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Comparison of Conventional Hydroponic Nutrient Film Technique (NFT) and Smart System Based on Internet of Things (IoT) in the cultivation of Bok Choy (*Brassica rapa* L.) Variety Nauli F1

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Abstract

Decrease of agricultural land due to increasing population, agricultural land conversion especially in urban communities lead to the use of technology for increasing the efficiency of cultivation practices. Modern agriculture or Smart Farming which utilized the use of automation and Internet of Things (IoT) is considered as one of the solutions for that purpose. This study aims to examine the comparison of Nutrient Film Technique (NFT) hydroponic using conventional and smart systems for the growth and yield of bok choy (Brassica rapa L.). Observations conducted on plant height, leaves number, SPAD, leaf color, plant width and plant weight 2 times a week for 4 weeks. Environmental observations were made on air temperature, water temperature, air humidity, pH and Total Dissolved Solution (TDS) 3 times a week for 4 weeks. Data analysis was carried out using T test. The Autonomus Monitoring and Controlling System (AMCS) was used in this study. The smart system monitored and controlled the pH and TDS, and environmental conditions using Internet of Things. Result showed that the smart system was able to monitor and control bokchoy requirements according to the range of references given. The test results showed that bok choy growth was not significantly different between the two systems. Further studies on biological and environmental aspect of more precise bok choy nutrition and microclimate requirements need to be conducted for better result.

Keywords: Internet of Things (IoT), Nutrient Film Technique (NFT), Smart Farming

Introduction

Indonesia's annual growth rate is directly proportional to the increasing demand for food commodities. According to data from the Central Statistics Agency [3], the average growth rate in Indonesia from 2021 to 2023 increased by 1.17% per year and continues to increase annually. Population growth continues to increase significantly, leading to a decrease in available land for agriculture, especially in urban areas, each year. Facing dwindling agricultural land in urban areas and the food crisis, urban communities are encouraged to seek adequate solutions. Hydroponics is the right solution to overcome land constraints for farming in urban areas. One type of hydroponic system that is very often used in urban areas is the Nutrient Film Technique (NFT) hydroponic system [8].

Nutrient Film Technology (NFT) is one of the most widely used hydroponic systems in Indonesia. The NFT system uses a shallow layer of water so that the roots can be irrigated by the water layer. The water will circulate continuously and be mixed with a nutrient solution that must be appropriate to the needs of the plants, so that the plant's nutritional needs will be met [5]. The nutrient often used in cultivation with a hydroponic system is a mixed nutrient AB. AB Mix nutrients contain 16 essential nutrients needed by plants, of which 16 elements are needed in large quantities (macro) namely N, P, K, Ca, Mg, S, and 10 elements are needed in small amounts (micro) namely Fe, Mn, Bo, Cu, Zn, Mo, Cl, Si, Na, Co [4]. In addition to nutrients, water conditions must also be considered such as the level of acidity pH, oxygen, temperature and humidity of the environment must also be maintained to suit the needs of cultivated plants. Bok choy is a very affordable vegetable commodity for all groups. This vegetable has a high nutritional content, making it ideal for consumption to support a healthy lifestyle [9].

Hydroponic vegetable cultivation in urban areas presents several challenges, one of which is the need for continuous, smooth monitoring to ensure no issues disrupt the bok choy cultivation process. This is exacerbated by the busy lifestyle of urban communities with limited time to manage bok choy. Therefore, an automation system utilizing Internet of Things (IoT) technology is needed to directly monitor plant nutrient requirements. This smart system is expected to make hydroponic vegetable cultivation more efficient and effective, and can help overcome the challenges of caring for plants in busy urban environments. The implementation of IoT provides users with easy access to real-time monitoring and regular monitoring, even while busy. IoT also helps regulate nutrient concentrations and maintain appropriate water pH levels, and alerts them to any errors or problems with the existing hydroponic system [11].

