Chapter

Applications of AI and IoT for Advancing Date Palm Cultivation in Saudi Arabia

Maged Mohammed, Nashi K. Alqahtani, Muhammad Munir and Mohamed A. Eltawil

Abstract

Date palm cultivation is an essential part of Saudi Arabia's economy. However, it faces several challenges: water scarcity, improper farm management, pests and diseases, inadequate farming practices, processing and marketing, and labor shortages. Artificial intelligence (AI) and the Internet of Things (IoT) can help enrich crop management, enable predictive analytics, increase efficiency, and promote sustainability in date palm cultivation. Recently, interest in this sector has begun by applying the latest precision engineering technologies integrated with AI and IoT techniques to address these challenges. This chapter aims to provide an overview of the applications of AI and IoT-based technologies, such as sensors, ML algorithms, and data analytics, and their potential benefits and challenges in supporting date palm cultivation in Saudi Arabia. Specifically, the applications of AI and IoT in smart precision irrigation, smart systems, cold storage management, pest infestation prediction, and date fruit quality optimization. In addition, the potential economic and environmental benefits of using AI and IoT in date palm cultivation in Saudi Arabia and the challenges that need to be addressed to realize these benefits fully. The chapter provides insight into the latest developments and future directions for AI and IoT in date palm cultivation, providing valuable information for researchers and policymakers.

Keywords: artificial intelligence, artificial neural networks, machine learning, prediction, estimation, precision agriculture, intelligent systems

1. Introduction

The agriculture sector worldwide has experienced significant changes recently, which have altered daily farm work activities. Due to the decrease in profit of certain farming businesses, the intensification of agricultural operations has followed, which has resulted in a diversification of farm activities. However, due to increasing industrial regulation, the agriculture sector's mechanization and automation have significantly influenced the qualitative transformation of farmers' daily work activities and those of the entire farming community globally. The farming industry has transformed because of new machinery, technological advancements, genetically modified seeds, new fertilizers, and organic and sustainable farming. Innovative technologies are becoming increasingly crucial in the agriculture industry as a tool for sustainable development. Agriculture automation is a valuable strategy that has enhanced product quality while reducing production costs and manual labor and improving environmental sustainability. Automation in farming equipment, irrigation and fertigation systems, climate control, pest and disease management, and soil fertility contribute significantly to agricultural productivity [1–6].

Artificial intelligence (AI) can help farmers improve crop yields, reduce biomass waste, and make better decisions. To build precise maps of crops and soil, AI is used to analyze data recorded from sensors, drones, and satellites. The data is used to optimize fertilizer, irrigation application, and pest control. AI-driven irrigation systems, for instance, regulate watering schedules based on weather patterns and soil moisture levels, lowering water usage and boosting agricultural yields. AI technology is also used for crop monitoring purposes. It examines satellite or drone-shot images of crops to spot problem regions. For instance, it can spot disease or nutritional deficiency symptoms before they appear to the naked eye. Farmers are then able to take measures before the issue gets worse. AI also analyzes historical data on weather patterns, soil conditions, and crop yields to predict future outcomes. This information can be used to optimize planting schedules, predict crop yields, and identify areas at risk of crop failure. Drones and robots with AI capabilities can perform many on-farm tasks, from planting seeds to harvesting crops. As a result, less manual labor is required, and crop productivity increases. The health and well-being of livestock can be monitored using AI technology. It can, for instance, examine sensor data from animals to find symptoms of certain diseases [7–15].

Internet of Things (IoT) is a network of devices that sense real-time conditions and then trigger actions to respond, but many IoT applications require more complex rules to link triggers and responses. IoT applications in agriculture use sensors and other connected devices to collect real-time data and automate farming operations, leading to better efficiency, decreased costs, and improved yields. The agriculture sector is undergoing a revolution because AI and IoT technologies provide farmers access to real-time data and insights that help them make precise decisions. Integrating AI and IoT in agriculture improves farm productivity, reduces waste, and optimizes crop yield. In order to collect real-time data on crop health, soil moisture, and meteorological conditions, IoT technology is being employed in agriculture. This data can be collected by sensors placed around a farm and transmitted to a central database for AI algorithm analysis. This enables farmers to decide on irrigation, fertilizer, and other farming practices. AI and IoT in agriculture help lessen the environmental effects of farming in addition to increasing crop yields and minimizing waste. Farmers can reduce the use of pesticides and fertilizers, consume less water, and produce less greenhouse gas emissions by optimizing their farming operations [5, 16–22].

The AI and IoT paradigms have seen widespread adoption by numerous businesses in recent years. Modern precision agriculture practices are largely mechanized and are integrated with effective and well-developed AI and IoT technologies. Although the concept of the IoT and AI is not new, it has recently gained massive popularity, mainly because of the upgradation in hardware technology over the past decade. AI and IoT technologies rapidly transform the agriculture sector through increased production, cost savings, and sustainability. Moreover, contemporary precision agriculture research has recently amalgamated with machine learning (ML) techniques to devise innovative solutions for agricultural challenges. Robots, drones, remote sensors, computer and satellite imagery, constantly evolving ML models, and analytical equipment are used in the AI and IoT to monitor crop and livestock, storage rooms, macro-, and microclimate, survey, and field mapping in real time, as well as to provide data to farmers for logical farm management strategies that will not only simple, time, and resources saving but also improve crop production. These technologies are, therefore, increasingly being employed in the agriculture sector to support more environment-friendly on-farm operations and improve ecological sustainability, all while maintaining the financial stability of farming enterprises [15, 23–27].

Date palm (*Phoenix dactylifera* L.) cultivation is an essential economic activity in many arid regions, including Saudi Arabia. Despite its economic importance, date palm cultivation faces several challenges, including water scarcity, pests and diseases, climate change, and the lack of postharvest processing technologies [28]. To address these challenges, there is a need for innovative and advanced solutions that can improve crop management and increase water use efficiency in date palm cultivation [29]. Recent AI and IoT advances can transform agriculture by providing real-time data on fruit quality, tissue culture systems, crop health, soil moisture content, and meteorological conditions [30]. In addition, using AI and IoT technologies in date palm cultivation can bring several environmental benefits, including optimized water use, reduced pesticide use, and improved soil health. Date palm cultivation is also water-intensive and can strain local water resources. AI and IoT technologies can bring several environmental benefits to date palm cultivation. One potential benefit of using AI and IoT in date palm cultivation is water use optimization.

By installing sensors in the soil and on the trees, farmers can monitor soil moisture levels and adjust irrigation accordingly. AI algorithms can analyze the data collected by these sensors and recommend when and how much water to apply. This can help reduce water waste and increase water use efficiency, particularly in areas with limited water resources. Another potential benefit is the reduction of pesticides and fungicides. IoT devices, such as drones equipped with cameras and sensors. Can detect pest and disease infestations early, allowing farmers to act before the infestation becomes widespread. AI algorithms can also analyze data from these devices to recommend the most effective and least harmful pesticides and fungicides. This can reduce the amount of these toxic chemicals used in date palm cultivation, positively affecting local ecosystems. Using AI and IoT in date palm cultivation can also improve soil health. By monitoring soil bionomics, moisture content, nutrient levels, and other factors, farmers can adjust their fertilization practices to ensure that they provide their trees with the nutrients they need while minimizing excess fertilizer application. This can help reduce soil degradation and improve overall health [31–34]. However, there is a lack of review research and book chapters on the application of AI and IoT in date palm cultivation, particularly in Saudi Arabia. Previous books and research on the application of AI and IoT in agriculture have focused primarily on different crops, with limited attention given to date palm cultivation.

Furthermore, most previous research has been conducted in temperate regions, where farmers face challenges that differ from those in arid regions, such as Saudi Arabia. Therefore, this chapter aims to address these gaps in knowledge by investigating the applications of AI and IoT-based technologies, such as sensors, machine learning algorithms, and data analytics, and their potential benefits and challenges for promoting sustainability and advancing date palm cultivation in Saudi Arabia. In addition, the chapter discusses the challenges that must be addressed to realize the full benefits of using AI and IoT in date palm cultivation. By providing insight into the modern developments and future trends for AI and IoT in date palm cultivation, the chapter provides valuable information for researchers and policymakers interested in using these technologies in arid regions.

The rest of the chapter is structured as follows: First, we introduce the importance and challenges of date palm cultivation in Section 2, Section 3 describes AI and IoT technologies, Section 4 provides an overview of applications of AI and IoT in agriculture, Section 5 details benefits and application of AI and IoT in date palm cultivation, Section 6 indicates the challenges of implementing ai and AI and IoT in date palm cultivation, Section 7 suggests future opportunities for AI and IoT in date palm cultivation, and Section 8 concludes the work.

