Chapter

Strawberry Cultivation Techniques

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Abstract

Among the berries, strawberries are the most commercially produced and consumed and their production and consumption are increasing in the world due to their enthusiastic aroma, taste, and biochemical properties. Strawberry is belonging to the genus *Fragaria*, from the family *Rosaceae*. It is indicated that the homeland of the strawberry is South America (Chile). It is well-known that people living in Asia, Europe, and America commonly use the wild *F. vesca*. In other regions such as Japan, North China and Manchuria, Europe-Siberia, and America there are different ecogeographic zones where alternative species are clustered. Despite its origins in the Pacific Northwest region of North America, *F. ananassa* is now grown all over the world. Strawberry is one of the most widespread berry species grown in almost every country including high altitudes of tropical regions, and subtropical and temperate areas. In this chapter, we aimed to offer new perspectives on the future of strawberry cultivation techniques by analyzing recent academic studies on strawberry production.

Keywords: strawberry, cultivation techniques, hydroponic culture

1. Introduction

Strawberry is a berry-like fruit that can be widely produced in almost all regions of the world, including tropical and subtropical regions. At the same time, its production and trade have been increasing around the world and in Turkey as it is one of the most profitable fruits due to its nutritional value and benefits for human health. In addition, the demand for marketing of fresh strawberries is higher in the world market because strawberries involve higher costs and are widely used either fresh or in prepared foods, such as fruit juices, jams, jellies, ice creams, chocolates, pies, syrups, pastries, and many beverages [1, 2]. Strawberry holds the most important place among the grape-like fruits in the world. It is preferred by consumers because it is the first fruit to ripen in the spring when no other fruit is available. For this reason, fruits can find buyers at high prices until other fruits reach the market. According to data from the Food and Agriculture Organization in 2019, world strawberry production is 8.885.028 tons. While China ranks first with 3.2 million tons of production, the USA ranks second with 1 million tons and Mexico ranks third with 861 thousand tons. 36.2% of total strawberry cultivation is provided by China in the world. Regarding the cultivation area, China leads with 126 thousand/ha, Poland is second with 50 thousand hectares, and Russia is third with 31 thousand hectares. According to world trade data for strawberries, the export amount of fresh and frozen strawberries in

2020 was 1.6 million tons. While there was a decrease in the export of frozen strawberries from Spain compared to previous years, it was estimated that the export of frozen strawberries from Mexico will increase and it will rank second with 1.7 million tons in 2020. It is predicted that the size of the world strawberry market may reach 22.450 million dollars by 2026 and that the USA alone can generate 18.370 million dollars in the world strawberry market in 2020. It is expected that world strawberry production will increase by 3.4% between 2021 and 2026. According to FAO data, an increase of 39.4% was observed between 2008 and 2018 when world strawberry production is examined. This objectifies the significant increase in the world strawberry production and market. This is an important profitability indicator in terms of strawberry production in the world [3]. In recent years, an increase of 3.1% was observed in the United States of America, which is an important country for the import of frozen strawberries or fresh strawberries, followed by Germany with an increase of 3% and Canada in the third place with an increase of 3.3%.

According to TUIK data, strawberry production in Turkey was expected to increase from 546 thousand tons to 646 thousand tons by the end of 2020 with an increase of 18.2% compared to the previous year. Turkey's foreign trade of strawberries is carried out in two ways as fresh and frozen strawberries. As most of the strawberries produced are consumed domestically, only 8.8% of the total strawberry production was exported in 2020. In addition, Turkey has become one of the most important strawberry producer countries in the world recently and exports strawberries to countries such as Russia, Serbia, Macedonia, Iraq, Bulgaria, and Romania. Although it ranks fourth in world in strawberry production, Turkey comes twelfth in terms of exports since, as mentioned before, the strawberries produced are consumed domestically. Strawberry exports in 2020 increased by 14.7% compared to the previous year and reached 47.912 tons. Strawberry exports became doubled in the last five years. Strawberry imports, on the other hand, vary from year to year but do not have a significant volume. According to the data from the Turkish Statistical Institute (thousand tons), Turkey exported 27.914 tons of strawberries in the first four months of 2021. During the first four-month period, Turkey exported about 14.543 tons to Russia with a rate of 44%, and about 4.129 tons to Iraq with a rate of 14% and the rest to other countries. Based on the above data, there was a significant increase in both strawberry production and the market in the world and in Turkey [4].

