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RAFT: An IoT-Based Nutrition Monitoring System for Bok Choy Hydroponics Plants

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Abstract

The Internet of Things (IoT) plays a crucial role in technology advancements, especially in the agricultural sector, such as hydroponics. Manual monitoring of parameters like nutrient levels, pH, and water levels in plants consumes farmers' time and energy and increases the risk of crop failure. This research aims to evaluate the effectiveness of using IoT RAFT (Remote Automated Farming Technology) system for farmers, particularly hydroponic bok choy farmers, in monitoring and controlling plant nutrient levels and the development process using waterfall as a research methodology. Parameters tested in this research include bok choy height, number of leaves, and bok choy harvest weight. We conducted this research on 14 plants for one harvesting period, then we used linear regression to determine the growth rate by calculating the slope. The results show that the plant height, the number of leaves, and harvest weight using the IoT RAFT system are 0.5897 cm/day, 0.6391 leaves/day, and 216.43 grams, respectively. We also compared the IoT RAFT system with a non-IoT bok choy growing method, and we concluded our IoT RAFT system has a better growth rate compared to the non-IoT bok choy growing method.

Keywords: *bok choy; hydroponics; internet of things; linear regression; nutrition monitoring system*

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1. Introduction

The concept of the Internet of Things has been widely applied in various aspects of life particularly in agriculture [1]. The integration of technology into agriculture has led to the emergence of Precision Agriculture (PA) [2]. Traditional farming is currently facing a serious challenge, including a decrease in land productivity and inadequate soil fertility. Moreover, frequent drought and unpredictable weather patterns pose a significant threat to traditional agricultural systems. One of the ways to face this issue is through the use of hydroponics farming [3].

Hydroponics is a method of growing plants without soil. In hydroponics farming, inert media such as gravel, sands, peat, perlite, or other substrates are used as a soil substitute. Some advantages of hydroponics cultivation include more efficient nutrient control, the ability to grow crops virtually anywhere, more efficient fertilizer and water usage, easy low-cost media sterilization, and higher planting density, which can lead to increased yield per hectare [4].

Hydroponics farming employs different techniques compared to traditional farming. In hydroponics, plants require specific treatment for controlling water temperature, water level, acidity level (pH), and nutrient solutions [5]. To achieve a good harvest, farmers need to perform daily manual inspections [6]. This method consumes a significant amount of time for farmers as they must inspect each hydroponics reservoirs, which mean the cultivated plants cannot be left unattended for extended periods.

On hydroponic crops, the nutrient needs of each plant and growth have different levels [7]. If the nutrient level for a specific plant exceeds the required limits, the plant will be defective. Meanwhile, if a plant's nutrition level is lacking, the plant will turn yellow [6]. When the nutrient doesn't align with the plant's actual conditions, it can hamper plant growth and potentially lead to crop failure.

Nutrients themselves can be divided into two categories: macronutrients and micronutrients. Macronutrients are required in large quantities for the survival of the plants. Based on their function,

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macronutrients are further categorized into two groups: primary and secondary macronutrients. These primary and secondary macronutrients play a crucial role in plant life by engaging in beneficial activities within plant metabolism and protecting from various effects, whether biotic or abiotic stressors, such as heavy metals, drought, heat, ultraviolet radiation, and pest and disease attacks [8]. Furthermore, micronutrient plays a crucial role in plant growth, development, and plant metabolism. A micronutrient deficiency can lead a various physiological disturbances or diseases in plants, ultimately affecting not only the quantity but also the quality of vegetable crops [9].

Many previous studies have primarily focused on the accuracy of the sensors used and have rarely discussed crop quality after using an IoT system. For instance, in the study by Endryanto and N. E. Khomariah [10], researchers developed a prototype to monitor temperature, acidity, and nutrient concentration in hydroponics. However, the study primarily assessed the accuracy of the sensors used and did not investigate the impact on crop quality. In a study conducted by Ma’shumah and Pramartaningthyas [11], researchers observed parameters related to water level and nutrient concentration. The results of the research indicate that the sensors used can function effectively, as evidenced by the pump’s ability to work according to the nutrient requirement. In a study conducted by Yuvaraju and Vasanthabalan [12], the researcher developed a system for controlling water pH, water temperature, and environmental humidity in hydroponics. The research results show that the developed device can operate automatically dan the data from the sensor are stored on the server. Furthermore, the researcher developed a device to monitor the quality of the shrimp ponds, with parameters including Dissolved Oxygen (DO), temperature, and TDS (Total Dissolve Solid) [13]. The research result indicated that the calibrated sensor results, analyzed using a linear regression method, had an average reading error of up to 14% for the DO sensor, and 1% for the temperature and TDS.