This study aimed to compare the growth of bok choy (*Brasicca rapa* L.) based on plant height, plant weight, header width, number of leaves in 2 NFT hydroponic systems, namely conventional and IoT-based smart systems and to optimize the smart hydroponic system for bok choy (*Brassica rapa* L.) cultivation.

Materials and Methods

Based on the research in the introduction, the author presents 4 pieces of data: bok choy vegetative growth, bok choy harvest, environmental and nutritional conditions of hydroponic NFT, and comparison of plant data with and without control.

This study tested two Nutrient Film Technique (NFT) hydroponic cultivation systems using two different systems, namely conventional with TDS and nutrient water monitoring and smart systems with monitoring and control systems for all conditions in the hydroponic environment such as pH meters, TDS meters, actuators for nutrient water including temperature, humidity and water level as shown in Figure 1.

Cultivation activities were carried out at the LAPTIAB Green House, BJ Habibie Science and Technology Area, Serpong, Banten, starting from preparation for installation, seeding, transplanting, monitoring and control and reporting from March to May 2024. The assembly of the Internet of Things-based Smart System was carried out at the Technology Building 3, BJ Habibie Science and Technology Area, Serpong, Banten.

The materials used are bok choy (*Brassica rapa* L.) Nauli F1 variety, mixed AB nutrients, rockwool, pH rise, pH fall and raw water. The equipment to be used is an NFT hydroponic installation, an IoT-based smart system, rockwool molds, rockwool cutting saws, TDS meters, pH meters, measuring cups, SPADs, meters and stationery. The experiment consists of 2 treatment populations, namely the Conventional NFT hydroponic system and the Internet of Things (IoT)-based Smart System, each of which consists of 20 samples randomly distributed in the front, middle front, middle back, back to adjust the conditions of plants representing the population, all samples from both systems are 40 samples. The total number of plants in the installation is 250. The data obtained is processed using the T test to see if there is a significant difference between the two groups.

The experiment began with sowing bok choy seeds in seed trays with rockwool as the growing medium. Rockwool was cut using a rockwool cutting saw on a rockwool mold measuring 2.5 cm × 2.5 cm. Wet the rockwool with water until evenly wet with water on the tray that does not exceed the height of the rockwool, then a hole in the center of the rockwool using a toothpick with a depth of about 0.5 cm. The seeds were first soaked in warm water for 15 minutes so that seed germination increases. The seed tray was placed in a dark room for 1 day and moved to a shaded place away from direct sunlight for 5 days. On the 7th day, the bok choy seedlings were given an AB Mix solution of 800-1000 ppm so that the growth of the bok choy seedlings increased. Seed transplantation was carried out on the 14th day after seeding to the NFT hydroponic installation. The fertilizer used in this experiment was AB Mix fertilizer. AB Mix fertilizer is made with a ratio of 10 ml AB Mix: 1000 liters of raw water with a TDS concentration of 800 - 1000 and a pH of the water solution of 5.8 - 6.2.

NFT hydroponics uses closed pipes and continuous circulation with a high slope of the hydroponic circuit of 3°. This circuit is equipped with a 50 liter water tank and a Yamano WP 104 water pump (capable of pumping 2000 liters of water per hour). The NFT Smart hydroponic system uses pH, TDS, T (temperature), RH (humidity) sensors and there are actuators that will automatically control pH, TDS, nutrients and automatically fill raw water for the nutrient tank. The microcontroller board used for the control process is Arduino Mega 2560 while the monitoring device uses Raspberry pi 4 which allows data from hydroponics to be accessed directly via the internet.

Observations will be made on the growth of bok choy during the transplantation period, which is 4 weeks with 2 observations per week for a total of 8 observations on 40 samples used as replicas. Observations on bok choy growth include height, number of leaves, weight and number of leaves of bok choy plants. Observations are made on the growth of bok choy during the transplantation period for 4 weeks with 2 observations per week for a total of 8 observations on 40 samples used as replications. Observations on bok choy growth include height, number of leaves, weight and number of leaves of bok choy plants. In addition to observing growth, environmental observations are also carried out including greenhouse temperature and humidity, pH and TDS of each system manually. Observations on environmental conditions are carried out after growth observations, namely 2 observations per week.