While rapid population growth and a corresponding increase in food supply motivate research about agricultural production, the aim is also to produce more with lower costs by using new production techniques for the production of strawberries. In this context, measuring plant features and determining these characteristics accurately in terms of various plant growing and breeding studies, especially in strawberry and vegetable breeding, is one of the most compelling factors for researchers and producers. One of the most important criteria in plant growing and breeding is to quickly and accurately estimate plant genetics within the plant populations to be bred and monitor plant health and development every minute. For this purpose, in a study conducted by Zheng et al. [5], remote sensing and machine learning techniques were used immensely for high-throughput phenotyping technology. Multiple sensors including high-resolution RGB (red-green-blue), multispectral, hyperspectral chlorophyll fluorescence and light detection and ranging (LiDAR) sensors were used in order to allow a range of spatial and spectral resolutions depending on the trait in question. At the same time, in this study, the computer vision and machine learning methodology for plant recognition provided great convenience in evaluating useful biological information and drawing conclusions quickly from these image data. They

discovered that these tools allowed the evaluation of various morphological, structural, biophysical and biochemical features of plants. In addition, the researchers pointed out in this study that remote sensing and machine learning facilitate strawberry cultivation with features such as (1) fruit/flower detection, fruit maturity, fruit quality, internal fruit attributes, fruit shape and yield prediction; (2) leaf and canopy attributes; (3) water stress; and (4) pest and disease detection. As a result, this study showed that the use of remote sensing and machine learning technologies will provide significant convenience as they respond quickly, accurately, and effectively to future prospects for strawberries in precision agriculture. In recent years, the use of mechanization and automation systems in plant production has been increasing rapidly. This chapter aims to analyze and evaluate in detail the academic studies about soil-less agriculture, vertical farming, hydroponic method, smart greenhouses based on sensor and software technology, and harvesting and packaging methods using the same technologies, which are among the new production techniques for strawberry cultivation. Additionally, the aim was to find answers to questions about which new strategy should be used by examining the latest developments and new perspectives in world strawberry production in terms of production techniques.

2. New growing systems for strawberry cultivation

In a study conducted in China to use new technologies and mechanization techniques in strawberry cultivation, a small electric strawberry planting machine was developed in order to reduce the workload during planting, improve the planting technique by machine, and facilitate plant nutrition and other activities. This strawberry planter is based on placing the strawberry seedlings at the desired depth, quickly and accurately. In addition, it was reported that these non-polluting machines meet the high-capacity requirements. In that study, it was stated that the working endurance of the planting machine was 4.5 h and a success rate of 97.46% was achieved in terms of planting rate [6]. In strawberry cultivation, it is extremely important that the environment or soil to be planted has suitable conditions. Today, new technologies and methods have been used to control and accurately determine soil conditions. In a study carried out for this purpose, soil moisture content, humidity level and soil temperature were monitored using advanced systems at present. It was also indicated that, in addition to these parameters, maximum and minimum temperature and humidity values can be determined by an Arduino microcontroller, moisture sensor, temperature/humidity sensor, and GSM module. It was reported that accurate and effective data regarding the temperature and humidity of the greenhouse can be obtained with the help of a DHT 11 sensor, which was placed in the greenhouse and can communicate via SMS [7]. Considering software and information technologies in strawberry cultivation, these technologies have also begun to be used in monitoring plant diseases and pests, and suitable growing environments. For example, the use of the combination of the internet of things (IoT) with an environmental sensing and image processing device provided a very important contribution to the early and accurate detection of plant diseases and increasing yield. In order to detect and classify the disease correctly, the IoT system needs to send images of the disease to the system and provide feedback about the symptoms. In a study carried out for this purpose using a raspberry pi-based IoT device, images of disease symptoms and environmental parameters (humidity, air temperature, soil moisture, and soil pH) were examined in real-time in the MySQL database in order

to detect and classify the disease accurately. After the preliminary stage, the k-mean cluster algorithm was employed in the study to segregate the afflicted part of the plant from other parts and convert it to L*, a*, and b* color space. For the classification of the diseases, multi-class SVM (Support Vector Machine) was used. Moreover, when using a gray level co-occurrence matrix, 14 different categories of color, texture, and shape properties were discovered. A total of 97.33% classification accuracy is achieved via the system. Therefore, the system used in this study will contribute significantly to the early detection of plant diseases, accurate and effective determination of environmental parameters, and yield increase [8]. In another study, Kim et al. [9] developed a common platform to collect agricultural environmental information using cloud-based technology. With the integrated system called Farm as a Service (FaaS), they monitored all data and models in agricultural enterprises. The connection and management of this system were carried out by using IoT devices. Moreover, the IoT-Hub network model was used in this study. It was stated that IoT-Hub ensures the accuracy of technology specialized for agricultural environments since this model supports efficient data transfer for each IoT device as well as communication with non-standard products, and exhibits high communication reliability even in poor communication environments. They reported that the customized FaaS system used in integrated agriculture implements different levels of specialized systems. As a result of this study, it was observed that this system played an important role in the early detection of infectious diseases regarding strawberries.