In a study similar to this research presented by Chiangmai, Gertphol, and Chulak [14], the researcher developed a device capable of monitoring and controlling the environment for lettuce cultivation and comparing the harvest results between using IoT and manual methods. The study’s findings indicated that using the device led to slightly better crop quality compared to not using the system. Additionally, the nitrate content in the lettuce was improved by 8.24%.

In this research, we developed an IoT device to monitor nutrient levels in hydroponics plants. Yuan Hidroponik is one of the *Kelompok Wanita Tani* (KWT) in the Mojokerto. Based on the interviews and field surveys conducted earlier, there are several issues were identified, including the manual process of the inspection faced by KWT. This manual process prevents hydroponic systems from being left unattended for an extended period, requiring someone to ensure that plant nutrients are in the correct balance. Additionally, the selection of bok choy hydroponic plants as the research subject was motivated by the variability in the application of IoT systems among different plants.

This study analyzes the growth rate of bok choy plants by directly comparing IoT and non-IoT farming methods. Previous research has explored the potential of IoT for lettuce plants. Existing research on lettuce growth shows the potential benefits of IoT in improving agricultural output quality but raises concerns about reduced plant height [14]. The lack of specific data on bok choy, coupled with contradictory findings on plant height in other hydroponic systems, highlights the need for a case study to assess the actual effectiveness of IoT in optimizing bok choy production in a hydroponic environment. This is achieved by measuring and directly comparing growth parameters such as plant height, number of leaves and harvest weight with and without the IoT systems.

Waterfall is one of the popular methodologies in software development [15]. According to Ellis J, Edwards D, Thwala W et al [16], there are three stages to using the waterfall method as a research methodology, consisting of (1) literature review and pilot study, (2) quantitative analysis of the case study data, and (3) qualitative data collection using a focus group, which required further adjustments in this research.

Generally, the research methodology includes literature review, observation, system requirements analysis, system design, system implementation, and system testing. The literature review identifies existing research on hydroponics systems and IoT [17], while the observation stage involves visits to hydroponics farms to understand the challenges faced by farmers [18]. System requirements are then identified based on findings from literature review and observation, describing how the system is developed and responds to specific user commands [19].

The system design stage produces a detailed plan for hardware and software components for system development. System implementation involves hardware creation and software programming. In this study, the programming language used is C++, and PlatformIo is used as the IDE [20]. Finally, the system is tested on hydroponic farms to evaluate its effectiveness.

2. Research Methods

As previously explained in the introduction, the methodology used in this research is the waterfall approach. The state of the waterfall methodology can be shown in Figure 1.

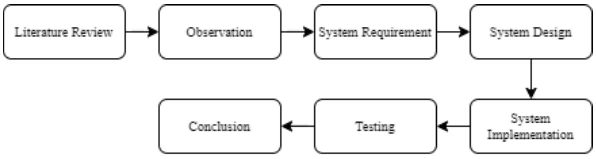

Figure 1. Research Methodology

The details of the stages of the waterfall method are:

The first stage of this research involves conducting a literature review by gathering relevant previous studies related to this topic. Broadly, a literature review can be described as a somewhat systematic way of collecting previous research. The sources for the literature review can include journals, books, articles, and other scholarly works.

The observation phase involves observing bok choy hydroponics plants at Yuan Hydroponics, in Mojokerto. There are several methods for collecting data, including experiments or surveys. During this stage, interviews with hydroponics systems owners are conducted to collect data and identify the problems that form the background of this research.

The system requirements analysis phase involves identifying system requirements based on the observations and literature review conducted earlier. This stage is performed to ensure that the system being developed aligns with the real-world or stakeholder needs, resulting in functional requirements as seen in Table 1, which represents the functional requirements of this research.

Table 1. Functional Requirements

No	Code	Requirement	Description
1	KF-01	Check Nutrient Level	Users can view the nutrient levels obtained from sensor readings.
2	KF-02	Controlling Actuators	User can control actuators to deliver nutrients if the nutrient levels are deemed insufficient.
3	KF-03	View Reading Sensor History	User can view the displayed sensor reading history.