2. Importance and challenges of date palm cultivation

Date palm is commonly grown in arid- and semiarid regions of the world on 1.31 million hectares and produces 9.82 million tons of fruit yearly. In Saudi Arabia, date palm is a major fruit crop in dry regions of North Africa, the Middle East, and parts of Asia, which provides food, nutrition, and building materials to the inhabitants and other byproducts. More than 120 million date palm trees are worldwide, and more than 84 million trees are grown in the Arab world (Egypt, Iraq, Saudi Arabia, Algeria, Morocco, Tunisia, and the United Arab Emirates). Arab countries have 70% of the world's date palm trees, contributing 67% of global production. More than 23 million date palm trees are grown in Saudi Arabia on 152,734 hectares of land, which yield 1.57 million tons of dates annually [35–38].

The cultivation of date palms in Saudi Arabia is significant for several reasons, including its economic importance. The date palm industry is labor-intensive and helps both males and females by generating revenue and jobs. Due to increased employment prospects in rural areas, widespread migration to cities is lessened. Women have a significant role, especially during the palm propagation stages (using *in vitro* or conventional methods) and postharvest stages, including packaging and marketing. Date production and trading help local economies and serve as a source of revenue for farmers and exporters. Over the past few decades, Saudi Arabia's agricultural sector, particularly the date palm sector, has experienced tremendous growth and support [39–43].

Many countries in the Middle East and North Africa, such as Saudi Arabia, Iran, Iraq, Egypt, and Tunisia, rely substantially on the export of dates. In 2021, Saudi Arabia was the leading global exporter of fresh or dried dates, with an export value of about 322.84 million USD [44]. However, the production and profitability of Saudi Arabia's date palm producers are constrained by several challenges. These challenges include water scarcity due to the depletion of groundwater, soil degradation by salinization, soil erosion, and desertification due to the loss of vegetation cover by overgrazing and overharvesting of wood for fuel, insect pest infestations, disease, an insufficient number of processing and packaging facilities and technologies, environmental pollution, and a decline in consumer demand for date fruit [29, 38, 45–47].

In Saudi Arabia, water scarcity is one of the biggest challenges that date palm producers face. The country's freshwater reservoirs are scarce, and most water sources are saline. As a result of the country's limited water resources, the agricultural sector consumes ca. 90% of the water. Due to the substantial water requirements of date palms, farmers have experienced decreased yields and elevated production costs. Extended droughts are common in the country, limiting the amount of water used for agriculture. In addition, because of urbanization and population growth, there is an increase in water consumption, creating competition for the limited supply of water resources. Farmers of date palms who rely on irrigation to sustain their crops are under strain because of this situation.

Additionally, date palm farmers lack effective irrigation systems, such as drip and subsurface irrigation systems. Many farmers employ ineffective traditional flood irrigation systems that cause significant water losses through evaporation and runoff. The farmers of date palms who use this method also contribute to soil salinization, worsening the irrigation water shortage. To address this problem, date palm farmers use desalinated seawater for irrigation, which is costly and unavailable to all farmers. The Saudi government has significantly invested in irrigation systems and technologies to encourage effective water use in agriculture to address this issue [48–50].

Desertification and soil erosion are further threats to the sustainability of date palm production. The process of topsoil being removed by wind or water and leaving unusable land that cannot support plant growth is called soil erosion. On the other hand, desertification refers to degrading formerly productive land into desert-like conditions because of natural or human-caused factors such as excessive grazing, deforestation, and unsustainable farming methods. In Saudi Arabia, several causes, such as climate change, excessive groundwater use, and unsustainable farming methods, have contributed to the deterioration of soil health and desertification. The country is especially prone to these issues because of its arid climate and constrained water supplies [51–57].

Another challenge date palm farmers face in Saudi Arabia is the prevalence of pests and diseases. Date palms are susceptible to various pests, including red palm weevils, long horn borer, dust mites, fruit flies, scale insects, and fungal diseases. The red palm weevil is an invasive species that infects young and mature palm trees, damaging their vascular system. The weevil larvae bore into the tree trunk, feeding on the soft tissues and creating tunnels that damage the tree structure. The leaves of infested trees display wilting and yellowing symptoms, resulting in death [58–66].

Postharvest losses are estimated to be around 10% in Saudi Arabia, where date palm farming is an important industry. Limited postharvest facilities in the country are one of the key reasons for these losses. Postharvest facilities are essential for the proper storage, processing, and packaging of dates. They help prevent spoilage, minimize losses, and maintain the fruit's quality. However, due to various issues such as high costs, lack of knowledge, and inadequate infrastructure, many date palm farmers in Saudi Arabia do not have access to these facilities [67–71].

Another issue Saudi Arabian date palm growers deal with is a skilled manpower shortage. Many date palm farmers rely on skilled migrant labor during harvest and perform different cultural practices such as pollination, pruning, fertilization, irrigation, chemical application, etc. However, changes in immigration policies and geopolitical strains have made it difficult for farmers to access skilled labor when needed. This has resulted in labor shortages during critical periods, which can lead to reduced yields and financial losses for farmers. As a result, skilled labor shortages during critical periods reduced production and financial losses for farmers [72, 73].

3. AI and IoT technologies

AI refers to a group of technologies that allow computers to do a wide range of complex tasks, such as seeing, comprehending and translating spoken and written language, analyzing data, making suggestions, and more. It revolutionized agriculture by making farming more efficient, sustainable, and profitable. In addition, many businesses are embracing IoT, which offers simple means to collect and evaluate technical data to identify and improve the performance of numerous daily operations. The technological revolution reveals new challenges and issues with our current IoT technologies. New technologies, such as AI, 5G, and blockchain, promise to solve these challenges. We can create intelligent machines with the help of IoT and AI integration. These innovative automation technologies not only make monotonous tasks more accessible but they also make smart decisions without human assistance. The IoT and AI are two of the most significant technologies in the computing industry, completely transforming how we communicate with machines and our environment. It is speculated that ca. 64 billion AI and IoT devices will be available by 2025. AI and IoT technologies work effectively together and are at the top of the latest innovations influencing the information technology sector. The industrial and agribusiness sectors have benefited from the duet's redesign of traditional solutions [74, 75].

Machine learning (ML) is a subset of AI that involves training algorithms to make predictions or decisions based on training data. ML is a rapidly growing field with numerous applications and opportunities for scientific innovation. It is a branch of AI that involves the development of algorithms and statistical models that allow computer systems to automatically improve their performance on a specific task as they gain experience. ML aims to develop intelligent systems capable of learning from data and making predictions or judgments without being specifically programmed to do so. In IoT, ML is a technique that can be applied to analyze sensor data and forecast future events. Deep learning has become a potent ML method in recent years. Deep learning includes putting multiple-layer neural networks through training to learn how to represent data hierarchically. As a result, developments have been made in fields such as speech recognition, natural language processing, and image recognition. Numerous industries, including agriculture, healthcare, finance, marketing, and transportation, use ML in various ways. ML in agriculture has the potential to be applied in a variety of ways with exceptional results from weed, pests and disease detection, crop yield, and quality prediction, to data collection, providing insights, and livestock production forecasting. It can be used in the healthcare industry to find novel medicines and disease diagnoses. It can be applied to finance to assess risk and detect fraud. It can be used in marketing for personalized advertisements and customer segmentation. It can be applied to autonomous driving and traffic forecasting in the transportation sector [29, 76–81].

Natural language processing (NLP) is a field of AI that applies to the interaction between computers and humans using natural language. NLP is vital to contemporary AI systems because it enables machines to understand, interpret, and generate human language. The development of smart homes, smart cities, and other intelligent systems now has more opportunities since integrating NLP in IoT devices. Users can communicate more effectively and easily with IoT devices by adding voice recognition and natural language understanding capabilities. One of the most significant applications of NLP in IoT is voice assistants such as Amazon's Alexa, Google Assistant, and Apple's Siri to turn on/off lights, play music, set alarms, or order groceries online. Weather data analysis is an example of how NLP is used in agriculture. Farmers can decide on crop planting and harvesting dates, irrigation requirements, and controlling pests and diseases by evaluating weather patterns and forecasts. Farmers may track crop growth and development rates, as well as soil moisture levels with the aid of NLP algorithms. In order to help the farmers choose the best crops to cultivate and the best times to sell, NLP models can also be used to assess market trends and forecast demand. Farmers may find new customers and bargain for higher prices with the aid of NLP algorithms. Improved consumer-farmer communication is another area, where NLP can be employed. Farmers can learn more about consumer preferences by examining customer feedback analysis. Using NLP algorithms, farmers can communicate more effectively with each other, sharing their best agriculture practices and working together on research initiatives [82–86].

Computer vision is a field of AI that enables computers and machine systems to extract useful information from visual data (digital images and videos) and then take actions or make recommendations. This technology is widely used in IoT to enable devices to see and interpret the physical entity through object, facial, and gesture recognition, thus making them more intelligent and responsive. With the help of deep learning algorithms, computer vision systems can identify objects in real time and classify them into different categories. This capability has been used in various IoT applications, such as autonomous vehicles, security cameras, and smart home devices. Similarly, computer vision systems can extract valuable environmental information by analyzing images captured by cameras or sensors. For example, they can detect anomalies or changes in a scene, monitor traffic flow, or track the movement of people or objects. IoT has also used this technology for gesture recognition and human-computer interaction. Computer vision systems can enable users to interact with devices more naturally and intuitively by analyzing hand movements and gestures. This capability has been used in various applications, such as gaming consoles, virtual reality systems, and smart home devices. Many agricultural activities are being automated and optimized using computer vision technology. Crop monitoring, yield prediction, and insect and disease detection are a few applications of computer vision technology in agriculture [87–91].