3. New irrigation techniques used in strawberry cultivation

Water scarcity follows population growth as a result of climate change. For this reason, using agricultural water effectively and safely has now become an unavoidable fact. This is exactly why there is a need for new irrigation methods, irrigation models, and stable water management. For example, low-cost IoT-based sensors and actuators were used to save energy and water, reduce costs, manage irrigation systems properly and effectively, reduce the effects of water-borne diseases and pests, and increase efficiency. Considering the above facts, in a study conducted by Cáceres et al. [10], proposed a control system with an economic and predictive feature that provides an advantage for irrigation periodicity. This system aimed to provide maximum efficiency, sufficient soil moisture for crops, and optimize appropriate water and energy consumption. For this purpose, the predictive controller was developed in this system to minimize damage from water-related problems and prevent energy loss by using soil moisture at different depths. Basic greenhouses, where expensive materials and smart systems are not used, are very common in China, as in many countries in the world. An intelligent planting management platform for strawberries was created based on IoT to intelligently maintain planting activities in these greenhouses. For this purpose, research was conducted in order to improve the intelligent planting system and efficient water use in IoT-based greenhouses with an intelligent planting management platform for strawberries. In order to provide computer-human interaction, a platform was developed that can accurately optimize the climate data required for the strawberry in the greenhouse, which can be controlled manually through the WeChat app on a mobile phone. In this study, the user module was added to the platform, which allows the producer to manually change the climate data in the greenhouse via IoT. This connection was based on narrowband IoT wireless transmission technology at 4G speed. Additionally, the application layer was developed with a design based on

water-saving management knowledge about the strawberry. This systematic design included seven features; strawberry variety selection, planting seedlings, flower and fruit thinning, environmental control, disease and pest control, plant nutrition and fertilization, and economic irrigation. Through the deployed human-computer platform, producers reported that they were able to make adjustments to options such as regular information regarding plant cultivation, query information retrieval, cultivation management, evaluations and alternative decision-making. In addition, the outcomes of the application were summarized as follows: in comparison to the management experiences of the producers, the efficiency of water use increased by 128.55%, the production value efficiency increased by 226.31%, chemical fertilization decreased by 40%, pesticide use decreased by 61.67%, and the cost of pesticide decreased by 32.48%. Therefore, there was a significant decrease in both fertilizer and pesticide use [11].

Lozano et al. [12] conducted a study in Doñana National Park in Spain, in which they measured parameters such as evapotranspiration, crop coefficient estimation, irrigation efficiency, crop yield and water efficiency in two common strawberry cultivars using drainage lysimeters. Later, they developed an Android application that facilitated manual irrigation planning in the strawberry sector and enabled water use. A similar study was performed by measuring agro-climatic data and water requirements for evapotranspiration in strawberry plantations in the Chilean San Pedro region. In the correlation analysis, the researchers primarily used the k-means of time in the series of agro-climatic variables and the methodologically convenient evapotranspiration parameters. The periods when plants need water were classified by the researchers in order to use a water balance controller [13]. For the use of the smart strawberry irrigation system in a greenhouse in Greece, a three-step method, which records data in a network in order to verify the plant nutrition solution and plan the application, was followed. First, hardware with a ready-to-use small-scale smart irrigation prototype solution and software that was tested and evaluated on different plant species was developed, giving useful insights into larger-scale applications. Second, a reference network architecture was introduced that specifically targets smart irrigation and edge data distribution for strawberry greenhouses. Third, by adopting the reference architecture proposed in the second step, a full-scale system and a conventional strawberry irrigation system were compared in a strawberry greenhouse environment. According to the results of this study, this system gave a more accurate result when measuring the amount of soil moisture change and determining the water consumption compared to the traditional irrigation system, and also reduced the cost of irrigation [14]. The authors [15] planned a study to develop and implement an autonomous and automatic irrigation system for irrigation in a strawberry field. For this purpose, Arduino, which uses a smart irrigation system, was developed. Software was used that provides daily information to farmers about the cultivation status, solenoid valve status, soil moisture, and water tank level. The data obtained from the sensors were transferred to the microcontroller and analyzed, and the user was allowed to decide whether to water the plant or not depending on the results. Thus, according to need, the microcontroller decides whether the solenoid valves will open or not. At the same time, the water level in the water tank could be monitored through the ultrasonic sensor. It was confirmed that this system information provided real-time information about the amount of water in the tank, soil moisture in three areas, time, and date. As a result of this study, the researcher acknowledged that the functionality of the system, which was operational throughout the season, was verified by different tests.