The Arduino Mega 2560 microcontroller functions as a data collector from various sensors: pH sensor, EC sensor, water level sensor, humidity sensor, and temperature sensor. All data transmission will be encrypted and sent to the Raspberry Pi 4 to cloud storage that can be accessed through an internal server in the form of a monitoring dashboard and stored in a database. A Real Time Clock (RTC) is used as a time tracker that can be used to monitor the situation according to the incident hour. Monitoring and controlling will run 24 hours with a data upload frequency of 30 seconds according to the scheme in Figure 1. Each sensor will be monitored using an Arduino Mega 2560 which will be able to accommodate all data from pH sensors, TDS sensors, water temperature sensors, temperature and humidity sensors supported by LoRa (Long Range) as a controller that will upload data to the cloud and can be accessed online.

In this study, the author only implemented the AMCS system tool that was already available and was not involved in the development or creation of the system. Therefore, the main focus of this study is on the process of implementing, testing, and analyzing the performance of the AMCS tool in the research context. Growth observations, environmental observations were also carried out which included the temperature and humidity of the greenhouse, pH and TDS of each system manually. Observations of environmental conditions were carried out after growth observations, namely 2 observations every week.

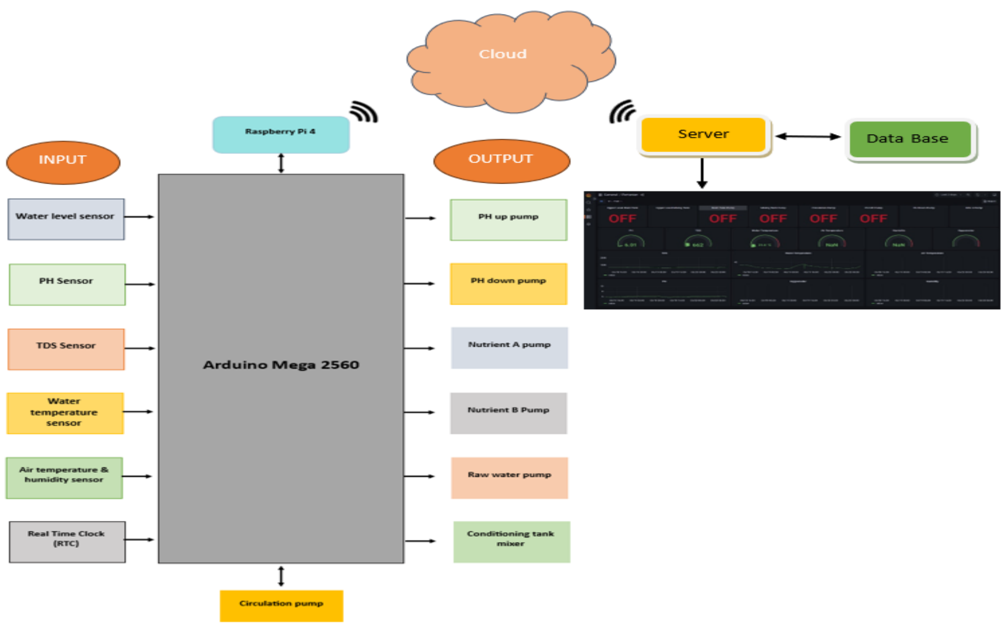

Figure 1. Flow Chart of Monitoring and Controlling in the Internet of Things (IoT)-based Smart System NFT Hydroponics

The Arduino Mega 2560 microcontroller functions as a data collector from various sensors: pH sensor, EC sensor, water level sensor, humidity sensor, and temperature sensor. All data transmission will be encrypted and sent to the Raspberry Pi 4 to cloud storage that can be accessed through an internal server in the form of a monitoring dashboard and stored in a database. A Real Time Clock (RTC) is used as a time tracker that can be used to monitor the situation according to the incident hour. Monitoring and controlling will run 24 hours with a data upload frequency of 30 seconds according to the scheme in Figure 1.