Robotics technology is a branch of engineering that entails creating and programming robots and is crucial to advancing AI and the IoT. It is used in IoT to create intelligent machines that can exchange data and connect. Robotics is using machines to carry out jobs that are either harmful or too difficult for humans. How we interact with machines has changed dramatically because of the inclusion of robotics technology in AI and IoT, improving their efficiency, dependability, and autonomy. These robots' 24/7, nonstop operation, which is also utilized for data entry and processing tasks, minimize errors, and boost efficiency. Automation of robotic processes has been widely used in several sectors, including agriculture, manufacturing, healthcare, logistics, and finance. The development of autonomous robots is another way that robotics technology is used in AI. Robots operating independently of humans may use sensors, cameras, and other cutting-edge technologies to navigate their environment. Robotic technology is being employed more frequently in agriculture to improve the productivity and efficiency of farming operations. Many benefits are reported from using robots in agriculture, such as improved crop yields, lower labor costs, and increased accuracy [15, 92–95].

Edge computing represents a decentralized computing model that moves computation and data storage nearer to the requirement point, enhancing response speed and minimizing bandwidth consumption. In IoT, edge computing can process sensor data in real time at the network's edge. ML models used in AI are substantially trained using massive volumes of data. This training can be carried out locally *via* edge computing, reducing the need to send large amounts of data to centralized servers. By storing sensitive data on local devices rather than transferring it over the internet, edge computing can decrease network congestion, enhance privacy and security, and increase reliability. Edge computing can also be utilized to run AI models in real time, enabling rapid response and decision-making. Edge computing, for instance, can be utilized to analyze sensor data from a localized area in real time and identify possible problems before they escalate [96–101].

Cloud computing technology plays a crucial role in developing and deploying AI and IoT applications. It provides an infrastructure that allows organizations to store, manage, and process large amounts of data generated by IoT devices and AI applications. Within the cloud computing framework, the vendor hosts and provides infrastructure, data, and software as a service to the user. Scalability is one of the most significant benefits of cloud computing for AI and IoT. Because cloud-based services are easily scaled up or down according to demand, businesses and organizations can manage the massive amounts of data and processing power needed for AI and IoT applications.

Additionally, cloud computing offers an affordable solution for users who need to store and process large amounts of data. By utilizing cloud-based ML platforms, cloud computing also enables the development of AI and IoT applications. These platforms give programmers access to robust machine-learning algorithms, resources, and libraries that they can utilize to develop sophisticated applications.

Additionally, developers can scale up or down their ML models in response to demand using cloud-based ML platforms. Additionally, cloud computing offers a safe environment for processing and storing private data produced by IoT and AI applications. To safeguard customer data from cyber threats, cloud service providers have implemented several security measures such as firewalls, access controls, and encryption [102–106].

Blockchain technology is a decentralized and distributed ledger system that securely and transparently records transactions across multiple computers. It enables secure transactions between parties without the need for intermediaries. It can be used for secure device authentication, data sharing, and supply chain management. This technology can enhance AI and IoT systems' security, privacy, and interoperability. Increased security is one of the main benefits of adopting blockchain in AI and IoT. It secures data and transactions using cryptographic algorithms, making it difficult for hackers to tamper with or steal data. Blockchain can also be used to develop secure digital identities for users and devices, which can help restrict unauthorized access. Improved privacy is a benefit of using blockchain in AI and IoT. Users can choose who can access their data and maintain control over it. This technology is essential when sensitive data needs to be protected, such as in healthcare and financial applications.

Additionally, blockchain can improve the interoperability of various IoT and AI systems. It enables different methods to communicate with each other more easily by establishing a shared decentralized ledger of transactions. This can make it simpler for developers to create new applications and lessen the difficulty of integrating various systems [107–111].

4. Applications of AI and IoT in agriculture

By 2025, it is anticipated that global spending on intelligent, interconnected agricultural technology and systems, including AI and IoT, will triple in size, reaching $15.3 billion. Understanding how factors such as sunlight, weather, animal, bird, and insect movements, crop use of specific fertilizers and pesticides, and planting and irrigation cycles affect crop production is a perfect subject for machine learning. Excellent data has never been vital for determining a crop cycle's profitability. For this reason, farmers and the agricultural sector are stepping up their data-centric strategies and broadening the scope and scale of the application of AI and IoT technology to improve crop yields and quality [112–116].

Crop yields are being increasingly optimized using AI and IoT. Farmers can understand more about the health of their crops and make intelligent decisions about water and fertilizer requirements and disease and pest control by utilizing data from sensors and other connected devices. Precision farming is a significant area, where AI and IoT are used in agriculture. This entails creating precise field maps and real-time crop growth monitoring using data from sensors, drones, and other sources. Farmers can identify areas that need water, fertilizer, or disease/pest control by examining this data and areas that are vulnerable to disease or pest infestation. Due to their increased ability to deploy resources effectively and efficiently, crop yields increase and costs decrease [117–120].

Predictive analytics is yet another approach AI and IoT use in agriculture. Farmers can use machine learning algorithms to accurately predict future yields by analyzing historical data on weather patterns, soil conditions, and crop performance. This enables them to plan for planting and harvesting crops and make smart decisions about pricing and marketing. Before a vegetation cycle even begins, it is now possible to know the potential yield rates of a field using AI and IoT technology. The potential crop yield can be estimated using machine learning techniques to analyze 3D mapping, sensors' soil analysis data, and drone-based soil color data. Farmers can automate the irrigation schedule of their crops based on real-time data on soil moisture content *via* remotely connected devices, such as smart sprinklers and soil sensors. Satellite-based thermal-infrared imaging remote sensing AI and IoT technology also monitor irrigation rates and crop water requirements. Automating tasks, such as fertilization is another possible application of AI and IoT in crop farming. Farmers can apply fertilizer more precisely based on real-time data on soil nutrient levels *via* GPS-connected fertilizer spreaders. The technology is used to apply fertilizer variably on most needy soil areas.

Similarly, the normalized difference vegetation index images recorded through drones or satellites can be used to apply variable nitrogen application at different crop growth stages. Variable seed rates of different crops can be estimated by scanning the electric conductivity of the field. The seed spreader is then connected to the GPS-kit with the field electric conductivity map, guiding the spreader to apply seed variably. Large-scale agricultural firms turn to robotics when they cannot find enough skilled workers. Self-propelled robotics machinery that can be programmed to apply seed and fertilizer evenly along each row of crops lowers operational costs and increases crop yield. Farmers can detect symptoms of disease or stress before they are noticeable to the naked eye, for instance, by employing computer vision algorithms to examine photographs of plants. This enables them to take corrective action before the problem worsens, resulting in healthier plants and better-quality produce. Farmers employing AI and IoT technologies can predict and detect disease/pest infestations before they occur by combining drone infrared camera data with sensors on fields that can monitor plants' relative health.

Moreover, the AI and IoT systems can identify disease/pest-affected areas by combining intelligent sensor data with visual data streams from drones. Farmers can gain more knowledge about the health of their crops and decide how to allocate resources and control pests/diseases by analyzing data from sensors and other connected devices. Crop quality can also be improved as well with the use of AI and IoT [121–131].

All agricultural supply chains have adopted track and traceability, and this trend is expected to continue. A well-managed track-and-trace system increases visibility and control throughout supply chains, which reduces inventory shrinkage. Modern AI and IoT-based track-and-trace systems can distinguish between batch, lot, and container-level material assignments in inbound shipments. Most cutting-edge track-and-trace systems rely on sophisticated sensors to record data for each shipment. Agricultural supply chains and shipments are increasingly using AI and IoT sensors. AI and IoT systems show different marketing scenarios to farmers to get the maximum return on their produce. When deciding on pricing strategies for a particular crop, price forecasting for crops based on yield rates that help forecast total volumes produced is crucial. Understanding yield rates and quality standards enables agricultural businesses to negotiate effectively for the best harvest price. The pricing strategy is determined by analyzing the total demand for a crop to determine whether the price elasticity curve is inelastic, unitary, or highly elastic [7, 118, 132–135].

One of the fastest-growing applications of AI and IoT in agriculture is monitoring livestock health, including daily activity and food intake. Various aspects of livestock management and monitoring, such as behavior, detection, counting, identification, grazing tracking, health issues, estimating the herd distribution, etc., can be achieved using AI and IoT technologies. The best way to care for livestock over the long term is to understand how each livestock responds to diet and boarding conditions. Producing more milk requires AI and IoT to comprehend what keeps cows happy and contented daily. AI and IoT technologies reduce the chances that domestic and wild animals may accidentally destroy crops or commit a break-in or burglary at a remote farm. Farmers can secure the perimeters of their fields and buildings through image analysis powered by AI and machine learning algorithms [136–141].