In parallel with the developments in irrigation methods in strawberry production, plant nutrition and fertilization studies have also started to gain momentum. Due to excessive land use for production, there are significant deteriorations in soil fauna and flora. The decline in soil organic matter (SOM) due to the intensification of agricultural practices has become one of the most important threats to soil quality [16]. The decline in SOM affects a number of issues adversely. It causes a decrease in soil fertility, biodiversity, microbial activity, and aggregate stability, all of which have a negative impact on plant productivity and health. Typically, small areas with no rotation cycles restrict the agriculture of strawberries. As a result, the soil deteriorates over time as a result of constant replanting. In the areas where strawberries are produced, the decline in soil fertility as well as the emergence of soil-borne plant diseases [17], require a sustainable agronomic technique that can enhance the productivity of strawberries in replanting conditions. The use of organic material in the reclamation of land, compost or cow manure seems to be an effective strategy for enhancing soil fertility, developing soil structure, increasing microbial diversity and activities, developing the water-holding capacity of soils [18], and having a positive impact on crop yields. Furthermore, organic additions maintain or improve soil productivity even after the nutrients required by the plants have been absorbed. Composting is one of the best options available to reduce the amount of organic waste [19]. It represents the largest proportion of the total solid waste generated globally at 46% [20]. The use of compost is one of the most promising and cost-effective options for restoring the structure of degraded soils. For example, 46% of total solid waste consists of organic matter [19, 20]. The conversion of organic wastes with high biological value for soil improvement can be considered to be a sustainable soil management strategy that is cheaper than other options and is compatible with the concept of zero waste [21, 22]. In addition, composting is a much more effective application than other soil organic waste removal methods such as landfilling and incineration, and it was reported that it is more environmentally friendly than other applications in terms of restoring the soil life cycle [23]. Previous studies demonstrated that the application of compost to strawberry plants improves plant growth, yield, and fruit quality [24]. It was reported that the increase in biomass and root proliferation in the root zone of strawberries and many plants causes excessive growth in the roots and causes a decrease in yield and quality [25]. It is very interesting to understand how the photosynthetic C (carbon) and biomass of strawberry plants are distributed among the growth organs and how it affects fruit size and quality [26, 27]. Due to global climate change, there have been great changes in the soil and climate structure. For this reason, new breeding studies about drought resistance are continuing for strawberry cultivation. In this regard, iron nanoparticles and salicylic acid media were used in order to determine the optimum combination resistant to arid conditions in the tissue culture of the strawberry (*Fragaria* × *ananassa* Duch.) plant. According to the results, salicylic acid reduces the negative effect of drought in strawberry plants and positively affects plant growth in vitro conditions. In addition, a better result was obtained in strawberries using iron nanoparticles compared to the control group regarding the drought. The use of iron nanoparticles together with salicylic acid in strawberry tissue culture studies will make strawberry plants more resistant to drought stress before they are transferred to the field [28]. In addition to the tissue culture studies related to drought stress resistance mentioned above, the use of dazzling technologies in irrigation systems along with plant nutrition is increasing day by day. It is important for plant development to plan plant nutrition programs and evaluate the results together with irrigation applications for strawberries. Therefore, sensor networks were used recently to measure

soil moisture, electrical conductivity EC (measures the total salts in solution), and climate data in both soil-less cultivation and traditional cultivation. These systems provide fast and reliable information to manufacturers at the right time. This provides the opportunity to intervene immediately in any negative situation in plant breeding, providing significant advantages in plant development and productivity. Wireless sensor networks can offer cost-effective solutions against adverse situations such as water shortage and climate change that strawberry producers may face. In a study conducted in the USA, controlled irrigation systems were installed on two commercial strawberry farms in Maryland using wireless sensor networks. Then, the efficiency of irrigation practices in these two commercial farms and the effects of irrigation practices on plant growth and fruit quality were compared. Sensor-controlled irrigation was based on measuring the volumetric moisture values taken from the sensors placed in the root zone of the plant on the predetermined soil sets. Using a software program (Sensorweb™; Mayim LLC, Pittsburgh, PA), control nodes were enabled to apply irrigation for a specified period of time when the average sensor reading drops below the set point. Real-time root zone humidity, temperature, and electrical conductivity values were recorded at 15-minute intervals by monitoring/control nodes, and information was transmitted to both producers and researchers thanks to the internet using Sensorweb™. Irrigation volumes, plant growth, fruit yield, and fruit quality parameters were evaluated for two commercial production systems on farms. The utility of the wireless sensor networks system for spring frost warning was also tested by researchers by comparing the accuracy of canopy-based temperatures and on-farm weather station data with satellite (e.g., Skybit™) data [29].