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Results and Discussion

Comparison of bok choy plants produced

Bok choy plant growth observations were conducted eight times during 23 Days After Planting (DAP). Figure 2 shows the results of bok choy plant growth observations compared between two hydroponic systems: a conventional system with only monitoring and an intelligent system with monitoring and control systems. This graph includes four main parameters: bok choy height, number of bok choy leaves, bok choy weight, and bok choy crown width. Meanwhile, Figure 3 shows the results of the wet weight of bok choy at the crown and roots, as well as the dry weight after being placed in an oven at 40°C for 3-4 days.

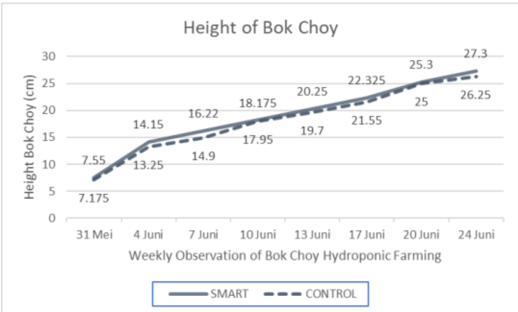
In Figure 2, each graph shows that bok choy cultivated without the intelligent system exhibited better growth than those cultivated with the intelligent system. Growth patterns for plant height, leaf number, plant weight, and leaf width were consistently higher in the control system, particularly in the final week of observation.

Based on the graph in Figure 2 (a) plant height, plant height was measured by measuring the plant from the root and crown boundaries on the rockwool media to the highest leaf using a ruler. The height of bok choy plants in the control and intelligent systems had a not very significant difference in plant height growth. At the last observation, the height of the intelligent system plant was 27.3 cm while in the control it was 26.25 cm.

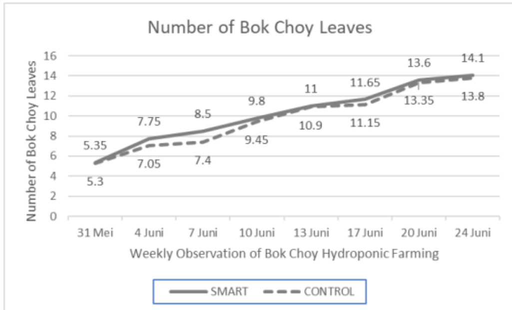
Based on the graph in Figure 2 (b) the number of leaves, the number of leaves is calculated by counting the leaves one by one in the plant sample for each observation. The number of bok choy leaves in the control and intelligent systems has a not very significant difference. In the 7th observation, the number of leaves owned by the intelligent system is not significantly different, namely 14.1 in the intelligent system and 13.8 in the control system.

Based on the graph in Figure 2 (c) plant weight, the plant weights were measured by weighing the bok choy plants, net pots, and rockwool using a digital scale. The weights of the bok choy plants in the control and intelligent systems differed slightly. The final observation showed that the weights of the plants in the intelligent system were 73.75 grams and 58.85 grams in the control.

Based on the leaf width graph in Figure 2 (d), leaf width was measured at the widest part of the sample leaf by measuring from tip to tip of the widest sample crown using a ruler. The width of bok choy leaves in the control and intelligent systems did not differ significantly. The final observation showed that the width of the leaves owned by the intelligent system was 28.2 cm and 26.45 cm in the control system.