5. Benefits and application of AI and IoT in date palm cultivation

Advances in technology have led to the integration of AI and IoT into the date palm farming sector, aiming to improve yield, reduce costs, and increase efficiency. One recent development in AI and IoT in date palm cultivation is using sensors to monitor soil moisture. These sensors are connected to a central system that uses AI algorithms to analyze the soil moisture data and determine the time and amount of irrigation water requirement. This approach has been shown to reduce water consumption by up to 30–60% and improve date palm yields. Another application of AI and IoT in date palm cultivation is using drones for crop monitoring. Drones equipped with cameras and other sensors collect data regarding plant health, growth rates, and other factors affecting palm growth and yield. This information can then be analyzed using ML algorithms to identify patterns and predict future crop performance. In addition to these applications, AI and IoT are also used to optimize fertilizer usage, predict weather patterns, and automate the harvesting time of different date palm varieties. For example, autonomous robots with AI algorithms can harvest dates more efficiently than human laborers, reducing costs and increasing productivity [20, 29, 63, 65].

In many parts of the world, date palm cultivation is a significant economic activity. Using AI and IoT technology in date palm farming can have several economic benefits. Enhanced crop management efficiency is one potential benefit. AI-powered sensors can monitor soil moisture, aerial temperature, humidity, and other environmental variables that impact the development and production of date palms. Date palm growers can optimize irrigation schedules, fertilizer applications, and disease and pest management strategies by analyzing AI and IoT data, leading to higher crop yields and lower input costs. Improved quality control is another potential benefit. AI algorithms can examine images of date palm trees to identify signs of water stress, diseases, or nutrient deficiencies. This can help farmers identify problems early and resolve them before they worsen. IoT devices can also track the shipment of date palm offshoots from the field to the market, ensuring that they are treated carefully and adhere to quality standards. Increased market access is a third potential advantage. Farmers can produce higher-quality dates that fetch higher prices in domestic and foreign markets by applying AI and IoT technology to enhance crop management and quality control.

Furthermore, IoT devices can deliver real-time information about market demand, allowing farmers to modify their production strategies accordingly. AI techniques made identifying different date palm varieties possible through leaf and fruit image scanning. In general, date palm farming could benefit from AI and IoT technology by increasing productivity, enhancing quality assurance, and giving farmers more market access. The economic benefits of these technologies are expected to significantly increase as they develop and become more accessible [19, 20, 30, 32, 38, 43, 142–144].

The following are some of the applications of AI and IoT that have been employed for advancing date palm cultivation technology:

5.1 Date palm irrigation management

Fresh water is an urgent priority in semiarid- and arid regions. With the steady increase in population, water is urgently needed to irrigate palm trees and increase the production of dates, food products rich in nutrients necessary for human health. The reclaimed and desalinated water can be used for irrigation, but these technologies' high energy and cost hinder this irrigation utilization [19, 145]. There is a need for intelligent irrigation and standalone photovoltaic systems, and new smart irrigation techniques to ensure sustainable energy and water for agriculture [20, 21, 146]. Mohammed et al. [29] implemented AI to predict optimum water and energy requirements for solar-powered sensor-based microirrigation systems. This study is a good example of how AI can improve agricultural practices. The study also found that the optimum water use efficiency was achieved when the maximum setpoints of irrigation control were adjusted at the field capacity and by adjusting the minimum setpoints at 40 of the available water for the subsurface irrigation system. The optimum yield was achieved by adjusting the minimum setpoints for subsurface irrigation, subsurface drip irrigation, and bubbler irrigation, respectively. Several ML algorithms were used in the study, including support vector regression (SVR), long short-term memory (LSTM) neural network, linear regression (LR), and extreme gradient boosting (XGBoost) were developed and validated for predicting the optimum irrigation water and solar energy requirements based on the limited meteorological data (average temperature, RH, wind speed, and solar irradiance) and date palm age for each microirrigation system used. The study evaluated the performance of the ML models using three performance metrics of root mean square error (RMSE), coefficient of determination (R^2), and mean absolute error (MAE). The dataset was prepared at various levels for 4 years to train and test the prediction models, and the fifth year was used to validate the performance of the most suitable model. The evaluation of the ML models indicated that the LSTM and XGBoost models were more accurate than the SVR and LR models in predicting the optimum irrigation water and energy requirements. The validation results showed that the LSTM model could predict the water and energy requirements for all irrigation systems with R^2 values ranging from 0.90 to 0.92 based on date palm age and limited meteorological variables. The authors stated that the benefits of implementing AI in sustainable farming include predicting optimum water and energy requirements for sensor-based microirrigation systems powered by solar PV, contributing to sustainable farming practices. They also highlighted the potential significance of AI in effectively overseeing irrigation water scheduling. AI could achieve this by handling gathered data and comprehending the evolving weather patterns, soil, and plant conditions throughout the cultivation phases. The LSTM model they created could serve as a potent instrument for supervising water allocation in date palm cultivation [29].

Consequently, AI's influence extends to water conservation in irrigation, fostering plant development, and augmenting crop yield. In addition, the study's results have significant implications for sustainable agriculture in arid regions. By using AI to predict the optimum irrigation requirements, farmers can save water and energy while still achieving optimal yields. This is essential for ensuring the long-term sustainability of agricultural production in arid regions [29].

A previous study highlighted the benefits of using the Internet of Things (IoT) in agriculture, especially irrigation management. Mohammed et al. [38] developed an automated system for scheduling irrigation using a cloud-based IoT platform, which positively impacted the yield of date palm and water use efficiency using FTTT (If This Then That) interface and Ubidots platform. **Figure 1** shows the main components of the cloud-based IoT platform used to monitor the meteorological variables in real time and control the irrigation water scheduling of the irrigation systems. The figure illustrates the flow of data from the sensors to the cloud platform and the control of the irrigation system through the Arduino UNO board and IFTTT interface. The meteorological variables were collected by the sensors and transmitted to the Arduino microcontroller in real time through the Wi-Fi module. The microcontroller

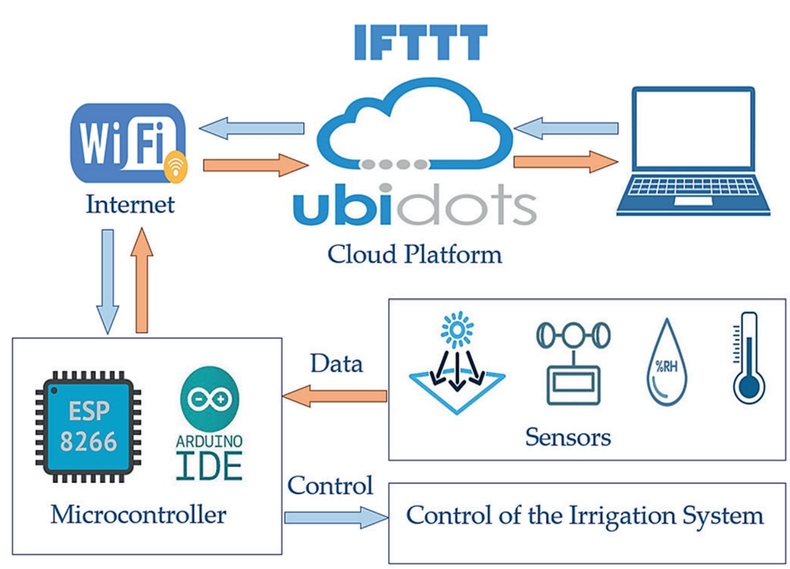

Figure 1.
A simple diagram for the components of the cloud-based IoT system employed for real-time monitoring of the meteorological parameters of the study area and managing water scheduling for date palms.

then sent the data to the Ubidots platform, where the user could access the real-time data through the graphical user interface using the private channel. The electronic relays of contactors, electronic valves, and irrigation pumps were controlled using the IFTTT interface to schedule the irrigation water of the irrigation system.

Implementing IoT procedures and creating sophisticated sensors for smart agriculture exert a significant influence on both crop yield enhancement and the preservation of irrigation water. Furthermore, integrating cloud computing and IoT advancements has bolstered the interaction and remote oversight between users and their agricultural operations. This enhancement permits multilayered cloud IoT and computing frameworks to orchestrate, supervise, and administer crop cultivation within a comprehensive automated structure. This has the potential to tackle the challenges posed by limited water availability and insufficient labor in the agricultural sector. The operation was overseen through a cloud-based IoT platform, allowing users to remotely observe the farm and retrieve pertinent meteorological information. This data empowered users to make informed decisions, considering the irrigation microcontroller's existing parameters. The IFTTT interface seamlessly integrated with the irrigation hardware, introducing functionalities that managed irrigation valves and pumps or dispatched SMS notifications to users based on their predefined actions. The IoT system optimized water use in date palm cultivation and improved yield and water use efficiency. In addition, the Ubidots platform was used in this study to monitor the meteorological variables data. The platform allows users to connect, visualize, and analyze data from various sources, including sensors, devices, and applications. The Ubidots platform provides a graphical user interface (GUI) that allows users to create custom dashboards, charts, and widgets to visualize data in real time. The platform also provides tools for data analysis, including statistical analysis, machine learning, and predictive analytics. This study used the Ubidots platform to collect and store real-time meteorology measurements on the farm to analyze and visualize the irrigation parameters [38].