4. Strawberry production methods

4.1 Hydroponics

The use of the hydroponics method in herbal production dates back many years. During the Babylonian period (605–562 BC), plants on the terraces were irrigated from the Euphrates River using pumps. It is understood from historical records that the Aztecs living in Tenochtitlan in the 40s BC produced plants on man-made islands by a method called chinampas, in which plants were directly in contact with water [30]. Until the present, chinampas have been producing 40.000 t/yr. of vegetables and flowers annually, consequently, the FAO recognized chinampas as a globally important agricultural historical heritage [31, 32]. As is known, hydroponic plant production systems are one of the fastest growing sectors in horticulture. The use of hydroponic crop production methods has increased by 20% worldwide between 2016 and 2019. In addition, the production value in dollar terms increased from 6.9 to 8.3 × 109 dollars in the same interval, and it is estimated that these values will increase up to 45% in 2025 [33]. In addition, the annual growth rate is estimated to increase by 6.8% between 2019 and 2024 in areas such as the United States, Canada, Germany, United Kingdom, China, Brazil, the Middle East, and South Africa [34, 35]. Strawberry is more popular than any other fruit in the world. Traditional strawberry farming, on the other hand, has major difficulties with productivity and plant loss due to soil-borne plant diseases. Besides, the chemicals needed to treat soil are quite toxic. That is why growers have opted for hydroponic strawberry cultivation. With this approach, the issues such as pest and disease control, high productivity in the field and good quality of the fruit are considerably achieved. In regions where the

climatic conditions are ideal, the soil is not a concern thanks to hydroponic farming. Soil-borne pathogens and the damaging impacts of pests are the main reason why hydroponics in greenhouse strawberry cultivation are demanded nowadays. Hence, owing to hydroponics, growers can increase yields and enhance product quality by using correct fertilization and water management [36–39]. For this method, producers have generally used the varieties such as Rubigen, Sabrina, Festival, and Albion.

Cocopeat is a growing medium used frequently by gardeners and especially for hydroponics. Cocopeat is made free from sand and out of coconut husk which is why it is appropriate for use in agriculture, particularly hydroponics. Thanks to its high water-holding capacity, %100 organic feature and pH of 5.7–6.5, Cocopeat is one of the best products to be used in agriculture. For the greenhouse cultivation of hydroponic strawberries, diagonal planting with 13 seedlings placed at 15 cm spacing is used for generally around 12 thousand seedlings per decare. Planting begins in October, with the first harvest occurring in December. This process continues until the middle of June. At the end of this process, approximately 10 tons of product can be obtained if suitable garden management methods are used and a correct plant nutrition program is implemented. Producers have become more aware of their production processes. Despite the ongoing rise in input costs, growers continue to crop since they still make a profit. Bumblebees are used to enhance pollination and fertilization, especially in greenhouse production. By avoiding the use of pesticides, bumblebees improve product quality while also contributing to natural production. Since the initial expense of growing strawberries in a greenhouse is so expensive, easiness, and productivity are critical. Strawberry production is generally limited to a six-month season, however, by using hydroponics in cultivation, this may be prolonged up to 12 months. Thanks to this benefit, fresh strawberries may be brought to market for a period of 12 months. When strawberries are properly cared for, production and efficiency in hydroponics may be four times higher than in traditional agriculture. Regardless of the significant initial investment, hydroponics has been used in the Mediterranean region by gardeners for the cultivation of strawberries in recent years.

This method is preferred since customers are prepared to spend the most and there is a lot of demand [40]. In addition, in greenhouse hydroponic strawberry cultivation, it was determined that frigo seedlings are advantageous in terms of yield and tubed seedlings are advantageous in terms of earliness [41]. Likewise, frigo seedlings are advantageous in terms of productivity and tubed seedlings are advantageous in terms of early maturing. Briefly, the productivity has been enhanced and fresh strawberries for the market have been available for over a year, thanks to the adoption of hydroponic technology in the strawberry greenhouse culture. Moreover, with this approach, plants have been protected from soil-borne pathogens and pests while the nutrition they provide has been boosted [4].