(a)



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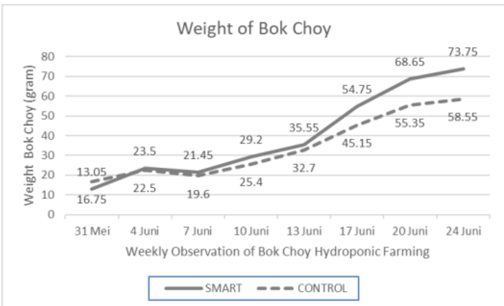
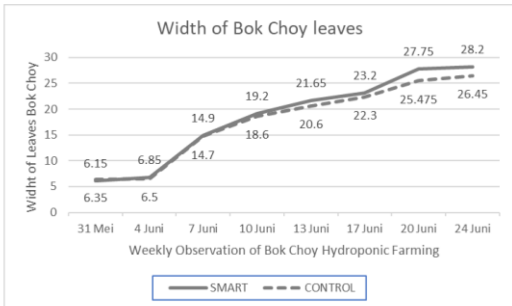


(c)



(d)

Figure 2. Vegetative growth of bok choy (Brassica rapa L.) The Nauli F1 variety for 4 weeks with 8 observations. (a) Height growth; (b) Leaves numbers of bok choy plants; (c) Fresh weight of bok choy plants; (d) Width of leaves.

Bok choy Cultivation Harvest

After observations were made during the hydroponic growing period for 4 weeks, the wet and dry weight of the harvested samples were calculated. The harvest yield was divided into two, namely crown weight and root weight. After the wet weight was weighed, the dry weight was weighed by placing the sample in an oven at 40°C for 3-4 days to obtain the dry weight of the head and roots. The samples were weighed using a digital scale without using netpots and rockwool media. The data results are presented as shown in Figure 3. Figure 3 shows the yield of bok choy plants in two different systems suitable for the research method. The results indicate that the yield in the smart system did not differ significantly in terms of crown and root wet weight and crown and root dry weight.

In the graph of Figure 3 (a) wet and dry weight of the head, the wet weight of the intelligent system is higher, namely at 49.45 grams, while in the control it is 33.46 grams. The intelligent dry weight is also higher, namely at 2.278 grams and 1.633 grams in the control system. In the graph in Figure 3 (b) wet and dry weight of the root, the wet weight of the intelligent system is higher than the control system, namely 7.547 grams in the control system and 7.074 grams in the intelligent system. The dry weight of the control root is also higher, namely at 0.976 grams and 0.748 grams in the intelligent system.

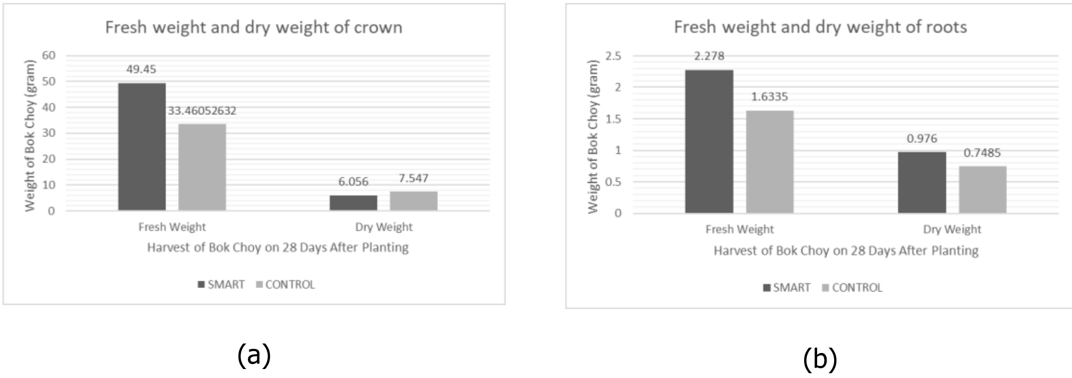


Figure 3. Bok choy harvest. (a) Fresh weight and dry weight of Bok choy crown; (b) Fresh weight and dry weight of bok choy root.

