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Development of Hydroponics Lettuce Production Process to Increase Productivity and Quality using Automated Control System via Internet of Things (IoT) Technology

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Abstract

This research aims to 1) study the growth, yield, quality, and production efficiency of lettuce cultivated in different hydroponic systems, 2) Develop a control system for the growth of lettuce in diverse hydroponic setups, utilizing Internet of Things (IoT) technology for all elements, and 3) compare the effectiveness of traditional lettuce production methods with automated control systems using IoT technology. The research equipment included 1) an automated control system, 2) applications, and 3) hydroponic cultivation methods. Statistical analysis includes mean, standard deviation, and t-test. The findings of the research reveal that 1) the growth, yield, quality, and production efficiency of lettuce in various hydroponic systems differ significantly and are generally very good, 2) the development of a growth control system for lettuce in different hydroponic setups, integrated with IoT technology, results in a comprehensive and efficient system with excellent performance across all functions, 3) the comparison between traditional lettuce production methods and automated systems with IoT technology shows significant differences. Lettuce grown in hydroponic systems controlled by IoT exhibits higher concentrations of all phytochemicals and better antioxidant capabilities than traditionally cultivated lettuce.

Keywords: *Lettuce, Lettuce Production Process, Hydroponics, Internet of Things (IoT) Technology, Automated Control System, Nutritional Value.*

Introduction

According to the policies and guidelines for driving Thailand's agricultural sector in 2020, presented by the Ministry of Agriculture and Cooperatives, the focus is on water management throughout the system to reduce the potential drought issues expected to occur in 2020. This campaign is achieved by creating additional water sources, including large, medium, and small-scale water storage in the form of reservoirs, with an emphasis on constructing contour trenches during the rainy season. These trenches help to collect water in various river basins and promote secure and organic agriculture to provide consumers with safe products. The Ministry of Agriculture and Cooperatives has implemented initiatives for sustainable and economically sufficient agriculture, comprising three main measures for organic farming:

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reducing and eliminating chemical usage, avoiding hazardous substances in potential areas, and discouraging the development of various chemicals. Additionally, environmental conservation efforts include replacing chemical usage with machinery, joint efforts between all sectors to address issues, and establishing market systems to bring agricultural products to the market, managing low agricultural product prices. The focus is on online markets that work together in all sectors to reduce production costs and increase production to support all farmers.

Moreover, the Ministry has established and compiled national agricultural information (Big data) at the Agricultural Technology Center, which is vital for the Ministry of Agriculture and Cooperatives. All agencies must have consistent information for easy access and coordination. Furthermore, the Ministry of Agriculture and Cooperatives emphasizes organic agriculture as a production approach that prioritizes food quality and safety for all stakeholders, including producers and consumers, while promoting sustainable resource conservation and environmental sustainability. The Ministry aims to enhance organic agricultural products' popularity and continuous expansion (Ministry of Agriculture and Cooperatives, 2020).

The Office of Agricultural Economics (OAE) conducted a study on the organic lettuce supply chain in Chiang Mai and Nakhon Ratchasima provinces, which are the provinces with the highest number of certified organic lettuce growers under the Organic Thailand standard in the northern and northeastern regions. The study aimed to add value to lettuce production for farmers by collecting data from various stakeholders in the supply chain, including marketing officers, production planning officers, promotion officers, and lettuce farmers involved in production planning, input procurement, and production management. The stakeholders in the midstream and downstream of the supply chain, including distribution and end-market, were also included in the study.