Mohammed et al. [20] employed cloud-based IoT solutions to control a modern subsurface irrigation system in date palm farms in the arid region of Saudi Arabia, which improved irrigation management. They designed and constructed a fully automated controlled subsurface irrigation system (CSIS) and validated its performance to monitor the irrigation process remotely. An efficient control system for subsurface irrigation utilizing marvelous cloud computing and IoT capabilities was used to manage date palm water. The user can be automatically notified by either a short or email message. The optimum water per tree can be applied by controlling the subsurface irrigation system in a date palm field. The methodology used in this study involves designing and implementing a cloud-based CSIS for date palm trees. CSIS is an IoT-based system that employs cloud computing and various sensors to monitor and control the subsurface irrigation system for date palm trees. A sensor-based subsurface irrigation scheduling (S-BIS) was considered. Based on the data received from the sensors, the amount of water can be scheduled. The measured data from sensors is uploaded to the ThingSpeak cloud platform for analyzing and sending the decision to the subsurface irrigation system. **Figure 2** shows the designed system that used the direct measurement of volumetric water content to make irrigation decisions, meanwhile monitoring different factors such as ambient air temperature, relative humidity, solar intensity, wind speed, and water flow rate per minute. The results indicated that the automatically irrigating date palm trees controlled by S-BIS were more efficient than the time-based irrigation scheduling (T-BIS). The amount of irrigation water was reduced by 64.1% and 61.2% based on S-BIS and T-BIS, respectively, compared to traditional surface irrigation

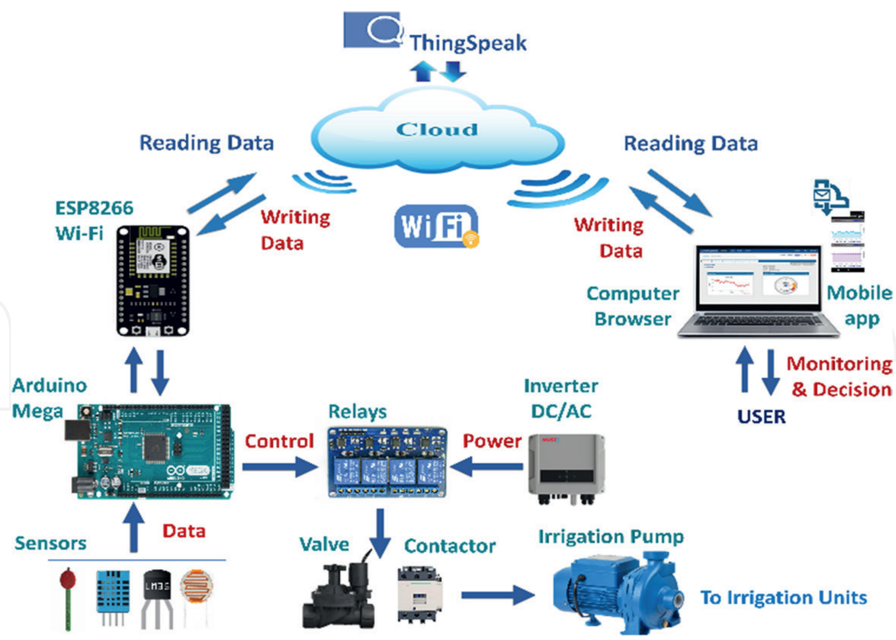

Figure 2.
A schematic diagram for the IoT-based control system for a smart subsurface irrigation for enhancing irrigation management of date palm.

(TSI). The yearly sum of irrigation water employed for CSIS utilizing the S-BIS technique, CSIS using the T-BIS approach, and TSI stood at 21.04, 22.76, and 58.71 m^3/tree, respectively. When integrated with the S-BIS methodology, the devised CSIS approach yields favorable outcomes regarding irrigation water administration and a subsequent improvement in date palm fruit yield within arid regions [20].

The IoT-based control system efficiently schedules the irrigation water to administer to the date palm at different intervals, relying on data from various sensors. The system collects measurements from these sensors, transmits the data to the ThingSpeak cloud platform for analysis, processes the information in the cloud, reaches conclusions, and then implements these conclusions into the subsurface irrigation system. The benefits of using IoT technology in this study include more efficient water management, improved crop yield, and reduced water waste. Additionally, the system can be remotely monitored and controlled, reducing the need for manual labor and increasing the accuracy of date palm irrigation management [20].

5.2 Tissue culture systems management

The smart *ex vitro* acclimatization systems (SEVAS) for tissue culture plantlets aim to minimize the initial shock of newly regenerated *in vitro* plantlets. This benefit decreases their mortality and improves their growth characteristics. In addition, the potential advantages of using SEVAS for tissue culture plantlets in agriculture include reduced production costs, reduced manual labor, enhanced product quality, and improved environmental sustainability. Utilizing automation is a pragmatic approach, particularly considering the extensive and time-consuming nature of *in vitro* propagation. This is especially true when dealing with limited outputs during the acclimation phase due to the mortality of plantlets. The benefits of automating the acclimatization process also encompass lower contamination risks and reduced labor expenses. Contemporary precision agriculture methods, such as glasshouse technology, are predominantly characterized by automation. In contrast, the combination of information technology and IoT solutions has advanced significantly, ensuring effectiveness and efficiency [43, 147, 148].

Mohammed et al. [43] designed an IoT-based automated system for the SEVAS to acclimate tissue culture plantlets. The designed system uses IoT technology to monitor and control the environmental conditions of the glasshouse, including temperature, humidity, and light intensity. The system also includes a feedback mechanism that adjusts the environmental conditions based on the real-time data collected by the sensors. The advantages of employing IoT technology in this research encompass the immediate tracking of crops and microclimate, surveying and mapping fields, and providing data to farmers for implementing well-founded strategies in farm management. These strategies aim to enhance efficiency, conserve time and resources, and elevate crop yield. Furthermore, IoT technology is progressively gaining traction within agriculture, facilitating the adoption of environmentally friendly on-farm methods and fostering improved ecological sustainability.

Figure 3 provides an overview of the IoT-based control and monitoring system for the SEVAS in the study. The figure shows the primary components of the system, comprising sensors, a microcontroller, an internet connection, the IoT platform hosted on the cloud, control apparatus, and web-based applications. These components are interconnected and harmonized to facilitate control and monitoring functionalities. The figure also depicts the trajectory of data from the sensors to the cloud-based IoT platform and the control devices responsible for overseeing the microclimate variables within the E-VAS system. The cloud-based IoT platform stores and analyzes the data and sends control signals to the control devices, which include relays for controlling the heating unit, cooling units, ultrasonic humidifier, and water pump and irrigation valves. The control devices adjust the SEVAS microclimate factors based on the sensors' data and the control signals from the cloud-based IoT platform [43].

5.3 Cold storage management

Cold storage is essential in food, vegetables, and fruit preservation. Refrigeration in remote areas away from the electricity grid needs an off-grid power system.

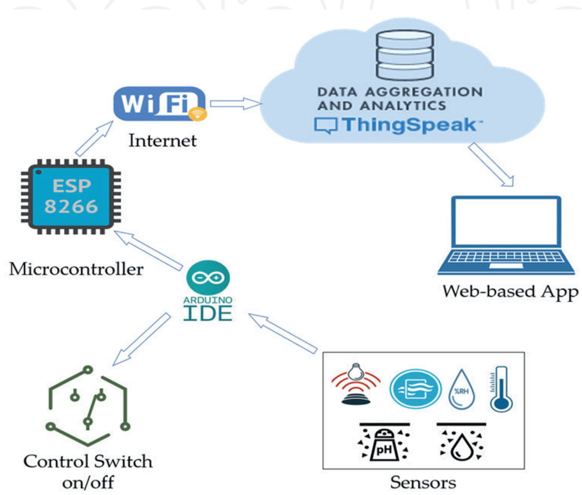

Figure 3.
A simple diagram for the components of the IoT-based controlling and monitoring system of the SEVAS for tissue culture plantlets.

Photovoltaic (PV) solar energy is an important power source for operating off-grid refrigeration. Due to a reduction in PV system cost, solar-powered refrigerators have become more economical [30, 71, 149, 150]. Refrigerators are considered one of the types of equipment that consumes a significant amount of electricity. Hence, reducing energy consumption and efficient systems are most important to reduce greenhouse gas emissions and the costs of PV systems [30, 151]. Eltawil et al. [152] developed and evaluated a machine learning-based intelligent control system (ICS) using artificial neural networks (ANN) for the performance optimization of solar-powered display refrigerators (SPDRs). The SPDR functioned initially at a consistent frequency of 60 Hz, and subsequently, it was operated at various frequencies ranging from 40 to 60 Hz. An integrated ANN-based ICS facilitated this frequency adjustment with a variable speed drive. An independent PV system provides the energy necessary for its operation. The performance of the newly developed SPDR was assessed and contrasted against its performance under a conventional control system (TCS). These evaluations were conducted at refrigeration temperatures of 1, 3, and 5°C, which align with ambient temperatures. The researchers employed an ANN-based regression model to enhance the SPDRs. The ANNHUB software's ANN technique created an optimal predictive model. This model was used to forecast the requisite power and ideal frequency for the SPDR, leveraging training data.

