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Smart Tower Farming System Based on the Internet of Things in Greenhouse System

Renny Eka Putri, Putri Arsyafdini Oktavionry, Irriwat putri1, Feri Arlius, and Ashadi Hasan

Department of Agriculture Technology, Andalas University, Padang, Indonesia.

*Correspondence email: rennyekaputri@ae.unand.ac.id

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ABSTRACT

The integration of IoT technology in smart greenhouses enables real-time monitoring of the microclimate, empowering farmers to remotely manage their plants. This capability proves invaluable to farmers, as the data collected by the smart greenhouse is automatically processed and seamlessly transmitted to the control system through the internet. These innovative systems enable the vertical cultivation of crops, maximizing space utilization a particularly valuable feature in densely populated urban areas where arable land is scarce and costly. The objective of this research is to develop a real-time, internet-based monitoring and control system tailored for smart greenhouses. The core concept in this research is precision, particularly in the monitoring and regulation of greenhouse temperature and humidity. By achieving optimal environmental conditions for cultivated crops, this system aims to significantly increase crop yield. Tower farming systems allowing for the cultivation of up to 144 plants per square meter—contrasting sharply with the limited yield of 5 to 10 plants in traditional farming methods. Moreover, this tower farming system offers several benefits: it enhances crop quality, reduces resource consumption, and fosters sustainability and efficiency in agriculture. The results showed that the average of the smart greenhouse plant height, the number of leaves, the length of the leaf, the width of the leaf, and the total weight of without roots was 22.34 cm, 12 leaves, 9.72 cm, 1.70 cm, and 18.96 grams. The results prove that water spinach in the smart greenhouse is better than control.

INTRODUCTION

The principle of Smart Greenhouse in its process uses renewable technology which consists of two supporting systems, namely automatic temperature and RH control. The control is done remotely based on the Internet of Things (IoT) so that the situation in the Smart Greenhouse can be monitored continuously through Android. Agriculture is one of the sectors that has the most serious impact caused by climate change. The climate element is a limiting factor for a crop commodity which requires a technology to control it. The resulting microclimate control data will be displayed and accessible through information technology. A crucial role in optimizing the environmental conditions necessary for successful plant cultivation, leading to higher-quality crop yields (Putri, Lestari, *et al.,* 2024)

A "tower farming system" typically refers to a vertical farming method where plants are grown in stacked layers or towers, often indoors or in controlled environments, and plants are grown on terraces or vertically to reduce the use of agricultural land (Putri, Wibowo *et al.,* 2023). This innovative approach to agriculture has gained popularity in recent years due to its potential to increase crop yield, conserve space, and reduce environmental impact. In practice, vertical farming recycles and reuses water and nutrients, resulting in less waste (Putri, A, *et al.,* 2022). Generally, this method is implemented in a limited area. The availability of agricultural land is currently receding and leading to a decrease in agricultural production. It can be seen from the data of the Central Statistics Agency (BPS), that the potential for rice harvest area in 2021 is 10.52 million hectares when compared to the rice harvest area in 2020 which reached 10.66 million hectares, the harvested area has decreased by 0.14 hectares. Vertical farming creates natural green spaces in the middle of narrow land. Then, Vertical farming may reduce the extent of area for farming purposes and obtain the same production as large conventional farming, furthermore, this farming method is one of the strategies to have sustainable food. The implementation of this approach provides clear evidence of utilizing narrow land to become production land, especially in urban areas. It can increase the production of vegetable crops by 13 times during the planting period, which is 8 years, thus the production increases 38% per year. This evidence occurred from 1997 – 2003 in Havana, Cuba (Fauzi *et al.,* 2016). Hydroponic systems reduce the need for plant maintenance and regular monitoring of nutrient solutions (Putri, Afifah, *et al.,* 2023).Vertical hydroponics, 1 m^2 of land with a tower height of 1.5 m, can plant 50-80 plants, whereas with the usual method we only get 25-30 plants (Putri, Habib, *et al.,* 2023). Internet of thing (IoT) would be the best option for monitoring (Putri, Darmadi, *et al.*, 2023). One way to address this is by using various sensors to monitor environmental factors that affect plant growth and development (Putri, A, *et al.,* 2023). Control of temperature and humidity is very important in the cultivation of hydroponic plants. Control will be easier by utilizing IoT. The solution to overcome this problem is to create a hydroponic system with an Internet of Things (IoT) (Putri, Oktavionry, *et al.*, 2023). Chowdhury *et al.*, (2020), the goal in this research is to create a simple, automated, and scalable cost-effective system that can be utilized by individuals in Gulf countries like Qatar for both personal and large-scale farming. The harsh summer conditions in these regions make traditional farming difficult, necessitating greenhouse and indoor farming with continuous air conditioning. However, it is possible for every household to become a small farm by using a small space within the house or apartment without significantly increasing water and power consumption, thereby growing the basic needs of the household. This motivation drives the project, and the Qatar government has announced subsidies to support such initiatives. The objective of this work is to design and construct an indoor automatic vertical hydroponic system that operates independently of the external climate. This system is designed to grow common crops that can be used as a food source within homes, requiring minimal space. The design process involved studying various types of vertical hydroponic systems, focusing on price, power consumption, and suitability for indoor automation. A microcontroller acts as the system's brain, communicating with different sensors to control all parameters and reduce human intervention. An open Internet of Things (IoT) platform is used to store and display system parameters and provides a graphical interface for remote access. The system can maintain healthy growing conditions for plants with minimal user input. The functionality of the overall system was confirmed by evaluating the responses of individual components and monitoring them via the IoT platform.

