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Monitoring and Control System Development on IoT-Based Aeroponic Growth of Pakcoy (*Brassica rapa* L.)

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Abstract

One of the methods that can be used by Indonesian people in urban farming is the Aeroponic method of planting plants. The aeroponic method has a faster nutrient delivery speed than hydroponics and normal plant cultivation. The main objective of this study was to design an aeroponic monitoring and control system for Pakcoy (Brassica rapa. L) using the blynk application as an interface for remote control. The control system used is NodeMCU V3, DHT22 sensor, HC-SR04 ultrasonic sensor and TDS sensor. Plants in the system use a container box measuring 110 cm x 80 cm with 10 nozzles on the inside of the box attached to a ½ inch pipe, with 24 planting holes on the lid of the box with a spacing of 20 cm. The pump will automatically turn on when the temperature in the box is >25°C and will stop when the temperature is =24°C, or when the humidity is <80%. The results obtained during the 30 days of research showed that the average R2 value of the DHT22 sensor was 0.9864 and 0.9864, the HC-SR04 sensor was 0.996 and the TDS sensor was 0.9899. Observations on the growth of pakcoy plants obtained an average height of 13.3 cm for system plants and 13.4 cm for control plants. The average leaf width in system plants was 4.3 cm and 3.6 cm in control plants. The average number of leaves on system plants is 8 leaves and 9 leaves on control plants. The system plant weight was 5.493 gr and that of the control plant was 2.961 gr. The control system that has been made can work well and can be used in aeroponic cultivation of plants.

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1. Introduction

Aeroponics is a farming technology by hanging plant roots in the air and growing them in a moist environment and not using soil. Aeroponics can be done anywhere because of the planting technique without soil and with roots hanging in the air. Aeroponics means air empowerment where the word aeroponics comes from the word aero which means air and ponus which means power, so aeroponics has the meaning of utilizing air (Wicaksono et al., 2017). Aeroponics is a way of growing plants by

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hanging them in the air and growing them in a moist environment without soil. Because the roots of the plant hang in the air, it is possible to grow almost anywhere using usable cubic space (Reyes et al., 2012). Even though the area used is not too large, the productivity of the land is still high. Aeroponics is a good method because it can produce droplets in the form of fine liquid droplets like mist. The aeroponic method has a nutrient delivery speed of up to 135% faster than hydroponics and normal plant cultivation (Kanisius, 1992). Aeroponics is also a development of the deficiencies that exist in hydroponic methods such as plant roots that are constantly soaked in nutrients thereby reducing the level of aeration and oxygenation of plant roots. Besides another drawback of hydroponics is growth that is not optimal because plant roots will have difficulty absorbing nutrients because the components of the nutrient solution require special care so that they do not have a toxic effect on plants. One way to overcome this is by using various sensors to monitor environmental factors that have an influence on plant growth and development. Research conducted by Yazid et al. (2020), regarding the prototype of IoT-based aeroponic cultivation observations. In this study, researchers used the Arduino Wemos D1R2 microcontroller using several sensors to control and monitor temperature and humidity, the water level in the grow box and the acidity (pH) of nutrients (Putri et al., 2022). However, the value for humidity used in the system made by researchers is > 99% so the humidity reading is very high, so the sensor will only read 100% humidity and does not match the needs of the plants.

Research conducted by Iriani et al. (2018) regarding an aeroponic monitoring system based on IoT, researchers use a Single Board Computer where the microcontroller used is ATmega16. Researchers only monitor temperature and humidity using the DHT11 sensor (Putri et al., 2023). Research conducted by Indrajaya et al. (2019), researchers created a control system for automatic monitoring of nutrient concentrations in aeroponics with a TDS sensor. The test results obtained by the researchers were in the form of sensor calibration results reaching 99% and having a measurement accuracy and precision of 95%.

However, the devices made by the researchers still use UTP (Unshielded Twisted Pair) cables and suggest that communication can be done wirelessly (Wireless) to make it more practical. The objective of this study is to design a prototype aeroponic system equipped with temperature and humidity control, control of the height of the nutrient solution and monitoring the concentration of plant nutrients based on the internet of things on pakcoy (*Brassica rapa* L.) plants, designing a control system on internet-based aeroponics of things on pakcoy plants (Brassica rapa L.), and testing the performance of the control and monitoring control system on an internet-based aeroponic system of things on pakcoy plants (*Brassica rapa* L.).

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2. Materials and Methods

The method used in this study is an experimental method by making aeroponic prototypes and control systems to monitor and control temperature and humidity in grow boxes made of container boxes, nutrients and nutrient solution heights in buckets.