In addition to the functional requirements, to create a system with an IoT concept, the materials needed for this research include ESP32, I/O Expansion ESP32 Shield, LCD I2C 20x4, Gravity: Analog TDS Sensor Meter for Arduino, Water Flow Sensor 1/8” YF-S401, Solid State Relay, Solenoid Valve 1/4”, Temperature Sensor DS18B20, Regulated AC Power Adapter 12V DC/2A, Jumper Wire, Terminal Block, PlatformIO as an Integrated Development Environment (IDE), and VSCode as the Text Editor.

The system design phase is carried out to create a detailed plan for a system based on the requirements analysis defined in the previous stage. The system design result is shown in Figure 2.

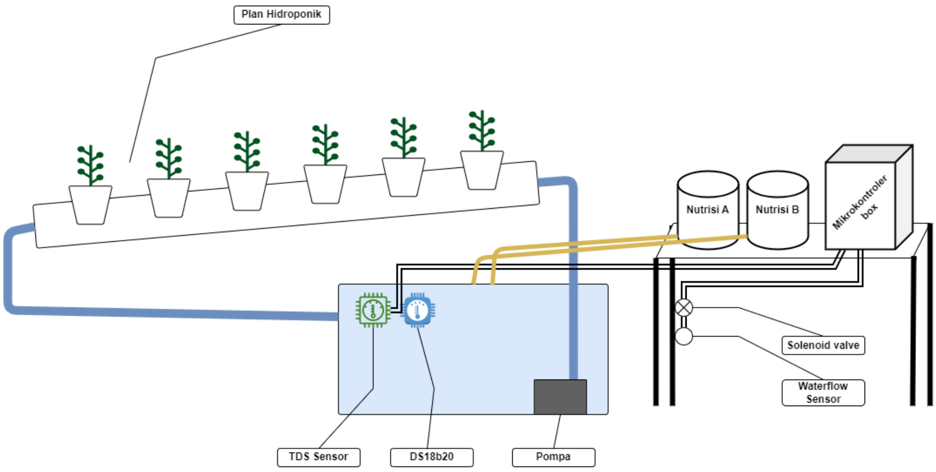

Figure 2. System Architecture Design

The design of the hydroponic nutrient monitoring system installation consists of a TDS sensor, which functions to measure the Electrical Conductivity (EC) present in the water. Additionally, there is a DS18B20 sensor to measure water temperature and a water flow sensor used to gauge the amount of nutrients required by plants. The TDS and DS18B20 sensors are placed inside the main nutrient reservoir by partially running the sensor cables. Subsequently, the water flow sensor is positioned under the shelf where the microcontroller box and nutrient box are located. The water flow sensor is connected to a solenoid valve as an actuator. The TDS sensor, temperature sensor, water flow sensor, and solenoid valve are then connected to the microcontroller as the communication hub for data exchange.

The system implementation stage is carried out to create previously designed hardware. The system that has been designed will be implemented in the form of actual hardware and programming language. At this stage, the system development uses the C programming language and uses the IO Platform as IDE, while the IoT platform uses Thinger.Io. The implementation of the previously designed hardware is shown in Figure 3.

Figure 3. Hardware Implementation

The system testing phase is carried out to test the developed IoT hardware and collect data in the location. The devices will be tested starting from the plants that have completed the germination or seeding stage until the harvest stage, with data collection taking place over approximately 30 days. After the germination process, 14 plants will be selected from both the IoT system and the conventional system as research samples. Measurements of the plants will be taken, including plant height which is measured from the rockwool to the highest point of the plant, the number of leaves on each plant, and the weight of the plants after harvest. These measurements are conducted to monitor the growth of bok choy plants and compare their growth when using the IoT system and without the IoT system (conventional system).

The conclusion phase is carried out to conclude the research. The conclusion is drawn from the system testing that has been conducted earlier.

3. Results and Discussions

To compare and evaluate the benefits of the Internet of Things-based Nutrient Monitoring System with the conventional method, two identical hydroponics installations were set up in Dlangu, Mojokerto. One hydroponic installation was equipped with the developed IoT system, while the other one was managed conventionally. The harvest was conducted for a single harvesting period, which was approximately 30 days. Fourteen random samples of plants were collected from both installations. The plants were measured every 3 to 5 days to monitor plant growth, including plant height, the number of leaves, and plant weight after harvest.