There is debate over the efficiency of vertical farming because of its high initial costs and substantial maintenance needs in urban settings. However, eliminating the seasonality of fresh vegetable cultivation could boost yield and profits in vertical farming. This approach offers economic advantages by not only increasing production but also reducing transportation and storage costs. Farmers can benefit from lower crop losses, better yields, more secure supply chains, decreased environmental impact, and enhanced agricultural sustainability. Additionally, soilless cultivation systems have been enhanced through upgrades like the use of atomization systems (Oh and Lu, 2023). One of the latest technologies introduced in the agriculture field to diminish the land use issue is vertical farming, which is also an effective way to grow plants. Vertical farming is environmentally friendly because recycled materials can be used to build the structure, and pesticide-free (Chin and Audah, 2017).

MATERIAL AND METHODS

The vertical farming tower is designed for planting spinach seeds vertically using a series of eight pipes, each measuring 125 cm in height. Within each pipe, there is a hole with a diameter of 5 cm. The spacing between these holes varies, with two options: 10 cm and 15 cm. Pipes with a 10 cm spacing feature seven holes, while those with a 15 cm spacing have six holes. Consequently, each pipe accommodates a total of 26 holes. One set of vertical farming tower has a total of 208 holes. This study created three sets of vertical farming towers, with each set comprising 8 pipes, resulting in a total of 624 holes (see Figure 1). Research flow chart (see Figure 2).