Hydroponic systems can technically be classified into two groups. The first is open systems that provide nutrients directly and once to plant roots, and the other is closed systems that provide a continuous and cyclical supply of nutrients to plants. In addition, the nutrient solution given once in open systems comes into contact with the plant roots continuously or occasionally. The media substrates and nutrient solutions used in this system are used only once; that is, they are not reused. Some advantages of open systems are that the plant nutrition solution application is simpler and the risk of infection is less for the plant [42]. In closed systems, plant nutrition solutions are applied to the plant roots, which are given alternately to the plants and collected in containers, as a liquid substrate or as a liquid solution. Substrates used can be organic (such as coconut fiber, rice husk, sawdust, and charcoal) or inorganic (pumice, sand,

gravel, and ground brick). In this plant production method, the use of water and nutrients is generally the best, and the disadvantage is the need for electricity [35, 43]. However, in recent years, attempts were made to minimize these disadvantages by using renewable energy. Furthermore, additional applications such as sufficient oxygen uptake of plant roots, suitable temperature environment, adequate nutrient supply, and increasing the activity of beneficial microorganisms for the plant are rapidly applied. Thus, smart farming methods are used in soilless culture in order to understand and follow the communication between plant roots and shoots in strawberry plants in a deeper and more detailed way, and as a result, new technology-based trends were developed to improve plant roots [44]. In another research, strawberry production was carried out using a hydroponic system in tunnel greenhouses to protect against the harmful effects of rain. In this study, a significant increase in yield was achieved by protecting plants from the harmful effects of rain and reducing disease and pest pressure [45, 46]. Hydroponics is a fairly new method that can produce products in and out of season under fully controlled conditions without soil. As is well known, plant feeding and fertilization processes are carried out entirely through the irrigation system in this production model.

In agricultural production, applications such as hydroponic production, vertical agriculture, or soilless agriculture are also increasingly popular for strawberry production [47, 48]. Production methods of vertical farming and hydroponics can be applied in smaller areas and use 95% less water and nutrients than traditional strawberry production methods [49]. At the same time, hydroponic production methods are more advantageous than other methods, since production can be closer to consumption centers in arid and semi-arid conditions regardless of soil quality [50]. Besides, this production model has many advantages such as more efficient and correct use of water management, production throughout the year, higher yields and minimizing the use of pesticides compared to soil culture [51]. It is extremely important to apply for an accurate and effective plant nutrition program in strawberry production with the hydroponics system. In this system, remote-controlled automation systems have been used in strawberry and tomato production in recent years [52, 53]. In this method, the properties of irrigation water and the accuracy of these properties are extremely important. In remote sensing systems, the turnkey solution collects information about the growth of plants in soilless strawberry cultivation and makes predictions accordingly. Previously, a compact sensor with an oscillator circuit was used to monitor the irrigation status and concentration of fertilization of the plants [54]. Moreover, there was a noticeable increase in the use of light emitting diode (LEDs) technology in strawberry production in recent years. Some researchers report that LED lights can be used alone or in combination with other light systems to increase plant behavior, yield, and fruit quality. In a study conducted for this purpose, three different light systems (LED blue, LED red, and fluorescence neon tubes as control) were used to evaluate the effect on plant growth and fruit quality in soilless strawberry production. According to the results, blue LED light with a wavelength of 400–500 nm promotes biomass accumulation, especially at the root and crown level. In addition, fruit set (65 g plant^{-1}) in plants treated with blue light was 25% higher than plants in the control group (45 g plant^{-1}) and with red light (35 g plant^{-1}). There was no change in the main quality traits of the fruit, but it was determined that the color and anthocyanin amounts were low as a result of both applications. As a result of this study, it was reported that the use of blue light increases fruit yield by keeping fruit quality stable [55].

Since the plant nutrient solution is used repeatedly in closed hydroponic systems, root exudates, which have an intraspecific allelopathic effect, accumulate in the

strawberry roots over time and inhibit plant growth by causing an autotoxic effect on the plants. In a study, electro-degradation (ED) was applied to the culture solution in order to degrade these root exudates in strawberries and to increase fruit yield and quality. During this application, four types of nutrient solutions were applied. These include renewed, non-renewed, and non-renewed with direct current electrode gradation (DC-ED) and finally non-renewed with alternative current electro-degradation (AC-ED). While 25% standard Enshi nutrient solution was added to the culture solutions which were renewed every three weeks, DC- and AC-ED were applied to the non-regenerated solutions. It was reported that the fruit yield obtained with the renewed solution (225.9 g plant^{-1}) and the yield obtained from the non-renewed and AC-ED solution provided statistically similar results. Fruit yield was decreased to approximately half (114.0 g plant^{-1}) in the non-renewed solution compared to the renewed solution, but plants treated with the non-renewed solution with DC-ED produced an intermediate yield between the non-renewed and renewed solution. The growth performances of the plants treated with the renewed nutrient solution were higher than the plants treated with the non-renewed solution with DC-ED. Briefly, it was indicated that nonrenewed and AC-ED nutrient solutions may have a positive effect on fruit development, yield, and quality in strawberries [56]. In addition to the hydroponic method mentioned above, new methods such as vertical farming are also used in strawberry production.