3.1 Plant Height Result Measurement

Plant height measurements were taken using a ruler, starting from the rockwool or growing medium and extending to the highest point of the plant. The comparison of plant height measurements with and without IoT systems can be resolved in Table 2 and Table 3.

Table 2. Hydroponics Bok Choy Plant Height Using IoT System

No	Days	Plant Height Using IoT														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
1	1	4.0	3.5	3.0	3.5	3.5	3.0	3.5	3.5	3.0	3.5	3.0	4.0	4.0	3.2	3.4
2	5	7.5	7.0	8.0	8.0	6.5	7.0	6.5	6.2	7.5	7.6	6.5	5.7	6.5	6.0	6.9
3	7	8.5	10.0	9.5	11.0	9.0	10.0	8.3	8.0	8.2	9.5	8.0	7.5	8.4	7.8	8.8
4	10	11.5	12.0	14.0	14.5	12.7	13.5	10.5	10.5	11.1	10.0	11.0	6.0	10.0	10.1	11.2
5	14	14.0	14.0	18.0	17.0	16.0	16.0	14.5	14.0	14.5	16.0	13.5	13.0	11.5	12.5	14.6
6	18	18.0	19.0	23.0	22.0	18.5	22.0	19.0	18.5	19.0	20.0	18.0	16.0	15.0	16.8	18.9
7	21	19.5	22.0	24.5	23.0	19.5	23.5	21.0	21.0	23.0	22.0	19.5	16.0	18.0	18.5	20.8
8	25	21.5	21.5	23.0	24.0	20.0	20.0	20.5	17.5	23.0	22.0	19.5	16.5	18.0	18.0	20.4
9	31	23.0	24.0	26.0	26.0	21.0	24.0	22.0	22.0	23.0	22.0	19.5	18.0	18.0	18.5	21.9
10	35	24.5	25.0	27.0	30.0	22.5	23.5	22.5	20.5	27.0	22.0	19.5	19.0	20.0	19.5	23.0

Table 3. Hydroponics Bok Choy Plant Height Without Using IoT System

No	Days	Plant Height Without Using IoT														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
1	1	3.5	3.5	3.0	3.0	4.3	2.0	3.3	4.0	4.0	3.0	3.0	3.0	3.0	2.5	3.2
2	5	5.5	4.8	4.4	3.0	6.4	2.6	7.0	6.5	8.0	3.6	4.5	4.0	4.7	4.0	4.9
3	7	7.0	7.0	5.8	5.9	8.4	3.5	9.0	8.7	9.5	6.3	6.0	6.0	6.5	5.3	6.8
4	10	10.0	9.7	6.3	9.2	10.8	4.3	11.5	12.3	11.0	6.3	7.0	9.0	8.5	8.7	8.9
5	14	13.0	14.0	10.5	11.0	14.5	5.0	14.5	16.0	15.5	9.5	9.5	10.5	13.0	11.0	12.0
6	18	18.5	20.0	13.0	15.0	18.5	6.0	17.5	20.5	20.5	13.0	14.3	14.4	18.0	14.8	16.0
7	21	18.7	22.0	14.2	18.5	20.5	8.0	19.0	23.0	22.0	16.0	16.5	16.0	20.5	17.5	18.0
8	25	18.7	22.0	15.0	19.0	20.0	8.0	19.0	23.5	23.3	18.0	17.0	18.0	21.0	18.0	18.6
9	31	21.0	23.5	15.0	19.0	20.5	8.0	19.0	23.5	24.0	20.5	18.0	18.0	23.0	19.0	19.4
10	35	22.0	23.0	17.5	21.5	22.0	10.0	18.5	23.5	25.0	21.5	18.0	17.5	24.5	19.5	20.3

The plant height measurement will then be averaged for each system, and the data will be presented in the form of a linear regression graph, as shown in Figure 4. This graphical representation allows for a visual assessment of the growth trends over the evaluation period.