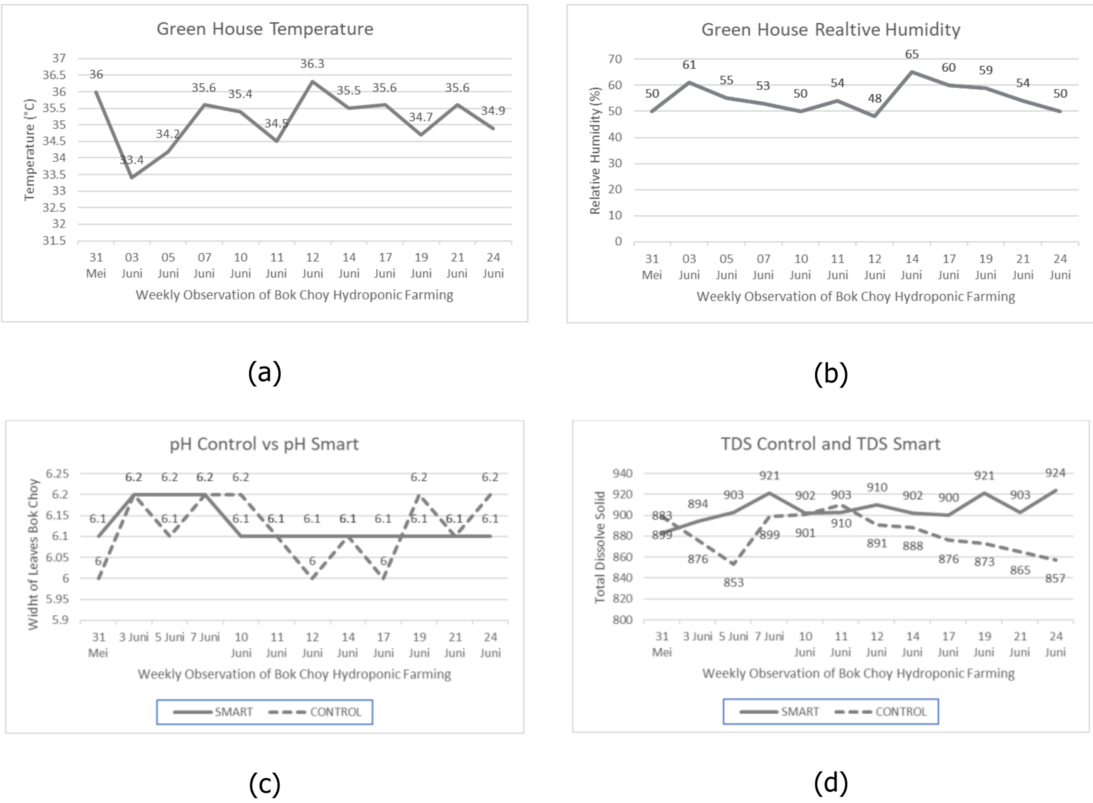


Figure 4. Environmental and nutritional conditions of hydroponic Nutrient Film Technique (NFT). (a) Greenhouse temperature; (b) Greenhouse RH humidity; (c) Comparison of pH of AB Mix solution on control and smart system; (d) Comparison of TDS of AB Mix solution on control and smart system.

Bok choy cultivation environment

Environmental observations included greenhouse temperature and humidity, as well as monitoring the pH and TDS of each culture for control, as shown in Figure 4. Observations showed that the intelligent system had a good ability to maintain the stability of the solution pH and nutrient concentration (TDS) compared to the control system. Conversely, the control system showed greater fluctuations in the two parameters compared, namely the pH and TDS of the solution. This is due to the role of the actuator in maintaining the nutritional environment so that it can comply with the given reference.

Based on the graphs in Figure 4 (a) and (b), the temperature and humidity of the greenhouse indicate that the condition of the greenhouse is still in a normal state, that is, not too hot and not too humid as seen from the existing observation data. Temperature data shows that the temperature conditions of the greenhouse range between 34.9 ° C – 36 ° C. While the humidity conditions are 48 – 65%. Based on the graph in Figure 4 (c) Comparison of the pH of the smart system and the control, the smart pH value is around 6.1 while the control is in the range of 5.8 – 6.2. This shows that there is a difference in the pH value which is quite different but still within the range of the given reference. Based on the graph in Figure 4 (d), the comparison of solution concentration (TDS) is not much different, but it can be seen from the graph that the control fluctuation is much higher than the TDS conditions of the smart system, where in the smart system the range of TDS changes is 924 – 899, while in the control system the range is 903 – 857.