4.2 Vertical farming (VF) in strawberry production

In recent years, the area of arable land has been declining gradually due to the increase in the human population, urbanization, pollution, and soil erosion. While the world population living in urban areas is 60%, it is estimated that this rate may increase to 68% in the 2050s with the increase in immigration in the 2030s [57, 58]. Vertical farming will be an important factor in solving problems occurring due to these challenges. Regarding advanced farming techniques such as vertical farming, controlled-environment agriculture is performed so that high yields are obtained by using fewer resources in a restricted area [54, 59, 60]. Unfortunately, industry-based agricultural practices disrupt the natural structure of the soil and increase the erosion rate (10–40 times). Moreover, according to some studies, it is estimated that these agricultural production methods can reduce clean water resources by about 70%. However, in VF applications, high-efficiency production can be achieved using much less water and space. It was stated, for example, that a Japanese agricultural tool named Mirai provides information on 25.000 m^2 of the indoor agricultural farm to producers and academics. This agricultural vehicle provides 40% energy and significant water savings [61]. As a leader of VF, the aviation farm has increased the agricultural product yield of New York by 390 times and 95% water savings [62]. Carbon dioxide is a very vital factor in agricultural production. As a result, a new toolkit was built with wireless communication that can be handled by mobile phones to properly determine carbon dioxide estimation in vertical farming. Moreover, these devices provide automatic observation for all developmental stages of plants [63, 64]. In recent years, hydroponic vertical farming has become the most advanced, environmentally-friendly agricultural production technique that does not harm biodiversity. Ways to achieve this are to focus on deserts, which make up one-third of the world. Based on this idea, Chinese and Norwegian experts are currently working on the application of these production methods in the deserts of Dubai, Qatar, Jordan, and China. The most important argument for achieving this goal is the use of technologies such as IoT

[65, 66]. In recent years, due to negative factors such as climate change in agricultural lands, pollution of soils due to the intensity of agricultural practices, use of agricultural lands as settlement areas, and deterioration of soil structure, plant production companies, or their investors have pioneered the use of horizontal farming techniques, which is a different and alternative method for strawberry production.

4.3 Using horizontal systems in strawberry production

Horizontal systems can be on the ground or have the potential to be stacked on top of each other. Since fruit harvesting and other agricultural tasks are easier at breast- or neck height, horizontal systems are preferred. Containers, pots, bags, and gutters can be used as a medium for plant growth. Since the plants need regular irrigation and fertilization, the preferred environments for growing plants should have sufficient depth and high water-holding capacity. In this method, in contrast to field production, the ability to store water and nutrients is limited. It was reported by experts that the use of galvanized metal, which cause high concentrations of zinc accumulation, should be avoided as a plant-growing medium. In this system, as the plants grow, they make use of wire and other support systems so the plants can stand upright to provide convenience during harvest [67]. In addition to the use of hydroponics, vertical farming, and horizontal systems in strawberry production, there has been an increase recently in the use of quite new techniques such as robot technology, artificial intelligence, and machine learning in the harvesting process.

4.4 New harvesting techniques used in strawberry production

As is known, harvesting is one of the most important criteria in determining product quality and productivity in agricultural production. It is reported that 3.1 billion USD product loss is expected every year in the USA due to the lack of qualified manpower [68]. According to data from the United States Department of Agriculture, 14% of agricultural input costs are spent on manpower. At the same time, the labor cost in industrial agriculture can reach up to 39% [69]. Deep studies are still needed about the production of more specific sensors for the effective use of automation systems in fruit harvesting. For example, strawberries are berry-like fruits that can be consumed in any season of the year. However, the use of manpower in strawberry harvesting and packaging processes is one of the most effective factors in increasing fruit prices [70]. Since the strawberries grown in greenhouse conditions are harvested with robotic harvesting technology, the cost is reduced. A robot named Agrobot was developed for this harvesting process and this robot can harvest and pack strawberries from rows of plants [71]. For example, Agrobot's SW 6010, which is a semi-automatic robot model, was reported to provide significant convenience in strawberry harvesting. Another example, Tektu T-100, is another strawberry harvesting robot model that can be charged with electricity and is environmentally friendly [70]. In recent years, due to the decrease in qualified personnel and manpower in agricultural production, the necessity of minimizing losses during the harvest, and reasons such as time and cost savings force farmers to use agricultural robotic technologies. Recently, some researchers reported that fruit-picking robots are being developed by private companies rather than academic researchers. Moreover, the problems in seasonal fruit picking jobs necessitate the use of automation systems in fruit harvesting. In the last 5 years, there was a significant increase in the number of companies producing fruit-picking robots. Advanced vision systems, image processing techniques and artificial