The Levenberg–Marquardt algorithm was employed in the training phase, allocating 75% of the data for training and 25% for testing. This algorithm optimized the weights in a composite estimation of outputs, thereby refining the prediction model. **Figure 4** shows the ANN architecture used in this study had a three-layered network consisting of one input layer, a hidden layer, and an output layer. The input layer has six nodes of six independent variables: target temperature (T1), ambient temperature (T2), cabinet temperature (T3), solar radiation intensity, and temperature differences of T2-T1 and T2-T1. The optimum hidden layer was one and contained eight nodes. The output layer had a single dependent variable, frequency, which was also standardized. The outputs were the optimum frequency to control the compressor speed and the required power. The approach used provided a more efficient and reliable means of control. The study suggests that using ML to optimize the performance of solar-powered refrigerators can lead to several potential benefits. For example, it can help

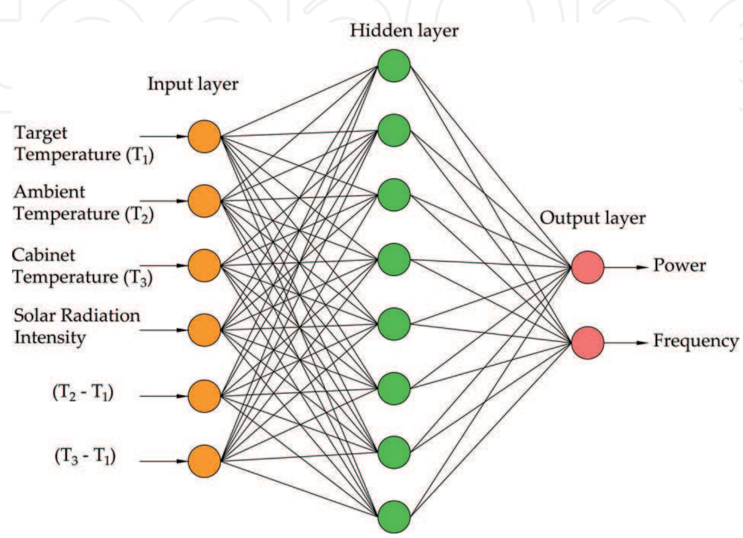

Figure 4.
The ANN architecture of the intelligent control system to optimize the performance of solar-powered refrigerators.

improve the reliability and efficiency of the control mechanism, save the required solar PV energy, and provide a basis for designing and optimizing PV-powered refrigeration systems. Furthermore, the research demonstrated that this approach can be extended to other refrigeration systems, offering a more effective and dependable regulation method [152].

IoT technology for managing cold storage facilities provides real-time system environment monitoring, allowing timely responses to any issues. This technology can give reliable data on the quality of food products during their storage duration, which can help with intelligent food quality management. Furthermore, the application of IoT technology in cold storage revolves around monitoring factors influencing the quality of stored products, with the goal of safeguarding them against potential contamination arising from external conditions. Among these crucial factors, cold storage rooms and warehouses focus on tracking parameters such as relative humidity (RH), temperature, alcohol gases, and light [71, 153].

Mohammed et al. [30] designed a smart IoT-based control system to manage cold storage facilities remotely. This study is a good example of how IoT can improve food safety and quality control. The study found that the IoT-based control system could precisely control the modified cold storage room, provide reliable data about the interior microclimate atmosphere, and send the necessary alerts in an emergency. This indicates that the IoT-based control system can improve the safety and quality of food products stored in cold storage rooms. The study also found that the IoT-based control system had no significant effect on the quality of date fruits stored in the modified cold storage room compared with the traditional cold storage room. This indicates that the IoT-based control system can maintain the quality of food products stored in cold storage rooms without affecting their taste or nutritional value. The study's results have significant implications for the food industry. By using IoT to monitor and control cold storage rooms, the food industry can reduce the risk of food spoilage and improve the quality of their products [30, 71]. **Figure 5** shows the main components of the designed IoT-BC. The figure illustrates the various elements of the system, including the IoT microcontroller, sensors, and cloud platform. The IoT microcontroller collects data from the sensors, which monitor various parameters such as temperature, humidity, and light. The collected data is then transmitted to the cloud platform, where it is analyzed in real time. The cloud platform is also responsible for sending notifications to the user in case of any issues that may arise [30].

5.4 Postharvest management

Climate change positively impacts date palm fruit growth and development by delaying fruit ripening, reducing color development and quality, inadequate pollination, fruit sunburn, poor fruit quality and fruit set, and lowering fruit yield [154, 155]. Date palm fruits can be ripened artificially using controlled temperature and relative humidity, such as the fruit drying process. Mohammed and Alqahtani [144] designed an automated sensor-based artificial ripening system (S-BARS) integrated with ultrasound pretreatment for unripe Khalas Biser fruits of date palm. They developed a straightforward technique for data acquisition and system control. Data on temperature and relative humidity were monitored using six DHT22 sensors. An Arduino Mega board collects the data sent by these sensors. **Figure 4** shows real-time data acquisition for temperature and relative humidity inside the treatment chamber of the designed S-BARS integrated with Arduino and Excel.

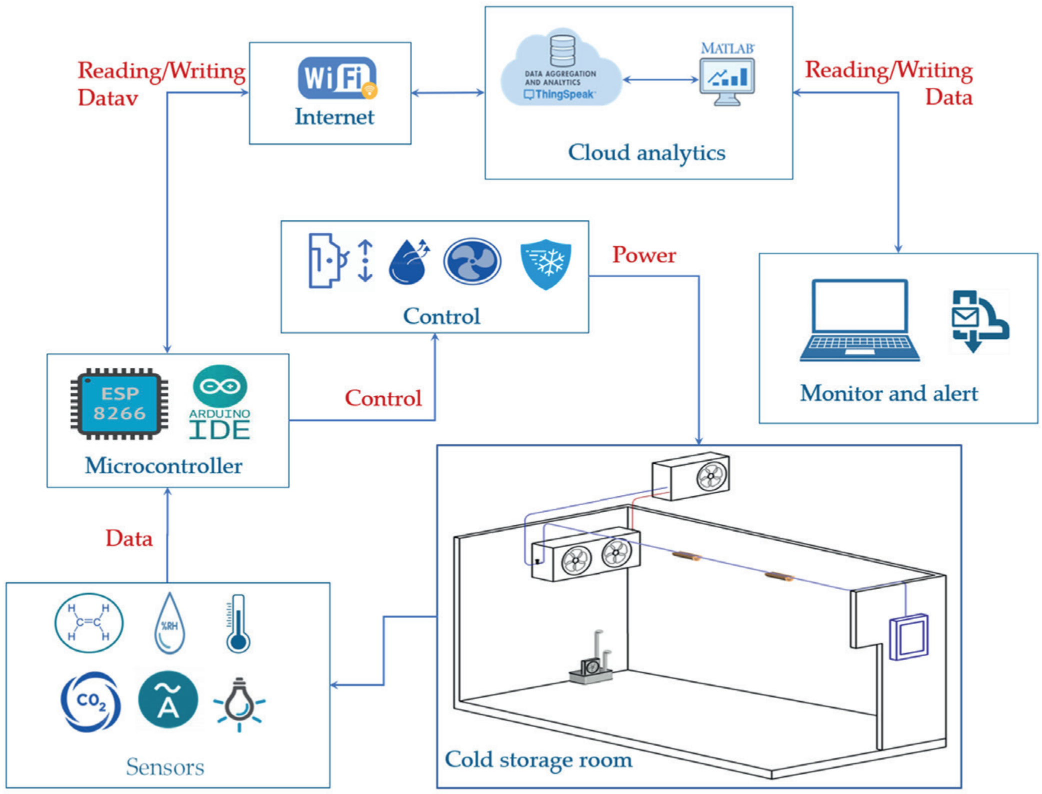

Figure 5.
A schematic diagram of IoT-based control system for cold storage room.

The control system in the study is an automated sensor-based artificial ripening system (S-BARS) that combines ultrasound pretreatment with automated sensors to enhance the ripening process of date fruits. The S-BARS are controlled by an open-source microcontroller board (Arduino Mega) and three relays (RL1, RL2, and RL3) that control the heating unit, ultrasonic humidifier, and main power of the S-BARS. The system also includes six DHT22 sensors that collect data on temperature and relative humidity (RH) and send the data to the Arduino Mega board's open-source microprocessor (ATmega328P). The acquired data is displayed in real time on a liquid crystal display (LCD) and stored in Microsoft Excel using the PLX-DAQ Excel Macro. The control system allows for precise monitoring and control of the ripening process, which can improve the quality and yield of date fruits [144].