As a result, the regression equation for the growth rate with IoT and without IoT systems was derived, and they can be seen in Formula 1 for plants with IoT systems.

$$y = 0.5897x + 5.1569 \quad (1)$$

Meanwhile, the regression formula for calculating the growth rate of plants without an IoT system is shown in Formula 2.

$$y = 0.5491x + 3.6446 \quad (2)$$

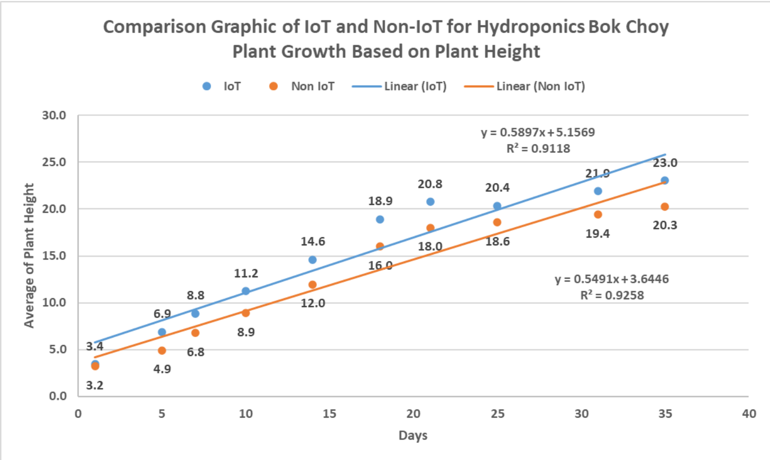

Figure 4. Comparison Graphic of IoT and Non-IoT for Hydroponics Bok Choy Plant Growth Based on Plant Height

The obtained equation can be analyzed by observing the slope of the graph. A stepper regression slope implies a better growth rate. In this case, the regression slope for plants using the IoT system is 0.5897, indicating that each day, plants using the IoT system can grow approximately 0.5897 cm per day. Conversely, the regression slope for plants without the IoT system is 0.5497, meaning that plants without the IoT system grow approximately 0.5497 cm per day.

The difference in regression slope between the two systems suggests that the growth rate of plants using the IoT system is slightly better than those without the IoT system, although the difference in regression slope is not significantly pronounced.

3.2 Number of Leaves Result Measurement

System testing on several leaves was carried out to compare the growth rate of bok choy plants when using IoT and without using IoT based on the number of leaves on the plant. The measurements of the number of leaves are calculated manually based on the number of leaves available at that time. The comparative results of measuring the number of leaves can be seen in Table 4 for the plant using the IoT system, and Table 5 for the plant without the IoT system.

Table 4. Hydroponics Bok Choy Number of Leaves IoT System

No	Days	Number of Leaves Using IoT														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
1	1	4	3	4	3	4	3	4	4	4	4	4	3	3	4	3.6
2	5	5	7	5	5	6	5	5	6	5	5	5	6	6	5	5.4
3	7	6	8	6	7	6	7	6	7	6	6	6	6	7	6	6.4
4	10	6	7	6	7	6	7	6	7	8	6	6	6	7	7	6.6
5	14	9	10	8	11	10	8	9	8	10	8	9	9	9	8	9.0
6	18	9	11	9	12	10	9	10	8	11	9	8	9	8	8	9.4
7	21	12	15	13	14	12	12	12	10	15	11	12	10	10	9	11.9
8	25	19	17	15	16	15	15	14	12	18	19	14	14	13	12	15.2
9	31	27	20	21	21	23	20	24	12	23	31	16	22	14	17	20.8
10	35	38	30	21	32	23	26	37	14	27	44	28	28	17	21	27.6

Table 5. Hydroponics Bok Choy Number of Leaves Without Using IoT System

No	Days	Number of Leaves Without Using IoT														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
1	1	3	3	3	3	3	3	4	4	4	2	3	3	2	3	3.1
2	5	5	4	3	4	5	4	5	5	5	4	4	4	5	6	4.5
3	7	6	4	4	4	6	5	6	5	6	5	5	5	5	6	5.1
4	10	6	6	4	4	6	5	6	6	6	5	5	5	5	6	5.4
5	14	8	7	7	5	7	4	7	7	7	7	6	7	6	7	6.6
6	18	10	8	7	6	9	5	9	10	8	6	6	8	8	8	7.7
7	21	13	10	8	8	10	5	10	12	11	8	8	11	9	11	9.6
8	25	18	14	12	11	13	7	13	17	14	11	12	14	10	16	13.0
9	31	18	16	15	15	17	7	15	22	16	16	18	19	14	23	16.5
10	35	25	19	18	19	19	9	18	28	20	17	17	21	18	28	19.7

The results of several leaf measurements between the IoT system and without the IoT system over approximately 30 days are presented in Table 3 and Table 4. In these tables, the averages of each system are calculated based on the collected samples. Subsequently, these averages are displayed in the form of a regression linear graph as shown in Figure 5.