intelligence are used in the harvesting of berries, pome fruits, apples, and stone fruits. For example, the mobile robot can pick up strawberry fruits growing on strawberry pads several feet above the ground and can sort them by size or weight and place them in fruit baskets as they move. RGB (Red-Green-Blue) cameras with three-dimensional (3D) features are used to determine the position and ripening times of the fruits. The robot gently harvests with the help of an arm that imitates the human arm extending from the bottom up, has padded soft-grip plastic claws and can rotate 90° to pluck the fruit from the stem. It can harvest soft fruits at a rate of 11.500 berries (between 180 and 360 kg) in a 16-hour day, well beyond the 50 kg typically collected by a human [72]. In light of this information, it is expected that there will be an increase in the use of robotic technologies in fruit harvesting.

In this context, many studies were carried out around the world. A deep learning algorithm, Rotate-YOLO (R-YOLO) was developed to perform real-time location and harvesting of strawberries regarding a strawberry robot technology that performs the strawberry harvest. In addition, with the help of the bounding box, it accurately detects the plucking point with an angle to follow the direction of the strawberry and harvests it gently. It was reported that the robot, customized for the harvest of ridge-planted strawberries, with fiber sensors on its end-effector to control its speed, avoids real-time distance measurements. As a result, the researchers stated that the robot using Rotate-YOLO (R-YOLO) was successful in correctly identifying strawberries at a speed of 0.056 per second, with a 640 × 480 resolution RGB camera and a rate of 94.43% [73]. Furthermore, the monitoring system used in the strawberry harvest monitors the ripening time of the strawberry, reduces possible injuries during the harvest and detects diseases and pests at the right time. Therefore, the strategic advantages of agricultural production are implemented in different strawberry production applications by using innovative technologies. Experts are working on a system that can monitor strawberry cultivation in real ecologies, as well as access more accurate information about the harvest time of the strawberry plant and make the right decision. The system recommended above has a design that analyzes and stores the climatic data for the strawberry and images recorded through the IoT-Edge-AI-Cloud concept [74, 75]. The IoT-Edge device, Arduino and Raspberry Pi will be sufficient to install such systems at affordable costs. Even if the strawberry producer expands their production area, the system operated through AI-Cloud can easily be expanded as well according to the purpose and demand. The system can effectively evaluate the climate data in strawberry cultivation by reasoning with an artificial memory of the maturity stages of the strawberry plant. All data obtained in strawberry production (such as harvest time, disease detection, and production data) are analyzed by evaluating the data transferred to the integrated interface. In a study, ecological data and images of strawberries from hydroponic strawberry production were obtained using the IoT-Edge module and transferred to a nano-sized private AI-Cloud-based analysis station module and visualized to determine when to harvest. The monitoring and analysis results were envisioned with an integrated interface supply for major data such as fluctuating yields, harvest periods, and pest diagnosis. The suggested system is based on the idea of AI-Cloud. This concept helps server container to be scaled up quickly and simply as it grows. The suggested system was put to the test in a home where Seolhyang strawberries were grown using hydroponics. Over the course of four months, 1.316.848 actual environmental data points pertaining to 13 data kinds were monitored. Using 1575 strawberry photos from the Smart Berry Farm and a Google Images search, the harvest time was predicted with a high accuracy rate of 98.267% [76].

5. Conclusion

In conclusion, the use of new methods and techniques in strawberry cultivation has become a necessity. The reason for this is the importance of strawberry in human nutrition, based on its good taste and aroma, pleasant smell, and also the increased demand and supply in world strawberry production and the market since strawberry is a dietary fruit. Due to the mismanagement of cultivated soils and water resources used in strawberry cultivation around the world, the decrease in these production areas, the pollution of soil due to excessive use, and the rapid increase in labor and input costs, researchers and producers have been searching for new alternative production models in strawberry production. For this reason, new production methods have begun to be developed for smart agriculture systems that are close to large consumption centers, and use less water and soilless farming methods. These new production methods are expected to achieve maximum efficiency by reducing manpower costs and minimizing the damage caused by human error, especially in harvesting and other processes. Consequently, this chapter shed light on studies performed about smart strawberry production models based on new technologies and will be a reference for information technology and artificial intelligence-based studies in strawberry production from planting to harvesting and packaging.

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