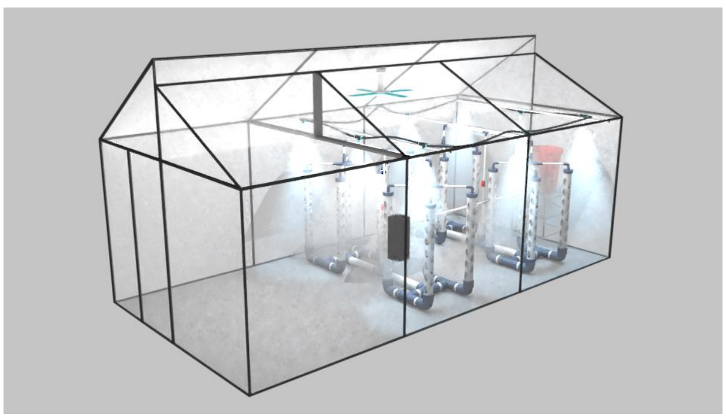


Figure 1. Overview of smart greenhouse

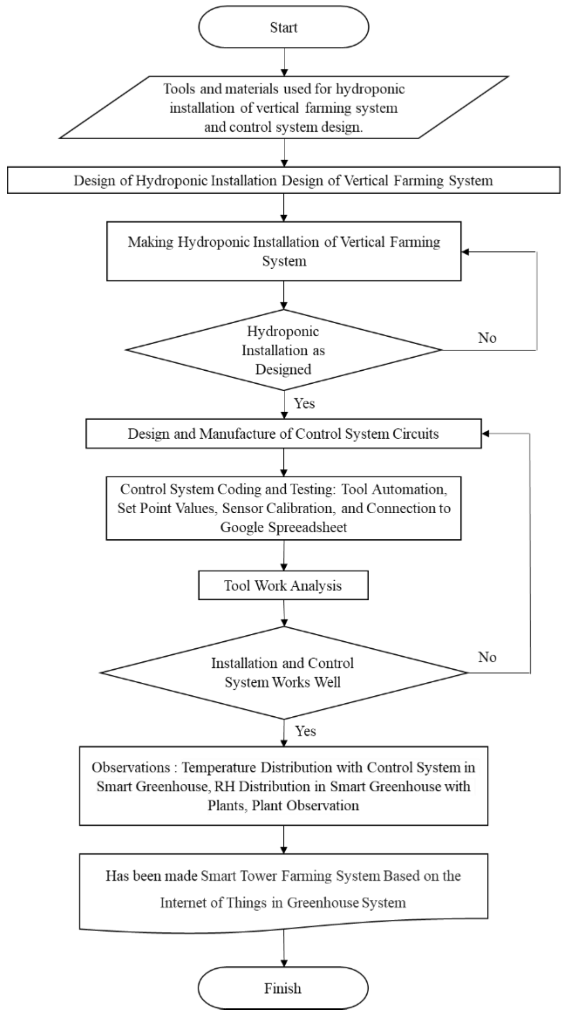


Figure 2. Research Flow chart

In within each set of vertical farming towers, an irrigation system is seamlessly integrated with the water pump. The water pump have 5 m of maximum height and 5000 L/H of maximum flowrate. The holes in the system are designed with a gentle 5% slope. Each plant within this system boasts nine leaves, a height of 18.4 cm, a root length extending to 41.5 cm, and a weight of precisely 34.49 grams. These specified attributes are paramount to the success of vertical farming, ensuring consistent flow rates and uniform nutrition and growth for all plants. The hole spacing options of 10 cm and 15 cm facilitate the cultivation of spinach plants within a limited planting area, providing the ideal separation for nurturing hydroponic plants with medium-sized leaf canopies.

This research was conducted in several stages, the development IoT systems and plants. First, the Calibration of the sensor by using a thermohygrometer and carried out with 10 variations of observations with 3 repetitions and programming DHT 22 sensor in the microcontroller IDE application. It can be seen in Figure 1. Next, determining the set point values for temperature and humidity. The command in the program that has been given the system is that when the humidity read the sensor ≤60%, the microcontroller would pass the signal to the relay to turn on the misting pump, then if the sensor reads the temperature value in the smart greenhouse 70%, the pump would stop.

The wind from the fan causes the temperature reduce from 34ºC to 32ºC. Then connect the microcontroller to Google spreadsheet, sensor reading results can be displayed in the Google Sheets App if the sensor has been properly calibrated beforehand. If the programming is connected then make programming from the Arduino IDE to Google Spreadsheet. Fourth, control system performance test in a greenhouse without plants, in this step, the system was tested without plants . If the control system worked in accordance with the command, so the next steps were monitoring and controlling temperature and humidity in smart greenhouses. Finally, test the accuracy of the sensor DHT22 reading. The experiment was carried out on plant observation. The data from the plant were observed every three days at 09.00 am after sowing. This observation was carried out by observing the development of plant height, number of leaves, leaf length, leaf width, and plant weight. The last observation was to compare the yields of spinach plants with a control system and spinach plants without a control system.

The control system design mechanism was made based on its provisions. The system run automatically and to read the temperature and humidity value inside the greenhouse, the DHT22 sensor was deployed. The best temperature set point value for water spinach plants is 28-34ºC (Nupriyanti Indah, 2020). The set point value for temperature was determined at 34ºC, and the set point value for air humidity was more than 60% (Lukito, *et al.,* 2021). The aim of defining the set point was to provide a limit of the running system. Internet of Things (IoT) is a data transmission activity that does not involve user-to-user or user-to-computer interaction. The IoT concept has three main components, namely physical objects in the form of sensor modules, internet connections, and data centers on servers that function to store data and information from physical objects. Storage of sensor reading values as well as control of the temperature and humidity system is needed for visualization media and sensor work control. For monitoring and control it is connected to the Google Sheets application on a smartphone .