2.1 Aeroponic Prototype Design

The aeroponic prototype design was made as a method of farming to save water and nutrients that will be given to plants. The grow box used in this study is made of a container box which has 24 planting holes located on the lid of the box. The planting hole has a distance between plants of 20 cm with the lid of the container box attached with a netpot with a diameter of 5 cm. The grow box is 110 cm long, 80 cm wide and 50 cm high. The box is raised with wood so that the plants are not exposed to rainwater splashes which can cause damage to the plants. On the side of the box there is also a hose and pipeline from the nutrient bucket to the grow box with a pipe size of 2.54 cm. On the side of the grow box there is a series box containing a control system and a nutrient bucket to distribute nutrients to the grow box which consists of nutrient A and nutrient B solutions that have been concentrated and then mixed with water to the required nutrient concentration. An overview of the tool can be seen in Figure 1. The DHT22 sensor, TDS sensor and ultrasonic sensor are mounted on the inside of the grow box as shown in Figure 2.

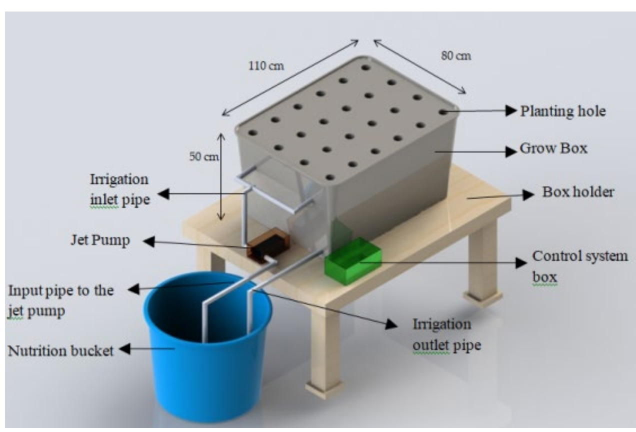

Figure 1. Aeroponic Prototype Design

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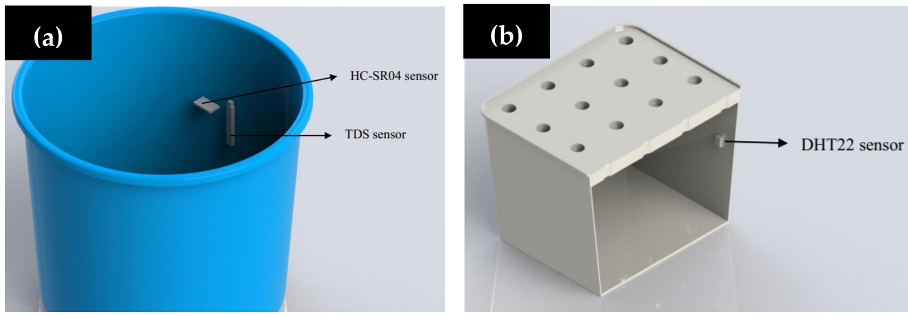

Figure 2. Sensor position (a) HC-SR04 sensor and TDS sensor (b) DHT22 sensor

The inside of the grow box contains a series of pipes attached to a nozzle used for irrigation or distribution of nutrients. 10 nozzles are paired. The nutrients in the bucket are channeled by means of a jet pump which is outside the grow box. The shape of the pipe series can be seen in Figure 3.

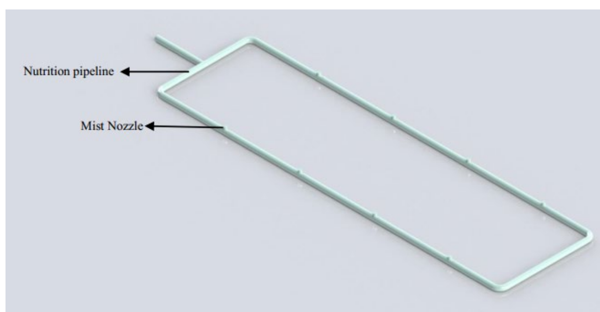

Figure 3. Irrigation Pipelines

Schematic of sensor placement and distribution of nutrition from the nozzle can be seen in Figure 4.

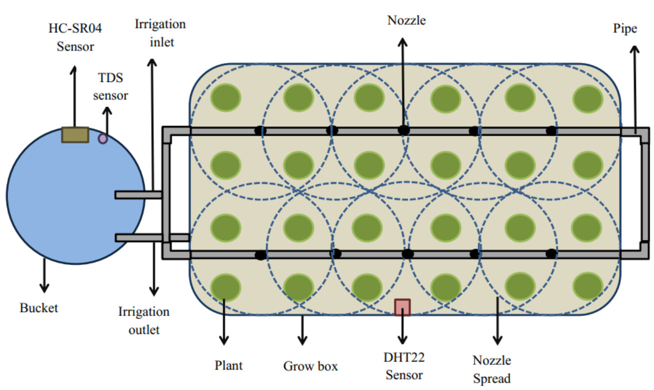

Figure 4.Schematic of Sensor Placement and Nutrition from the Nozzle

2.2 Control System Design

The control system is made to facilitate monitoring and control of temperature and humidity control, the level of nutrient solution and the concentration of plant nutrients in grow boxes and buckets. The hardware required for the control system consists of components such as NodeMCU V3 as a microcontroller used in the system and connected to the Blynk application via an internet connection. The circuit schematic can be seen in Figure 5.

