**, *247*, 1–9. [CrossRef]
85. Vivekanand, P.; Pant, M.; Snasel, V. Blockchain technology in food supply chains: Review and bibliometric analysis. *Technol. Soc.* **2022**, *69*, 101954.
86. Abbas, N.; Zhang, Y.; Taherkordi, A.; Skeie, T. Mobile Edge Computing: A Survey. *IEEE Internet Things J.* **2018**, *5*, 450–465. [CrossRef]
87. Shi, W.; Cao, J.; Zhang, Q.; Li, Y.; Xu, L. Edge computing: Vision and challenges. *IEEE Internet Things J.* **2016**, *3*, 637–646. [CrossRef]
88. Satyanarayanan, M. The Emergence of Edge Computing. *Computer* **2017**, *50*, 30–39. [CrossRef]
89. Chang, Z.; Liu, S.; Xiong, X.; Cai, Z.; Tu, G. A Survey of Recent Advances in Edge-Computing-Powered Artificial Intelligence of Things. *IEEE Internet Things J.* **2021**, *8*, 13849–13875. [CrossRef]
90. Guillén, M.A.; Llanes, A.; Imbernón, B.; Martínez-España, R.; Bueno-Crespo, A.; Cano, J.-C.; Cecilia, J.M. Performance evaluation of edge-computing platforms for the prediction of low temperatures in agriculture using deep learning. *J. Supercomput.* **2021**, *77*, 818–840. [CrossRef]