The schematic of the overall circuit of this system serves to show the system or workflow of the existing circuits. The reference for the relay to work is the value read by the sensor. When the sensor reads a temperature value of 33ºC, the relay is active to turn on the fan and if the temperature reaches 31ºC, the fan turns off and when the sensor reads a humidity value of 60%, the relay is active to turn on the misting, and if the humidity is 75%, the misting will turn off. The circuit in this system is made to form a system that works without overlapping, can read, process and produce output according to what has been determined. The overall circuit scheme (see Figure 3).

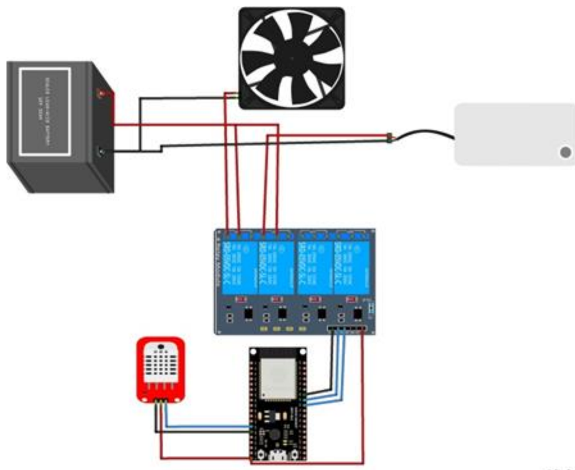


Figure 3. Schematic of the overall circuit

RESULTS AND DISSCUSION

Temperature Distribution with Control System in Smart Greenhouse

Temperature distribution in the smart greenhouse occurs in several conditions (see Figure 4). These conditions have a different length of time to lower the temperature each day. Details of the temperature distribution from increasing temperature to falling back to the optimum temperature each day (see Figure 5).

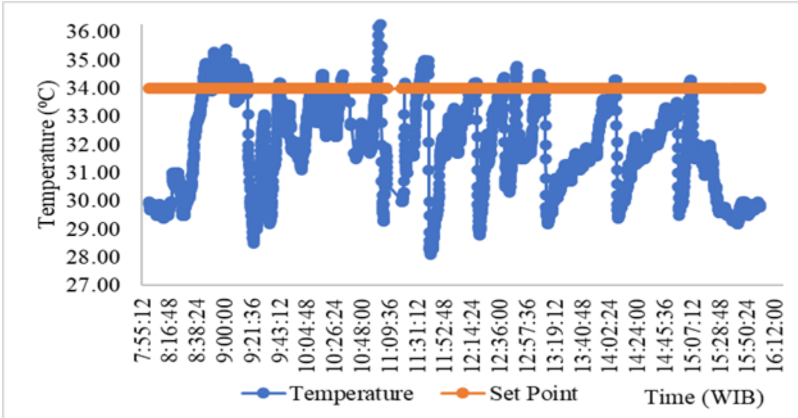


Figure 4. Graph of temperature distribution in smart greenhouse

Figure 5 describes a fragment of data from Figure 4, so as to clearly show the performance of the system. Figure 5 shows the time required for the sensor to reach the desired set point. shows an increase in temperature at 14:27:10 WIB, exceeding 34.20ºC. After that, the temperature dropped to 31.90ºC at 14:43:07 WIB. So it could be calculated that it takes 16 minutes to reduce the temperature to the optimum temperature.