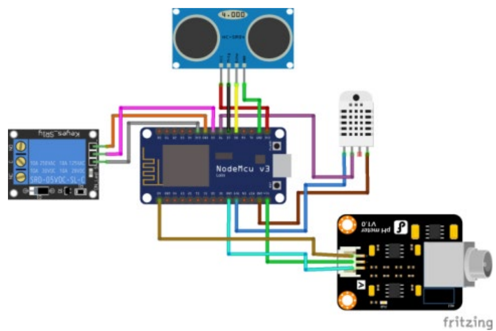

Figure 5. Network Schematic

2.3 Making Aeroponic Installation and Monitoring and Control System Testing

2.3.1 Making Aeroponic Installation

The aeroponic system is made using a pre-planned design. The plants will then be placed in a grow box that has been equipped with a planting hole. Plant holes on the lid of the box made as many as 24 plant holes. Each hole will be placed in a netpot with plants that have been sown on rockwool as a growing medium. The inside of the box is fitted with a pipe as a distributor of nutrients which is equipped with 10 mist nozzles. The grow box is also equipped with a jet pump to pump water into the pipe, the pump used in this system is a jet pump with a pressure of 100 Psi in order to produce fog at the nozzle because the aeroponic system used is the High Pressure Aeroponic (HPA) system and the TDS sensor to see plant nutritional value.

2.3.2 Plant Preparation and nutrition

Preparation of the pakcoy plants begins with preparing the pakcoy seeds which are sown using rockwool for 14 days, by placing the pakcoy in a dark place for 1 to 2 days until sprouts appear, the next day the pakcoy seeds are given light 4 hours per day. After 14 days after sowing the seeds were transferred to the netpot and put in each planting hole provided in the grow box.AB Mix nutrition is given to plants starting from sowing the seeds when entering 7 days after sowing as much as 300 ppm until the plants are transferred to the aeroponic installation, then nutrition is given according to the

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needs of the plants per week until harvest later. Fertilizer was also applied to control plants when mixing with soil and 2 weeks after planting.

2.3.3 Determination of Set Point Value

The optimal temperature for pakcoy growth is 20°C to 25°C with 80% to 90% humidity (Sariayu et al., 2017).The distance between the water level in the grow box and the ultrasonic sensor is 5 cm and it is maintained that the availability of nutrients from the bottom of the bucket is not less than 10 cm. Good nutrition for pakcoy plants is 1000 ppm-1400 ppm so that when the concentration value does not match this value, you can add AB Mix nutrients or add water. These values will then be used as a setpoint in this study.

2.3.4 Tool Reading Response Time

Calculating how much power is used in running the control system is needed by determining the total electric power. According to Wibowo, (2021) the electrical power of each component can be determined by equation 1.

$$P = V \times I \qquad (1)$$

Note: P = Electrical Power (watts), V = Voltage (Volts), I = Current (Amperes)

2.3.5 Connection to the Blynk App

The control system that has been properly operated is then connected to the blynk application. This application serves as an Internet of Things (IoT) platform. The blynk application connection is made with the token aunth code obtained from the blynk application when logging in and opening a new worksheet as an interface. After that the code obtained will be entered into the microcontroller to be connected.

2.4 Observation

2.4.1 Monitoring

Monitoring of temperature and humidity is carried out at 08.00 AM, 12.00 AM and 04.00 PM every day. Data retrieval is done by looking at the readings from the DHT22 sensor displayed on the blynk application. Monitoring the height of the nutrient solution in the bucket is carried out every day by looking at the readings on the HC-SR04 ultrasonic sensor displayed on the blynk application. Monitoring is carried out to determine the height of the nutrient solution in the bucket, so that when the bucket starts to empty there will be a notification on the smartphone, so we have to add nutrients manually. Data collection was carried out once every 30 days. Observation and data collection is carried out based on the TDS sensor and TDS meter measurements.

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2.4.2 Sensor reading accuracy.

Testing the accuracy of sensor readings is carried out to find out whether the sensor is working properly or not. Testing the accuracy of readings is done by comparing data readings using the DHT22 sensor with a thermohygrometer. The accuracy of sensor readings can be determined by equation 2.

$$\text{Error (\%)} = \frac{|\text{read value} - \text{comparison value}|}{\text{comparison value}} \times 100\% \quad (2)$$

Note: Read value = value obtained from the sensor, Comparison value = the value read from the measuring instrument

2.4.3 Pump Lifetime

The pump will turn on when the DHT22 sensor reading inside the grow box detects a temperature exceeding 25 ^{o}C or humidity in the small grow box of 80%. The pump will stop when the sensor reading has reached the temperature set point at 24 ^{o}C. The lifetime of the pump is calculated by means of the time interval required for the pump to reduce the temperature when the reading is 25 ^{o}C until it reaches 24 ^{o}C using a stopwatch.