Mohammed et al. developed ANNs-based models for predicting date fruit quality attributes based on their electrical properties during cold storage. This study is a good example of how machine learning can be used to improve food safety and quality control. The study found that ANNs were more accurate than multilinear regression (MLR) models in predicting the physicochemical properties of date fruits during cold storage. Therefore, ANNs can be used to develop nondestructive methods for predicting the quality of date fruits. Ensuring a consistent provision of premium fruits to meet market requirements is paramount. The research also identified that the most effective prediction model utilizing ANNs comprised an input layer with 14 neurons, a single hidden layer with 15 neurons, and an output layer with four neurons. The study's findings have significant implications for the food industry. By using ANNs to predict the quality of date fruits, the food industry can reduce the amount of food waste, improve the quality of their products, and meet the demands

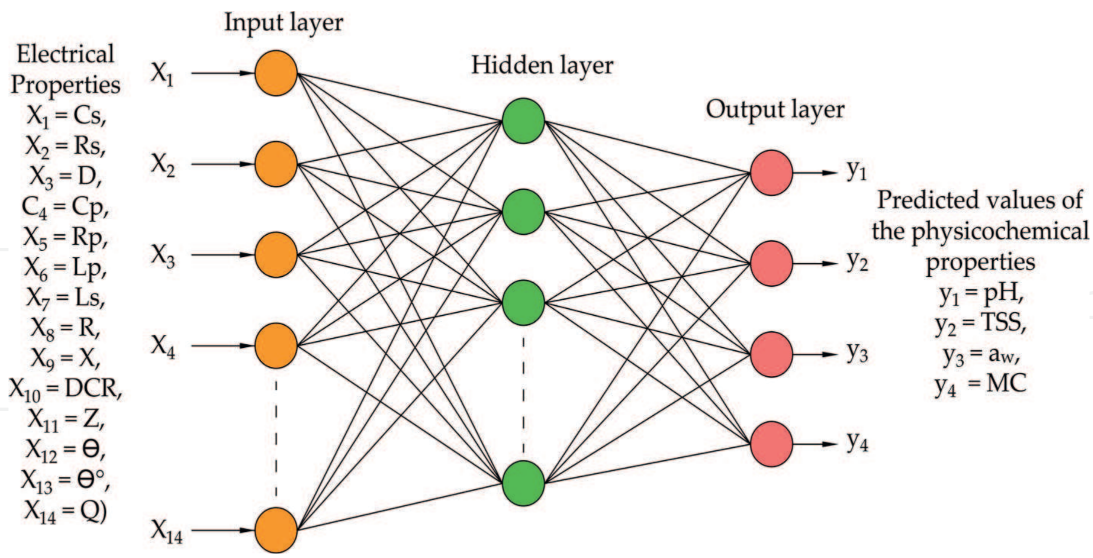

Figure 6.
A simple block diagram of the employed ANNs prediction model for prediction of fruit quality based on their electrical properties during cold storage.

of consumers. The study is a valuable contribution to food safety and quality control. The study's results have significant implications for the food industry, and food manufacturers and policymakers should consider them [78]. **Figure 6** shows a block diagram of the applied ANNs prediction model. The ANNs predict date quality parameters of the pH, total soluble solids (TSS), water activity (aw), and moisture content (MC) of date fruits during cold storage, which is based on 14 electrical parameters of the capacitance value at the series equivalent circuit model (Cs, nF), the dissipation factor (D), the equivalent series resistance (Rs, kΩ), the equivalent parallel resistance (Rp, kΩ), the capacitance value at the parallel equivalent circuit model (Cp, nF), the inductance value in the series equivalent circuit model(Ls, H), the inductance value in the parallel equivalent circuit model (Lp, H), the resistance (R, kΩ), the direct current resistance (DCR, kΩ), the reactance (X, kΩ), the absolute value of the impedance (Z, kΩ), the phase angle (θ°, degree), the phase radian (θ, rad), and the quality factor (Q).

Srinivasagan et al. [156] used a TinyML-based multispectral sensor for the shelf life estimation of fresh date fruits packed under modified atmospheres. This sensor uses ML algorithms to estimate the shelf life of fresh dates based on various fruit properties such as moisture content, total soluble solids, tannin content, and sugar content. **Figure 7** shows a block diagram of the applied ANNs prediction model. The ANNs predict shelf life and fruit quality based on 18 spectroscopy reflectance, packaging types, and storage temperatures. The ANN used in the study has three layers: an input layer with 20 nodes, two hidden layers, and an output layer with one node. The input layer collects the AS7265x Triad optical sensor data *via* the I2C port of the Arduino Nano33 BLE Sense microcontroller. The hidden layers perform data transformation and feature extraction. The output layer is a single neuron that produces a continuous output value. The ANN layers are designed to predict the shelf life of fresh date fruits based on various fruit properties such as color, texture, and temperature. The authors conducted experiments to validate the sensor's accuracy and found that it could accurately estimate the shelf life of fresh dates. This technology can potentially improve the efficiency of the date fruit industry by reducing waste and increasing

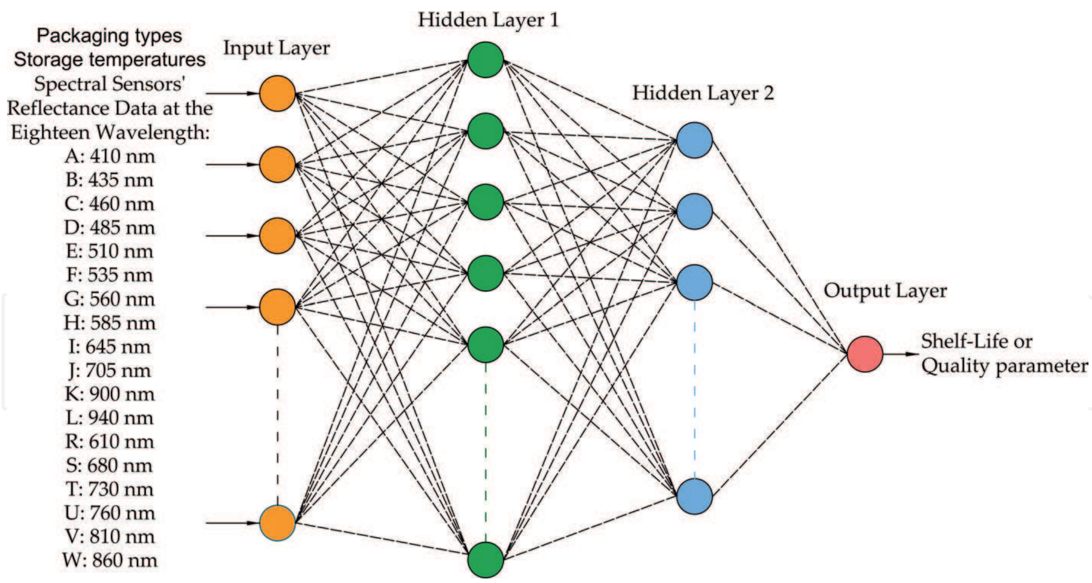

Figure 7.
A simple block diagram of the applied ANNs model for estimating shelf life and quality of date fruit using multispectral sensor during storage under modified atmospheres.

profits. The study also found that modified atmosphere packaging (MAP) can extend the shelf life of date fruits. The researchers observed variations in fresh fruit shelf life estimations across the three main stages of fruit maturity from the Khalal to the Tamr stage. The study suggests that using TinyML for shelf life estimation can improve the efficiency of the date fruit industry by reducing waste and increasing profits. Overall, the study provides a promising approach for estimating the shelf life of fresh date fruits using TinyML and low-cost sensors [156, 157].

5.5 Pest management

One of the most critical problems of date palm mite control is an objective decision-making method for monitoring and predicting date palm mite infestation on date fruits. Mohammed et al. developed, evaluated, and validated prediction models for date palm mite infestation on fruits based on meteorological parameters, i.e., relative humidity, temperature, solar radiation, and wind speed and the physicochemical parameters of date fruits, i.e., firmness, weight, moisture content, total sugar, total soluble solids, and tannin content, using two ML models, i.e., linear regression and decision forest regression. The study is a good example of how ML can improve agricultural practices. The study found that the decision forest regression model was more accurate than the linear regression model in predicting the date palm mite based on the input parameters. This indicates that the decision forest regression model can be used to consider several factors that can affect the infestation of date fruits by the date palm mite. The study's results have important implications for date palm cultivation. The study also found that the developed model could predict the date palm mite count on date palm fruits based on the combination of meteorological and physicochemical properties variables. Farmers can take preventive measures to protect their crops by using ML to predict the date palm mite infestation. This can help to reduce the impact of the date palm mite on the date palm industry and ensure the availability of high-quality dates [66]. **Figure 8** illustrates an experiment to predict date pam infestation on date palm fruits based