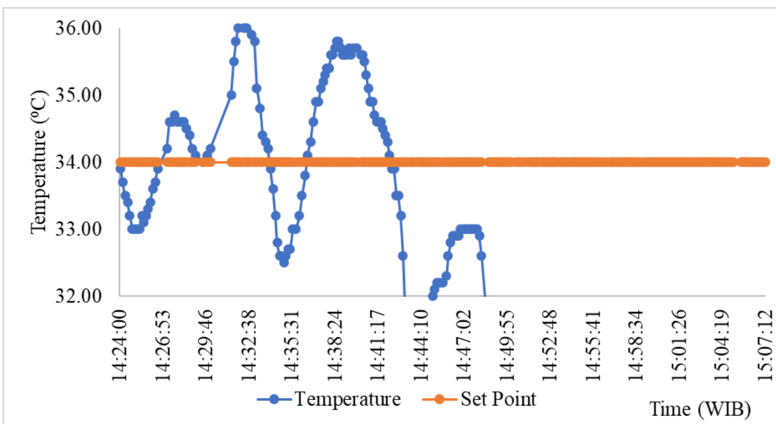


Figure 5. Time to achieve the optimal temperature

Wahono's (2014) conducted research on greenhouse testing from 08.00-15.00 WIB for three days and found that the temperature in the greenhouse was relatively high from 30ºC to 47ºC. Khafi (2019) conducted research on a greenhouse carried out for one week with a temperature in the greenhouse every day from 22ºC to 48ºC. It could be concluded that the temperature in the greenhouse was relatively high so the creation of a temperature control system was able to control the temperature to suit the needs of the plants.

RH Distribution in Smart Greenhouse with Plants

The distribution of moisture inside the smart greenhouse (see Figure 6). In Figure 6 shows that in one day the humidity distribution in the smart greenhouse occurs in several conditions. These conditions have a different length of time to lower the temperature each day. Details of humidity distribution from decreasing to increasing and optimum each day (see Figure 7). It provides information about the decrease in humidity, namely 60.00% at 09:36:12 WIB. Afterward, the humidity increased until 10:18:03 WIB reaching 70.00%. In condition, it took 42 minutes to increase the humidity to 70.00%.