2.4.4 Plant Height, Leaf Width, Number of Leaves and Plant Weight

Observation of pakcoy plants was carried out by measuring the height of the plant, the width of the plant and counting the number of leaves and calculating the weight of the plant for one net pot during harvesting. Observations were made 3 times a day starting from 3 HST after transplanting the plants. Observations were made to find out how the development of the pakcoy plant against the use of the control system given to the plants. The same observations were made on uncontrolled plants by measuring plant height, leaf width, number of leaves and plant weight for one polybag.

2.4.5 Data analysis

The results of the data that have been obtained in the study, then carried out a descriptive statistical analysis of the observations. Calculations are performed based on the results obtained by finding the mean and regression analysis.

3. Results and Discussion

Aeroponik is made of a container box that is used as a grow box which has a lid with a box length and width of 110 cm x 80 cm and a height of 50 cm. The lid of the box has a planting hole that has been installed with a net pot of 24 planting holes with a spacing of 20 cm x 20 cm. The following results of the design of the Aeroponic prototype can be seen in Figure 6.

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Figure 6. Aeroponic Prototype

Inside the box there is a pipe that is used to distribute nutrients directly to plant roots. There are two interconnected pipes that are attached between the 2 plants so that they can hit the roots of the two plants. On the pipe section, 10 nozzles are also installed which have a diameter of 0.7-0.9 m with a nozzle hole size of 0.5 mm. The design results of the pipe can be seen in Figure 7.

All components such as sensors and microcontrollers are combined into a control system that can maintain and condition aeroponic conditions to remain stable. The control system series is connected to a smartphone using the blynk application to display data read by the sensor. The following results of the control system circuit can be seen in Figure 8.

Figure 7. Pipe and Nozzle Design Results

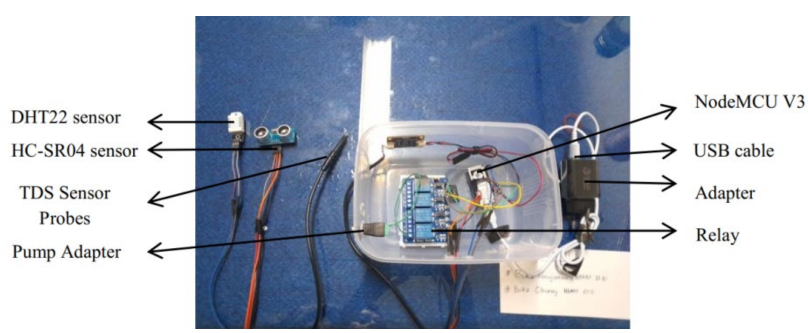

Figure 8.Aeroponic Monitoring and Control System Series

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The blynk application is a platform that can be used to support IoT-based projects. The blynk application can be found on the Play Store and App Store.After the blynk application is downloaded, first register using an email to get an auth token code.The auth code is entered into the Arduino IDE application programming to connect to blynk and NodeMCU V3.The script code for connecting the blynk application with the Arduino IDE application can be seen in Figure 9.

```
#define BLYNK_PRINT Serial
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
char auth [] = "-3AxstVqsw40rRuWjpa2Ww3WL51SmXm2";
char ssid [] = "Www.com";
char pass [] = "ciwinciwin";
Blynk.begin(auth, ssid, pass);
 Blynk.run();
 timer.run();
 Blynk.virtualWrite (V0, temp);
 Blynk.virtualWrite (V1, hum);
 Blynk.virtualWrite (V2, water);
 Blynk.virtualWrite (V3, tdsValue);
}
```

Figure 9. Script Code Auth Token, WiFi Name and Password

Monitoring and control of this study used widgets such as gauges which function to display readings from each sensor used, levels which function to see the level of nutrient solution in 2D form, charts which function to display sensor reading data presentations in the form of graphical displays and notifications. which serves to display information related to nutritional conditions and the height of the nutrient solution in the bucket. The user interface display can be seen in Figure 10.

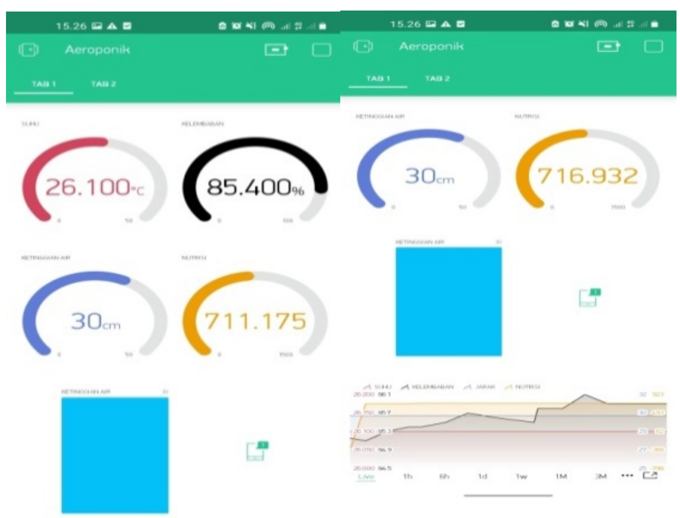

Figure 10. Script Code Auth Token, WiFi Name and Password

The main components in systems that require electrical power consist of the NodeMCU V3 and the jet pump. The input and output voltage limits contained in NodeMCU V3 are 3.3 volts to 5 volts with a current required for one pin of 40 mA. The total pins used in the control system are 4 pins with

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3 pins connected to a voltage of 3.3 volts and 1 pin connected to a voltage of 5 volts. The jet pump requires a voltage of 12 volts with a current of 4 mA. The total power required for the system to run is 48.596 watts.