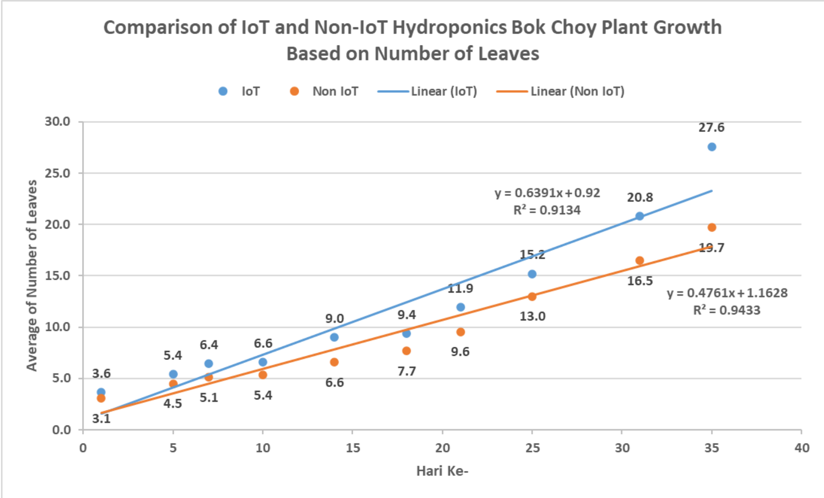

Figure 5. Comparison Graphic of IoT and Non-IoT Hydroponics Bok Choy Plant Growth Based on Number of Leaves

As a result, the regression equation for the growth rate with IoT and without IoT systems was derived, and they can be seen in Formula 3 for plants with IoT systems, and Formula 4 for plants without IoT systems.

$$y = 0.6391x + 0.92 \quad (3)$$

Meanwhile, the regression formula for calculating the growth rate of plants without an IoT system is as follows.

$$y = 0.4761x + 1.1628 \quad (4)$$

Based on the regression equations generated above, these equations can help us to understand the comparison of growth rates concerning the number of leaves in bok choy hydroponic plants between the IoT system and the non-IoT system. The obtained equations can be analyzed by observing the slope of the graph, a higher regression slope indicates better plant growth. In this case, the regression slope for plants using the IoT system is 0.6391, indicating that each day, plants using the IoT system can grow approximately 0.6391 leaves per day. In contrast, the regression slope for plants without the IoT system is 0.4761, which means that plants without the IoT system can grow around 0.4761 leaves per day.

By analyzing the regression slope, it can be concluded that the use of the IoT system in Bok Choy hydroponics is more effective than not using the IoT system. This indicates that the IoT system has a positive impact on the number of leaves, leading to better bok choy plant growth.

3.3 Plant Weight Result Measurement

The system was tested for plant height and weight during the harvest of bok choy plants using the IoT system and without using the IoT system. Plant weight measurements were taken using scales, and the measurements were in grams. The results of the pant weight measurements can be seen in Table 6.

Table 6. Comparison of the Weight of Bok Choy Hydroponics Plants Using IoT System and Without Using IoT System

Comparison of IoT and Without Using IoT for Hydroponics Plant Weight		
Sample	IoT	Non-IoT
1	255	235
2	205	215
3	300	95
4	315	185
5	255	210
6	250	15
7	240	100
8	115	235
9	280	185
10	290	165
11	130	110
12	160	90
13	90	230
14	145	170
Average	216.43	160

Based on the results of weighing the plant weight after harvest in Table 5, the average weight of the plants indicates that the average weight in the IoT system shows better results compared to the average weight in the conventional system. Specifically, the average with the IoT system is 216.43 grams, while the average weight without the IoT system is 160 grams. This suggests that the IoT system contributes to a notable improvement in plant weight after harvest, highlighting its potential benefits in enhancing crop yields.

4. Conclusions

From the test result conducted to evaluate the effectiveness of using IoT for bok choy hydroponics plants, several conclusions can be drawn. In the test for plant growth based on plant height, the use of an IoT system in hydroponics farming showed a growth rate effectiveness of 0.5897 cm/day, which is slightly better than the manual system. The test results for plant growth based on the number of leaves showed an effectiveness of 0.6391 leaves/day. Furthermore, the weight measurement result for plants using the IoT system had an average weight of 216.43 grams.

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