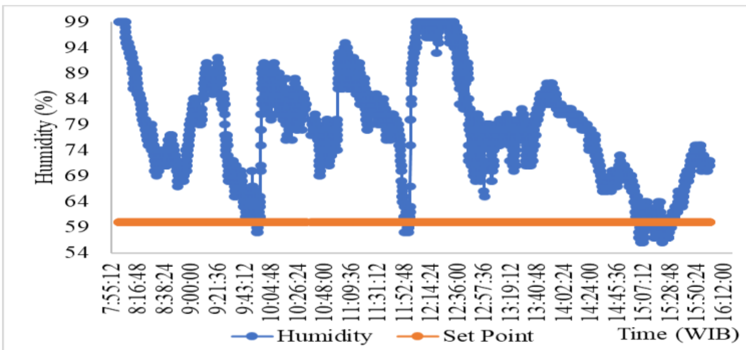


Figure 6. Graph of moisture distribution in smart greenhouse

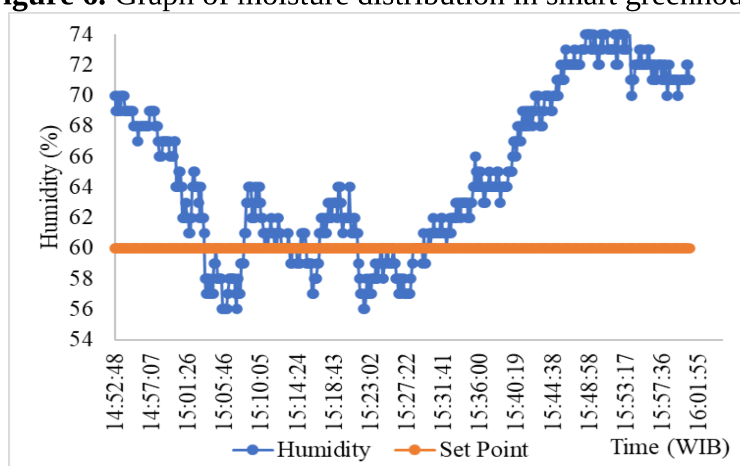


Figure 7. RH distribution to optimum humidity

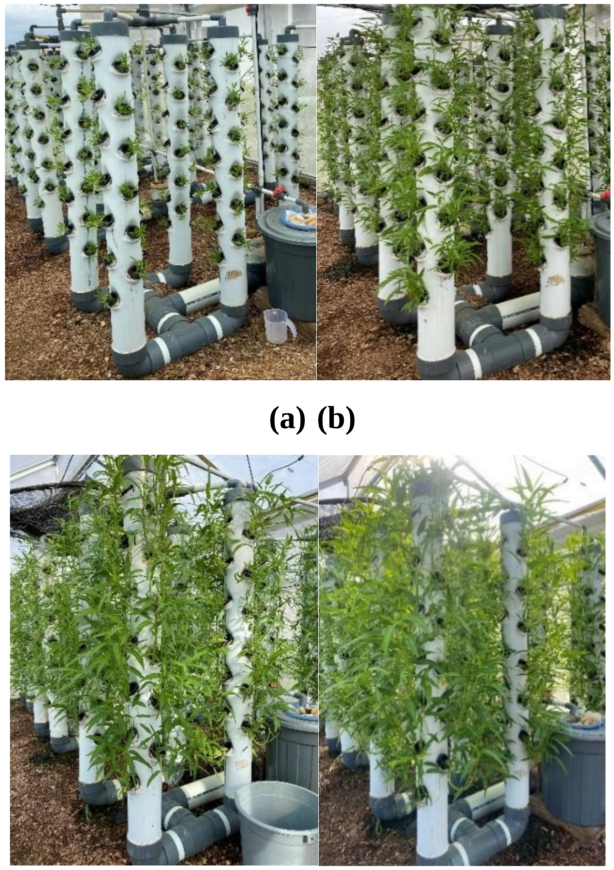
In Figure 7 shows the condition of decreasing of humidity, it reached 58.00% past the set point at 15:03:32 WIB. Then the humidity again increased to 70.00% at 15:42:40 WIB. So in this condition, it took 39 minutes to increase the humidity.

Wahono's (2014) conducted research, namely testing the humidity in the greenhouse which was carried out for three days then starting at 08.00-15.00 WIB and obtained humidity results ranging from 50% to 61%. Khafi (2019) conducted research on monitoring humidity in greenhouses for one week every day and then obtained humidity in the greenhouse, namely 29% to 85%. It could be concluded that an automatic control system for controlling humidity in the greenhouse worked for controlling humidity according to the needs of plants.

Plant Observation

Tower farming systems allow for the cultivation of up to 144 plants per square meter—contrasting sharply with the limited yield of 5 to 10 plants in traditional farming methods.. Each plant hole has 4-6 plant stems. The observation of plants in this study was divided into two, namely observation of plants on water spinach plants controlled using a control system and water spinach plants grown without a control system. Observations aim to determine the difference between plants with suitable temperature and humidity and plants with conditions of temperature and humidity that are not in accordance with the conditions for plant growth.

The development of spinach plants with a control system (see Figure 8). Observations were made every three days with a span of 18 Days After Sowing (HSS) every 09.00 am. This observation was carried out by observing the development of plant height, number of leaves, leaf length, leaf width, and plant weight. Furthermore, the last observation was to compare the yields of water spinach plants with a control system and water spinach plants without a control system. The results of the average comparison of the height development of smart greenhouse water spinach plants with control water spinach plants can be seen in Figure 9.



(a) (b)

(c) (d)

Figure 8. Water spinach plants with control (a) plant age 3 hss, (b) plant age 9 hss, (c) plant age 15 hss, (d) plant age 18 hss