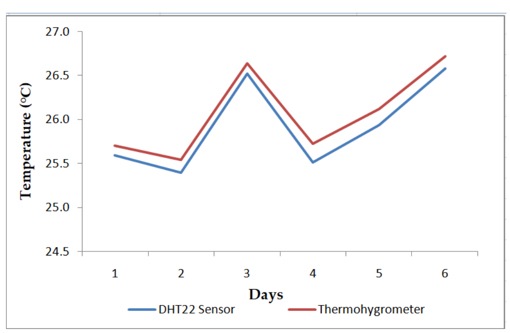
Preparation of the pakcoy plants is done by sowing the pakcoy seeds for 14 days until they are ready to be transferred to the netpot. The planting medium used for seeding is rockwool. Pakcoy seedlings that are ready for transplanting have an average height of 6.7 cm with an average number of leaves of 5 strands. The results of the preparation of the pakcoy plant can be seen in Figure 11.

Figure 11. Pakcoy Plant Preparation

3.1 Monitoring and Sensor reading accuracy

3.1.1 Growbox temperature

The results of the accuracy of reading the temperature of the grow box on day 5 to day 30 obtained a successive R square value of 0.9945; 0.9779; 0.9947; 0.9937; 0.9836 and 0.9939. The average accuracy of the grow box temperature reading by the sensor is 0.9897. Previous research by Suganda (2021) obtained an R2 value of 0.9776. The results of the regression values obtained on the DHT22 sensor readings show a value that is almost close to the value 1, so it can be concluded that the temperature readings by the sensor during research activities can function properly. The error value of the accuracy of temperature readings by the sensor can be seen in Figur 12.



Figur 12. Difference of Temperature Readings by the DHT22 Sensor with a Thermohygrometer

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Figur 12 above shows the difference in the DHT22 sensor readings with the thermohygrometer which has the largest difference of 0.2°C. According to Bogdan (2016) the accuracy for temperature readings on the DHT22 sensor is 0.5°C, so it can be concluded that the temperature reading by the DHT22 sensor has good results because it is still within the accuracy range of the sensor. The biggest error value is found on the 20th day of 0.7776% and the smallest error value occurs on the 1st day of 0.3891%. The average error during observation is 0.5631. The error occurs because of the sensitivity of the sensor so that there is a difference in temperature readings on the DHT22 sensor and the Thermohygrometer.The graph of the results of temperature observations can be seen in Figure 13.

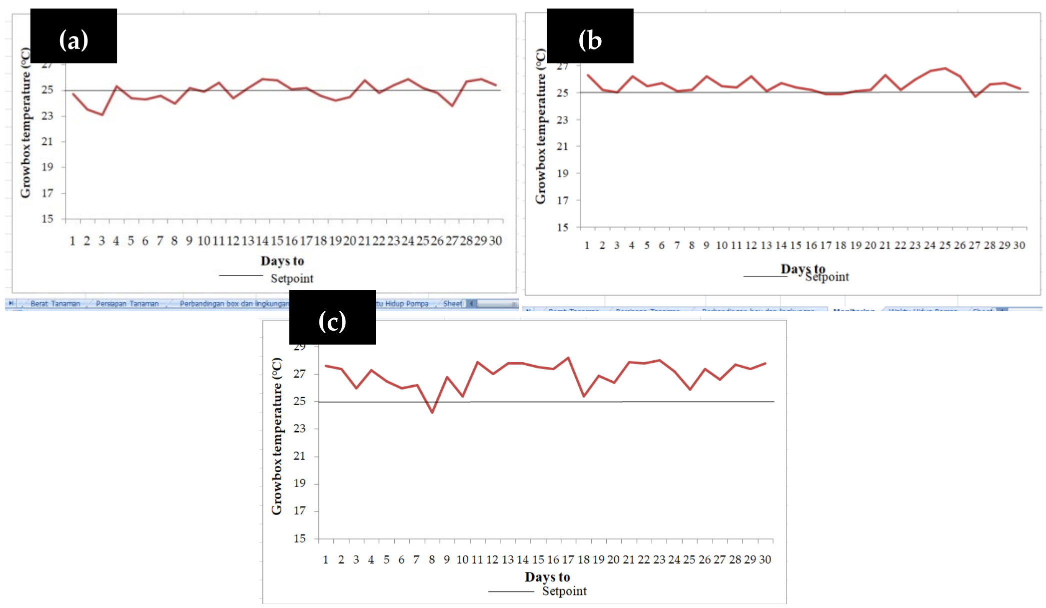

Figure 13. Observation of Grow Box Temperature (a) 08.00 AM (b) 12.00 AM (c) 04.00 PM

3.1.2 Grow box humidity.

The accuracy of the DHT22 sensor humidity readings from the 5th to the 30th day in a row obtained an R square value of 0.9848; 0.9876; 0.9573; 0.9737; 0.9505 and 0.9784. The average accuracy of the DHT22 sensor in reading the humidity of the grow box obtained a value of 0.9721. Previous research by Suganda (2021) obtained an R square value of 0.9677. The results of reading the accuracy of the DHT22 sensor for humidity obtained show results close to 1, so it can be concluded that the DHT22 sensor can still work properly. The error value for reading the accuracy of the sensor for humidity can be seen in Figure 14.