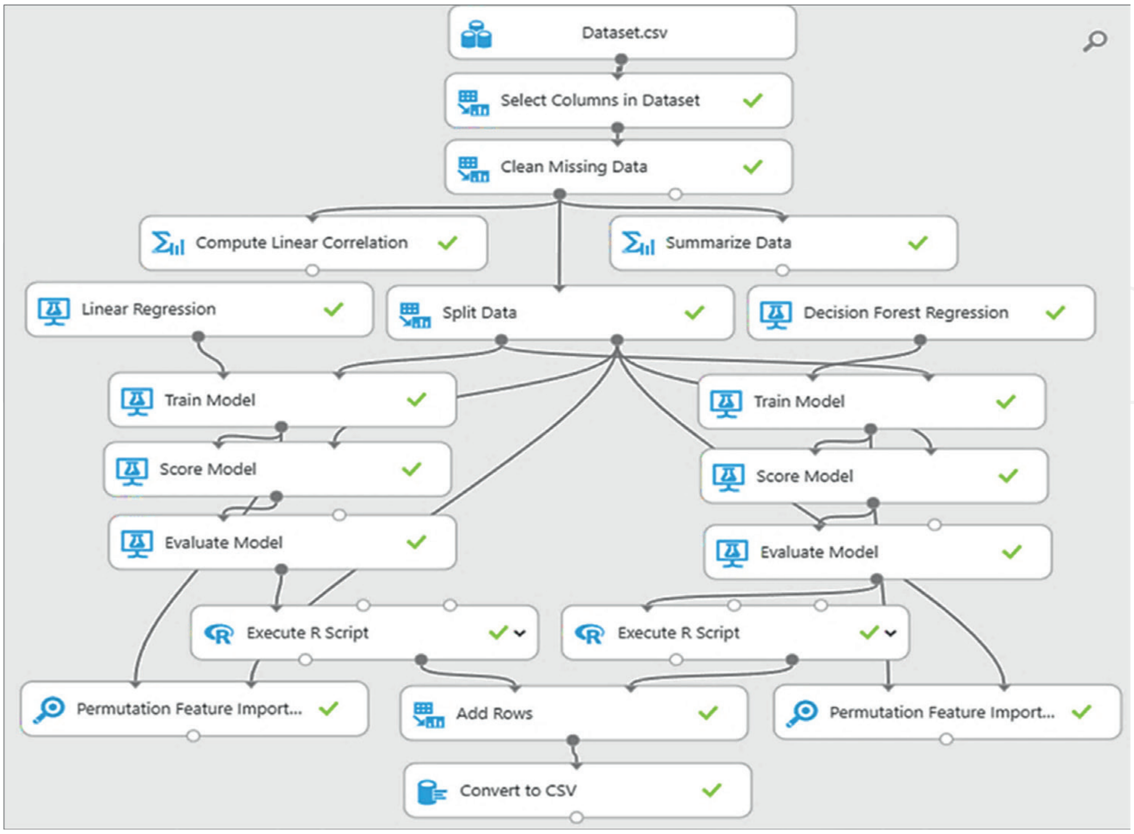

Figure 8.
A screenshot for the architecture of the developed models using Microsoft Azure Machine Learning.

on the study area's meteorological parameters data, the date fruits' physicochemical parameters data during the development stages, and the combined data of meteorological variables and physicochemical properties.

6. Challenges of implementing AI and IoT in date palm cultivation

The transformation brought about by integrating AI and IoT is undeniable, significantly revolutionizing the cultivation of date palms. Farmers can optimize operations, reduce costs, and improve yields using AI and IoT technologies. However, there are several challenges to implementing AI and IoT systems in date palm cultivation. The main challenges to using AI and IoT technologies in date palm cultivation are the lack of infrastructure and connectivity in rural areas, where most farms are located. There is a lack of the necessary infrastructure to support these technologies in many regions, where date palms are grown. For instance, there might not be a stable power source or internet connection to power the devices needed for AI and IoT implementation. This makes it challenging for farmers to gain access to and efficiently utilize these techniques. IoT devices require a stable internet connection to function effectively, and in areas with poor connectivity, the data collected may be inaccurate or incomplete. This can lead to incorrect decision-making and ultimately impact date palm yields and profitability. The high cost of implementing AI and IoT technologies is another challenge.

Implementing IoT and AI systems demands a substantial hardware, software, and training investment. Many small-scale farmers may lack the funding necessary to purchase these technologies. The initial investment required to purchase and install sensors, drones, and other IoT devices can be unaffordable for small-scale farmers. Additionally, the cost of maintaining and upgrading these technologies can increase over time. Furthermore, the expense of maintenance and repairs can deter farmers from adopting these technologies. Data security and privacy are other significant problems applying AI and IoT in date palm farming. Large amounts of data are collected for these technologies from numerous sources, including sensors, drones, and cameras. Sensitive information about the farm's operations is contained in this data, making it vulnerable to misuse or cyberattacks. This is particularly important as farming data can be sensitive and valuable, providing insights into crop yields, soil health, weather patterns, and more.

Special skills are needed to install and manage AI and IoT systems on farms. Many farmers may not have the technical expertise to install and maintain these systems themselves, requiring them to hire outside experts or invest in training their staff. It is also a concern that AI and IoT technologies may replace human labor on farms, leading to job losses. While these technologies can increase efficiency and productivity, they may also lead to a decrease in demand for manual labor. Moreover, integrating AI and IoT technologies with conventional farming practices is another challenge. Many farmers may have little or no prior experience utilizing these technologies, which can cause resistance or reluctance to adopt them. Some farmers may prefer to rely on traditional methods they have used for generations. Finally, several challenges must be overcome before AI and IoT technologies in date palm farming may be widely adopted. Limitations in the infrastructure, high implementation costs, security and data privacy concerns, and reluctance to change are some of these challenges.

7. Future opportunities for AI and IoT in date palm cultivation

Advances in AI and IoT technologies offer new opportunities to improve the efficiency and sustainability of date palm farming. One potential application of AI in date palm cultivation is predictive analytics. By analyzing weather patterns, soil conditions, and other environmental factors, AI algorithms can help farmers predict when to propagate offshoots, irrigate, and harvest their crops for optimal yields. This can help reduce farm waste, increase crop productivity, and improve profitability. Another potential application of AI is precision agriculture. By using sensors and other IoT devices to collect data on soil moisture, temperature, and other environmental factors, farmers can use AI algorithms to optimize water amounts, irrigation schedules, and optimum doses of fertilizer applications. This can help reduce water usage and minimize environmental impact while maximizing palm yields. AI and IoT can also be used to monitor the health of date palm trees. AI algorithms can detect early signs of disease or pest infestations by analyzing images of leaves and trunks. AI noses or electronic noses can diagnose insect pests and diseases, which is a fast and noninvasive approach. This can help farmers take corrective action before the problem spreads, reducing yield losses and minimizing the need for pesticides and fungicides. In addition to AI, IoT technologies such as drones and robots offer new opportunities for precision agriculture in date palm cultivation. Drones equipped with cameras and sensors can provide high-resolution images of date palms, allowing farmers to monitor their health and growth more closely.

Meanwhile, robots can be used for tasks such as pruning and harvesting, reducing labor costs and increasing efficiency. AI and IoT technologies can be used for fruit sorting purposes based on fruit size, weight, color, maturity indices, etc., saving time, labor, and resources. Uneven in situ fruit ripening is a common problem in date palms. AI and IoT technologies can also sort out ripe and unripe fruits. Then the unripe fruits can be ripened artificially using the same technologies to avoid wastage and to enhance farm income.

8. Conclusion

The application of AI and IoT in date palm cultivation in Saudi Arabia shows enormous potential for enhancing productivity, sustainability, and quality management. There is a growing interest in applying AI and IoT in cultivating and managing date palm trees in Saudi Arabia. Several studies have explored AI and IoT technologies in various aspects of date palm cultivation, including pest management, postharvest quality management, yield improvement, and mapping of date palm trees. Using AI and IoT technologies in date palm cultivation offers benefits such as improved crop yield, efficient pest management, and enhanced postharvest quality control. These technologies enable real-time monitoring and data analysis, which can help farmers make informed decisions and optimize resource allocation. Integrating AI and IoT can contribute to the sustainability of date palm cultivation by reducing water consumption and mitigating the impact of climate change. However, it is essential to note that while AI and IoT technologies hold promise, challenges still need to be addressed. These include the need for robust data collection and analysis, ensuring data security and privacy, and addressing the digital divide in rural areas. Further research and development are required to fully harness the potential of AI and IoT in date palm cultivation. Continued research and innovation in this field can contribute to advancing date palm cultivation practices and support the agricultural sector.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Maged Mohammed[1,2*], Nashi K. Alqahtani[1,3], Muhammad Munir[1]
and Mohamed A. Eltawil[4,5]

1 Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa, Saudi Arabia

2 Faculty of Agriculture, Agricultural and Biosystems Engineering Department, Menoufia University, Shebin El Koum, Egypt

3 Department of Food and Nutrition Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

4 Department of Agricultural Systems Engineering, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

5 Faculty of Agriculture, Agricultural Engineering Department, Kafrelsheikh University, Kafr ElSheikh, Egypt

*Address all correspondence to: memohammed@kfu.edu.sa

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