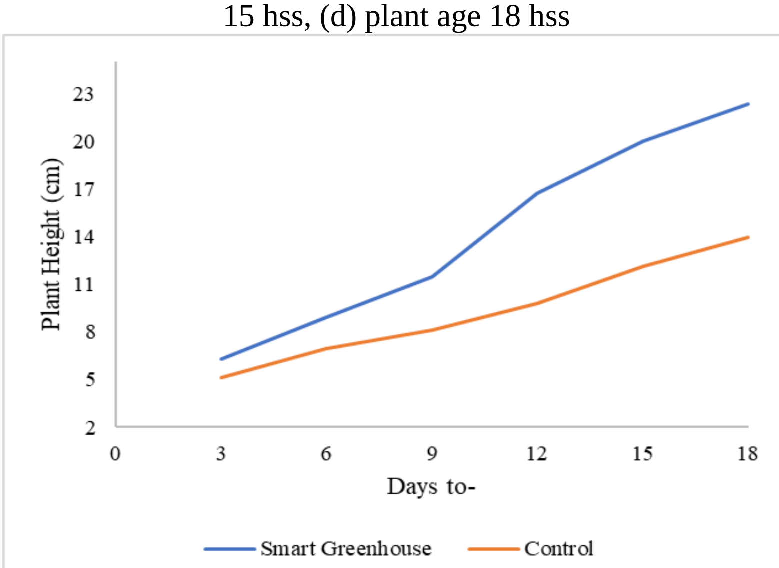


Figure 9. Graph of observation of water spinach plant height

Observation of water spinach the tallest obtained in smart greenhouse and control 30 cm and 20 cm respectively on 18 HSS (day after sowing). Macro nutrient elements in AB Mix nutrition have importand influence on plant growth processes, especially the N and P nutrients (Fadhlillah *et al.*, 2019). According to Subandi *et al.*, (2015), the process of growing plants in hydroponics must also be fulfilled by providing a nutrient solution because the pH value can affect the availability of nutrients in the nutrient solution. Hidayati (2017) conducted a study of water spinach plants which were controlled for 21 days to obtain an average plant height of 19.3 cm. The results of the observations made were close, so it can be said that the control system applied did not adversely affect plant growth. The results of the comparison of the average development of the number of leaves of the smart greenhouse water spinach plants with the control water spinach plants (see Figure 10).

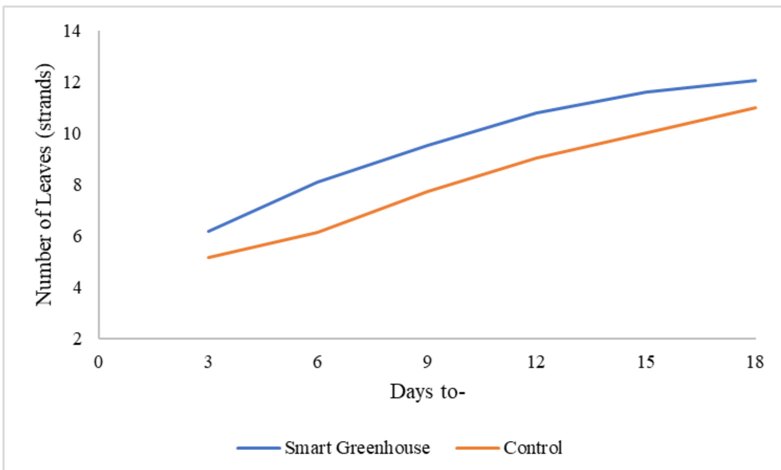


Figure 10. Graph of observation of the number of leaves of water spinach plants

Meanwhile, observation the number of leaves on the smart greenhouse and control were 12 and 11 leaves, respectively. Hidayati (2017) conducted a study of water spinach plants which were controlled for 21 days to obtain an average number of leaves, namely 11 leaves. A comparative study of the average leaf length of smart greenhouse water spinach plants and control water spinach plants (see Figure 11).

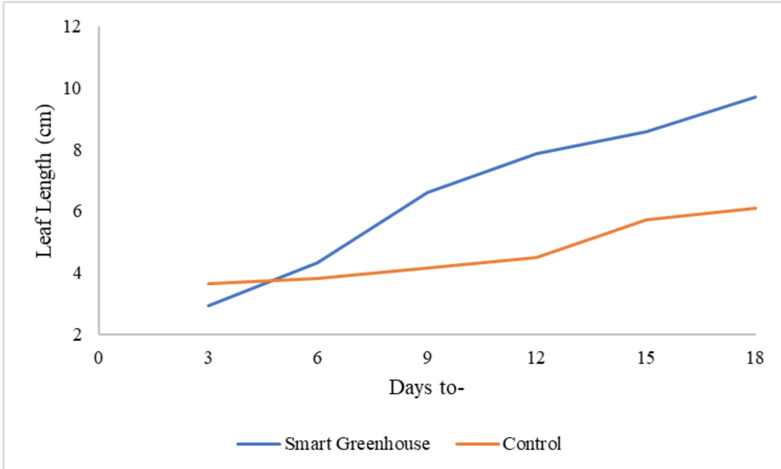


Figure 11. Graph of observation of leaf length of water spinach plants

Observation of leaf length on smart greenhouse water spinach plants obtained an average of 9.72 cm and the longest leaf being 13.5 cm. The control water spinach plants obtained an average leaf length of 6.10 cm and the longest leaf being 7 cm. Sasongko *et al.*, (2021), conducted a study of water spinach leaves have a length of 7 - 14 cm. The results of the comparison of the average leaf width of smart greenhouse water spinach plants with control water spinach plants (see Figure 12).