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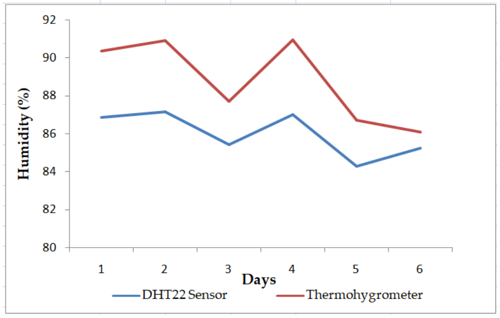

Figure 14. Difference of Humidity Readings by the DHT22 Sensor with a Thermohygrometer

Figure 14 above shows the difference in the value of humidity readings on the DHT22 sensor. The biggest difference in humidity readings that occurs is 3.78%. According to Bogdan (2016) the accuracy of humidity readings by the DHT22 sensor is 2% -5%, so it can be concluded that the humidity readings have good results because they are still within the accuracy range of the DHT22 sensor. The largest error value occurs on the 20th day with a value of 4.3536% and the smallest error value occurs on the 30th day with an error value of 0.9756%, so that the average error value for humidity readings is obtained on the accuracy of the DHT22 sensor is 3.1251%. The greater the difference in the value of the sensor reading with the tool, the higher the error value will be obtained. The results of observing humidity can be seen in Figure 15.

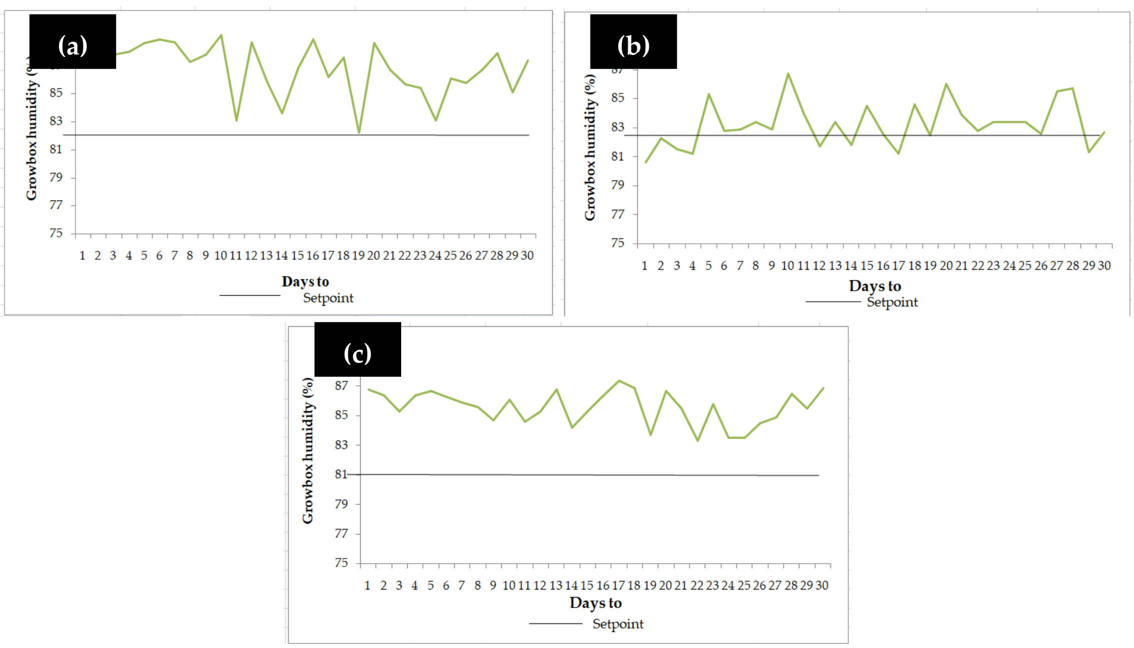

Figure 15. Observation of Grow Box Humidity(a) 08.00 AM (b) 12.00 AM (c) 04.00 PM

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3.1.3 The height of the Nutrient Solution in the bucket

Monitoring observations on the HC-SR04 ultrasonic sensor are carried out every day at 08.00 WIB in the nutrient bucket. The function of applying the HC-SR04 sensor in an aeroponic system is to ensure that the level of nutrient solution in the bucket remains available so that it does not cause problems with the pump if the bucket is empty. The results of observing the height of the nutrient solution can be seen in Figure 16.