Processing bok choy growth data

Processing bok choy growth data from research parameters using SAS version 9.4 application. The results of data analysis with T Test for comparison of several bok choy growth parameters between two systems, namely the control system and the smart system at 4 weeks after planting which include plant height, number of leaves, crown width, fresh crown weight, dry crown weight, fresh root weight and dry root weight are shown in Table 1.

Table 1. Result of T Test at 4 weeks after planting on height, leaves number, canopy width and fresh weight of bok choy (*Brassica rapa* L.)

Variable	Control		Smart		T-test control vs smart	
	Mean	Standard Error	Mean	Standard Error	T value	P value|
Height (cm)	26.25	0.16	27.3	0.48	-2.69	0.012*
Leaves number	13.10	0.31	14.10	0.52	-1.97	0.056*
Canopy width (cm)	25.48	0.44	27.20	0.52	-2.51	0.017*
Weight (g)	58.55	2.1	73.35	4.3	-3.20	0.003**
Dry weight	1,643	0.092	2,278	0.18	-3.17	0.004**
Fresh weight roots	7.06	0.26	7.55	0.54	-0.82	0.420 tn
Dry weight roots	0.748	0.019	0.976	0.055	-3.92	0.001**

Description: tn= not significantly different; *= significantly different at α =5%; ** = very significantly different at α =1%.

Discussion

Overall, each parameter observed included plant height, number of leaves, crown width, and plant weight. The smart system had higher values than the control system. This is due to environmental conditions, such as pH and TDS, in the smart system being more maintained according to the given reference values. The bok choy harvest parameter showed that the fresh weight and dry weight of the plants in the smart system had higher values than the control system, where dry weight is the result of water loss in the plants. Dry weight is calculated to determine the plant's ability to absorb nutrients from the provided nutrients [6].

Unstable environmental conditions result in decreased vegetative growth efficiency in bok choy plants. Plant growth is inevitably influenced by both biotic and abiotic factors. Biotic factors originate from within the plant itself, such as genetics and hormones. Abiotic factors, on the other hand, originate from outside the plant, such as the environment, such as the concentration of nutrient solutions [12].

The Nutrient Film Technique (NFT) is one of the most widely used conventional hydroponic systems for cultivating leafy vegetables such as bok choy (Brassica rapa L.) variety Nauli F1. In this method, a thin film of nutrient-rich water continuously flows along a slightly inclined channel, allowing plant roots to absorb nutrients and oxygen. The simplicity and cost-effectiveness of NFT have made it popular among small to medium-scale farmers. However, the system relies heavily on manual monitoring and adjustments, which can be labor-intensive and may lead to inefficiencies if environmental conditions change rapidly [10].

In contrast, a smart hydroponic system based on the Internet of Things (IoT) integrates sensors, controllers, and automation to manage water, nutrients, temperature, humidity, and light conditions. This technology enables real-time monitoring and control of plant growth environments, often through mobile or web applications. By using IoT devices, farmers can receive instant alerts and remotely adjust system parameters, minimizing human error and ensuring that plants consistently receive optimal growing conditions. This advanced approach has the potential to significantly improve productivity and quality in bok choy cultivation [11].

When cultivating bok choy variety Nauli F1 using the conventional NFT system, farmers typically rely on their experience and visual inspection to determine nutrient concentration, pH levels, and water flow rates. This manual process can result in inconsistencies, especially when environmental conditions fluctuate due to weather changes or variations in greenhouse ventilation. While experienced growers can manage these fluctuations to some extent, there is still a risk of reduced yields or quality when precise control is lacking.

The IoT-based smart system addresses these challenges by employing sensors to measure parameters such as electrical conductivity (EC), pH, water temperature, and air humidity in real time. Data collected from these sensors are sent to a central processing unit or cloud platform, where automated algorithms adjust nutrient dosing, water circulation, or even greenhouse ventilation. This level of automation allows bok choy plants to receive exactly what they need at any given moment, reducing waste and enhancing growth efficiency [11].