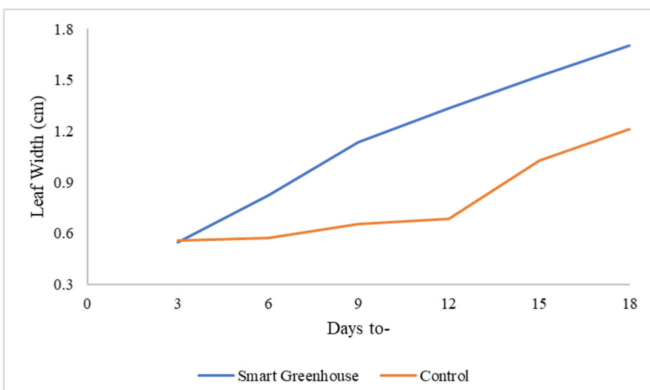


Figure 12. Graph of observation of leaf width of water spinach plants

Observation of leaf width in smart greenhouse water spinach plants obtained an average of 1.70 cm with the widest was 2.1 cm. The average leaf width of the control water spinach was 1.21 cm with the widest leaf was 1.5 cm. Ningtias *et al.*, (2021), conducted research on monitoring the automatic provision of nutrients for hydroponic kale plants, which obtained the widest leaves of 2.5 cm. A comparison of the weight of smart greenhouse water spinach plants with control water spinach plants (see Figure 13).

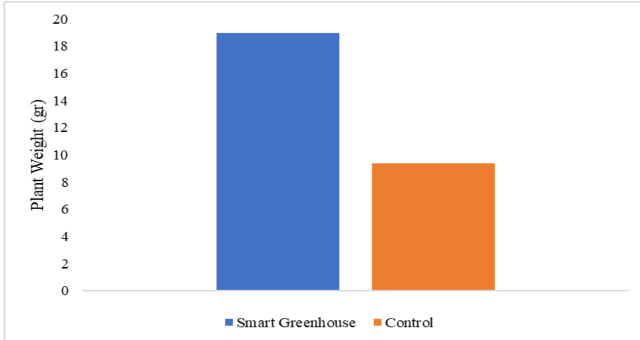


Figure 13. Graph of observation of water spinach plant weight

In Figure 13, the observed weight of the smart greenhouse water spinach plant was 18.96 grams. The weight of the control water spinach was 9.36 grams. Hartati *et al.*, (2021), conducted a study of water spinach plants which were controlled to obtain an average plant weight of 18,9 grams. Observations that have been made on plant height, number of leaves, leaf length, leaf width, and plant weight can prove that water spinach growers with a hydroponic vertical farming system and controlling temperature and humidity can produce good and good plants. Temperature and humidity control in the smart greenhouse can automatically adjust to the optimum temperature and humidity requirements of the plants. So it can be said that the control system applied to water spinach does not inhibit plant growth and development.

CONCLUSION

Based on the research that has been done it can be concluded that: The vertical farming tower has been made with a height of 125 cm. One set of vertical tower has 8 pipes where each pipe has 26 plant holes. So for one set of vertical tower has 208 plant holes. The design of the control system on the smart greenhouse can work well, it is characterized by misting can maintain humidity within 40 minutes so that the humidity in the smart greenhouse remains at the optimum humidity for the plants, and the fan can work properly to reduce the temperature to reach the optimum temperature within 16 minutes for the plants according to the program that has been made. Data on temperature and humidity readings in the smart greenhouse can be accessed and monitored by the user without having to go to the smart greenhouse first via Google Spreadsheet on the smartphone as long as it is connected to the internet network. The results prove that water spinach in the smart greenhouse is better than control.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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