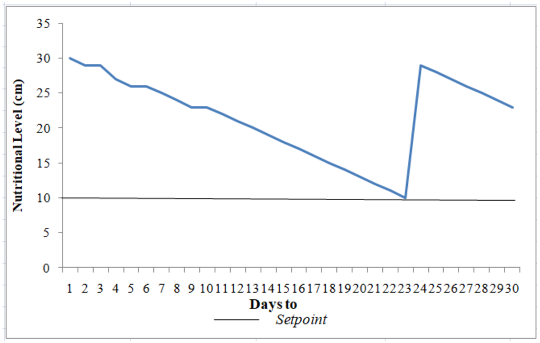

Figure 16. Graph of Observation of Nutrient Solution Height

3.1.4 Plant Nutrition

Observations of plant nutrition monitoring using the TDS sensor were carried out for 30 days on the nutrients in the bucket. Observations are made every 08.00 WIB by looking at measurements from the TDS sensor on the blynk application. The nutrition needed by the pakcoy plant in the 1st week is 1000 ppm, then increases every week by 100 ppm until the 4th week. The results of reading nutrient concentrations using the TDS sensor can be seen in Figure 17.

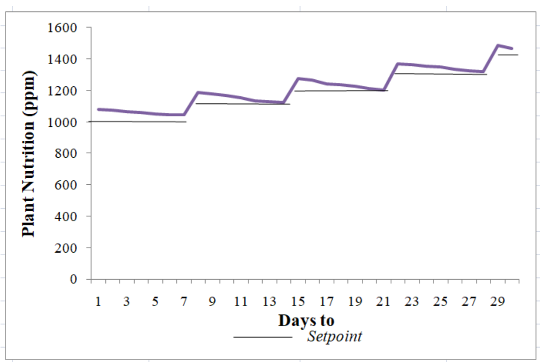

Figure 17. Graph of Plant Nutrition Observation

Figure 17 shows that plant nutrition has decreased every week, but is still within the set point range that has been determined. There is a decrease in nutrients due to evaporation (evaporation) and transpiration which causes the nutrient water level in the bucket to decrease. The increase in nutrient

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density every week occurs because nutrients are added manually every week to meet nutritional needs and increase the ppm of nutrients according to the nutritional needs of the pakcoy plant.

3.1.5 Pump Lifetime

The lifetime of the pump or jet pump is calculated by calculating the live time of the pump using a stopwatch. Observation of the lifetime of the pump is carried out to see the time needed by the pump when the temperature is 25°C until it reaches 24°C. Calculations on the lifetime of the pump were carried out three times. Pump lifetime can be seen in Table 1.

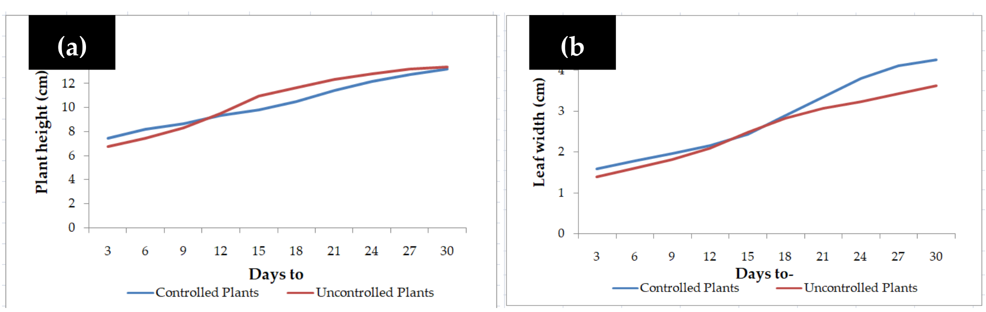
Table 1. Pump Life Time

Test	Time	Time (s)
1	5 minutes 24 seconds	324
2	4 minutes 57 seconds	287
3	6 minutes 32 seconds	392
	Average (s)	334

Table 1 shows that the longest time it took the pump to reach a temperature of 24°C was 392 seconds, while the fastest time for the pump to reach a temperature of 24°C was 287 seconds, so the average obtained from 3 repetitions of calculating the lifetime of the pump was 334 seconds. The lifetime of the pump can be affected by temperatures that are too hot or too cold, so it takes longer time to reduce the temperature if the grow box temperature is high, as well as when the temperature is low, the time needed to reduce the temperature will be faster.

3.2 Plant Height, Leaf Width, Number of Leaves and Plant Weight

Observations of plant height, leaf width and number of leaves were carried out once every three days for 30 days of the study. Observations were made on day 3, 6,9,12,15,18,21,24,27 and 30. A graph of the comparison of plant height, leaf width and number of leaves can be seen in Figure 16 and the overall picture of the system and plants can be seen in Figure 17.