In terms of growth performance, research and practical trials have shown that IoT-based hydroponic systems can lead to faster growth rates and higher yields compared to conventional NFT. The precise regulation of nutrients and environmental factors ensures that bok choy Nauli F1 maintains optimal photosynthetic activity throughout its growth cycle. As a result, plants tend to develop more uniform leaf size, better coloration, and improved overall market quality. In contrast, NFT systems without automation may occasionally face nutrient imbalances or water flow disruptions, which can stress plants and slow growth [10].

Water and nutrient use efficiency also differ significantly between the two systems. Conventional NFT may use more water due to less precise control and occasional overflows or leaks that go unnoticed. On the other hand, IoT-based systems can track water usage in real time and adjust flow rates to match plant demand, reducing both consumption and nutrient wastage. This efficiency not only lowers operational costs but also contributes to more sustainable agricultural practices, which is increasingly important in modern farming [2].

Another key difference lies in labor requirements. In a conventional NFT system, farmers need to be physically present for routine checks, adjustments, and maintenance. This can be time-consuming and physically demanding, especially in larger installations. An IoT-based smart system reduces the need for constant human supervision by automating most operational tasks. Farmers can focus more on strategic decision-making, such as crop planning and market management, while the system handles day-to-day environmental adjustments [1].

However, the IoT-based approach does come with higher initial investment costs. Purchasing and installing sensors, controllers, and connectivity modules can be expensive, particularly for small-scale growers. Moreover, the system requires reliable internet access and some level of technical knowledge for operation and troubleshooting. In contrast, the NFT system has relatively low startup costs and is easy to learn, making it more accessible to beginners or farmers with limited capital [4]. In the context of long-term profitability, the higher yields, improved quality, and resource savings from IoT-based hydroponics can eventually offset the initial investment, especially in commercial-scale operations. As technology becomes more affordable and user-friendly, the barrier to adoption may continue to decrease, making IoT systems a viable choice for a broader range of growers [11].

Overall, both the conventional NFT system and the IoT-based smart hydroponic system have their strengths and limitations in the cultivation of bok choy variety Nauli F1. NFT offers simplicity, affordability, and ease of use, while IoT brings precision, efficiency, and higher potential yields [10]. The choice between the two will depend on the grower’s resources, technical capabilities, and production goals. As agricultural technology continues to evolve, hybrid approaches combining the strengths of both systems may offer the most practical and effective solutions for sustainable and profitable bok choy production [11].

The smart system's superiority over the control system can be attributed to several factors, including its more efficient nutrient absorption. This is supported by observational data showing that the smart system's TDS and pH changes tend to be more stable, according to the reference or examples provided. Meanwhile, the control system exhibited significant fluctuations or changes, possibly due to abiotic environmental factors such as temperature and humidity, and the absence of an actuator system to maintain a stable solution at the specified concentration [7].

Conclusion

This study demonstrates that the Smart AMCS system is capable of maintaining nutrient solution pH and TDS within the recommended reference range, resulting in superior growth performance of bok choy compared to the control system. The improvements are reflected in key agronomic parameters such as plant height, leaf number, fresh weight, and dry weight. Beyond growth performance, the system also enhances water and nutrient use efficiency, reduces dependency on manual labor, and minimizes human error caused by environmental fluctuations. Although the initial investment is relatively high, Smart AMCS shows strong potential as a strategic solution for sustainable and commercial-scale hydroponic vegetable production. Future research should focus on evaluating the performance of Smart AMCS across different vegetable crops and under diverse environmental conditions to broaden its applicability. In addition, efforts to integrate renewable energy sources and cost-efficient sensor technologies would further improve system sustainability and affordability. Finally, practical implementation studies involving farmer training and adoption models are recommended to bridge the gap between experimental validation and real-world application.

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