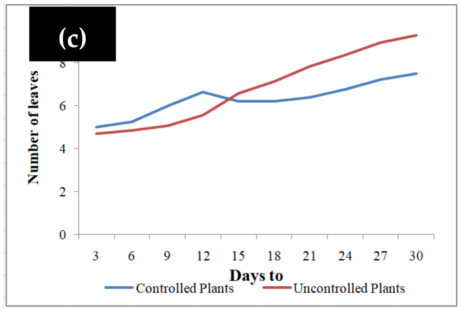


Figure 16. (a) Plant height chart (b) Plant width chart (c) Number of leaves

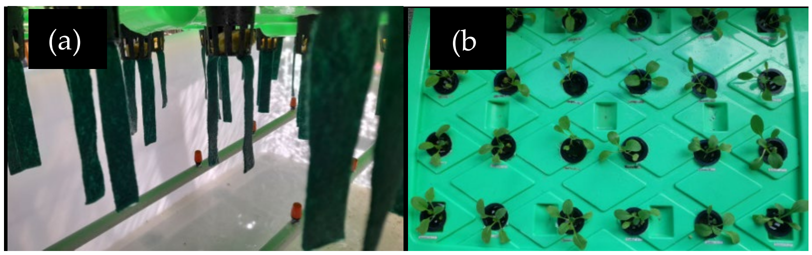


Figure 17. (a) The inside of the box (b) Plants

The average height of pakcoy plants in the controlled treatment in controlled plants was 13.3 cm, while the plant height in uncontrolled plants obtained an average plant height that did not differ much from the plants in the aeroponic system, namely 13.4 cm. According to Lingga (2003) genetic factors and environmental conditions where plants grow can affect plant height. The average leaf width of the pakcoy plant obtained showed that the average leaf width of the pakcoy plant in controlled plants system was 4.3 cm, while the plants planted in uncontrolled plants control had an average leaf width of 3.6 cm. According to Sarido et al (2017) that differences in leaf width can be caused by the nutrient content given, the higher or lower the nutrients given, the more it will affect plant growth and development. The average observation of the number of leaves on pakcoy plants in controlled plants obtained an average of 8 leaves while the average number of leaves on pakcoy plants in uncontrolled plants was 9 leaves. According to Utomo (2006) at the germination stage and the early stages of plant growth, seeds are very vulnerable to physiological stress, infection and mechanical damage, which causes inhibition of vegetative growth. Three factors that affect growth are light, temperature and humidity factors.

After harvest on day 31, the plant weight was measured in each net pot and polybag. A graph of the comparison of plant weight in the controlled plants with uncontrolled plants can be seen in Figure 18.

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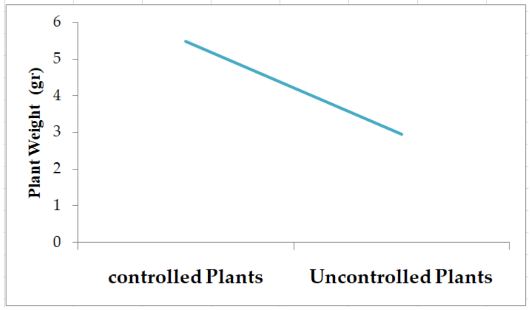

Figure 18. Graph of Plant Nutrition Observation

The average plant weight in controlled plants was 5.493 gr with the heaviest plant in unctrolled plants being 16.463 gr, while the average plant weight in the control plant was 2.961 gr, with the heaviest plant in the control being 5.582 gr. The standard deviation of controlled plants was 5.513 and that of uncontrolled plants was 0.918. Plants in the aeroponic system have a low average weight due to the influence of the small number of leaves on the weight of the plant. This was also stated by Polii (2009) that the number of plant leaves will automatically increase plant fresh weight. The leaves of vegetable plants are the parts that contain a lot of water, so the more leaves, the higher the water content of the plant and the higher the weight of the plant.

4. Conclusion

The conclusions obtained from the research that has been done are as follows.

1. Aeroponics by controlling temperature and humidity, the level of nutrient solution and the concentration of plant nutrients using a container box measuring 110 cm x 80 cm with 10 nozzles on the inside of the box attached to a ½ inch pipe, with 24 planting holes on the lid of the box which has spacing of 20 cm.
2. The control system with the DHT22 sensor for temperature and humidity readings can start the pump at >25^{o}C and stop at =24^{o}C, the HC-SR04 sensor for reading the nutrient solution level can read the water level and pop up a notification on the smartphone when the bucket starts to empty. TDS sensors for reading plant nutrient concentrations can take nutrient concentration readings. control system can work well during 30 days of research. Observations and sensor readings can be done remotely using the blynk application.
3. Calibration results on temperature and humidity readings by the DHT22 sensor get R square values respectively 0.9864 and 0.9893. The R square value on the HC-SR04 ultrasonic sensor is 0.996 and the R square value on the TDS sensor is 0.9899. The average regression analysis of the accuracy of the DHT22 temperature and humidity sensor readings was 0.9897 and 0.9721. The average plant height

in the system was 13.3 cm, leaf width was 4.3 cm, number of leaves was 8 and plant weight after harvest was 5.493 gr.

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