The findings of the study revealed that organic lettuce farmers, such as romaine lettuce, iceberg lettuce, cos lettuce, Green Oak lettuce, and red oak lettuce, incur an average production cost of 9,501 Baht per rai (approximately 0.16 hectares) and achieve an average yield of 842 kilograms per rai. The selling price for the farmers' produce is 52.41 Baht per kilogram, resulting in an average return per rai of 44,112 Baht and an average net return per rai of 34,611 Baht. In Chiang Mai province, the marketing channel for organic lettuce involves selling to centers/project stations, such as the Royal Project Doi Inthanon Center in Chiang Dao district and the Royal Project Ang Khang Center in Chom Thong district, as well as the Ang Khang Royal Agricultural Station. The produce is distributed to retailers, wholesalers, companies, and consumers. On the other hand, in Nakhon Ratchasima province, the majority of the lettuce produce is sold to cooperatives and community enterprises in Wang Nam Khiao district, such as the Wang Nam Khiao Agricultural Cooperative, and to sizeable organic vegetable plantations at the Nikhom Mek Economic Self-sufficiency Community. The produce is also sold directly at the farms.

The price difference between what consumers pay and what farmers receive is evident in the lettuce market. Collectors and project stations deduct 25 Baht per kilogram from the farmers' selling price, while retailers, wholesalers, and companies in the provinces and Bangkok deduct 20 Baht per kilogram. However, retailers in Bangkok charge consumers an additional 53 Baht per kilogram. This price variation is attributed to the perishability and susceptibility of organic lettuce to spoilage, but it benefits from good production management and an assured market with high returns. Therefore, the government should promote organic lettuce farming to increase farmers' income and support the development of technology to enhance production processes, including establishing organic vegetable seed centers to reduce seed costs for farmers (FAO, 2018).

Hydroponic Vegetable Gardening is a method of cultivating kitchen garden vegetables without using soil but instead utilizing a nutrient-rich water system to promote plant growth (Gauthier, L., 2016). Hydroponic farming offers numerous advantages since it eliminates soil contamination and potential habitat for tiny pests like worms. Furthermore, it eliminates soil transportation, making it suitable for limited spaces, such as condominiums, with minimal plant pests. Additionally, hydroponic farming allows precise estimation of yields and harvest times. Lettuce, a popular and widely imported vegetable in Thailand, is used fresh or as a garnish for various dishes, such as yam sakoo (tapioca dumplings with pork fillings) or kao kriab pak mo (fried rice wrapped in an omelet). Lettuce is known for its high nutritional value, vibrant appearance, and delicious taste. Its demand is consistent throughout the year, especially during festive occasions like the New Year when its sales peak. Therefore, it holds significant economic importance (Department of Agricultural Extension, 2020).

The agricultural business in Thailand faces multiple challenges, including low crop yields, weather fluctuations, natural disasters, and rapidly changing consumer behavior. These factors have made the newer entrepreneurs perceive entry into agriculture as complicated and potentially unrewarding. However, agricultural technology, known as Agritech, has significantly addressed these challenges. By integrating Internet of Things (IoT) technologies across the entire agricultural supply chain, Agritech offers intriguing options for enhancing competitiveness among agricultural entrepreneurs. The core of IoT lies in utilizing sensor technologies to collect data, aiding decision-making, and efficient production management. This technology covers the entire production system. Given these challenges, there is an inclination to develop hydroponic lettuce farming processes using automated control systems through IoT technologies to increase productivity and quality. This research aims to compare the effectiveness of traditional lettuce and automated farming with IoT technologies and disseminate knowledge to the community (Department of Agricultural Extension, 2023).

Objectives

1. To study the growth, yield, quality, and production efficiency of lettuce cultivated in different hydroponic systems.

2. To develop a controlled growth system for lettuce cultivated in various hydroponic conditions, utilizing Internet of Things (IoT) technologies.

3. To compare the effectiveness between traditional lettuce farming and automated farming using IoT technologies regarding productivity and quality.

Research Methodology

The research on "Development of Hydroponic Lettuce Farming to Increase Productivity and Quality using Automated Control System via Internet of Things" is a mixed-method study that combines experimental research and research and development. The research process will follow the following objectives:

1. To study the growth, yield, quality, and production efficiency of lettuce cultivated in different hydroponic systems.

2. To develop a controlled growth system for lettuce cultivated in various hydroponic conditions, utilizing Internet of Things (IoT) technologies.

3. To compare the effectiveness between traditional lettuce farming and automated farming using IoT technologies regarding productivity and quality.

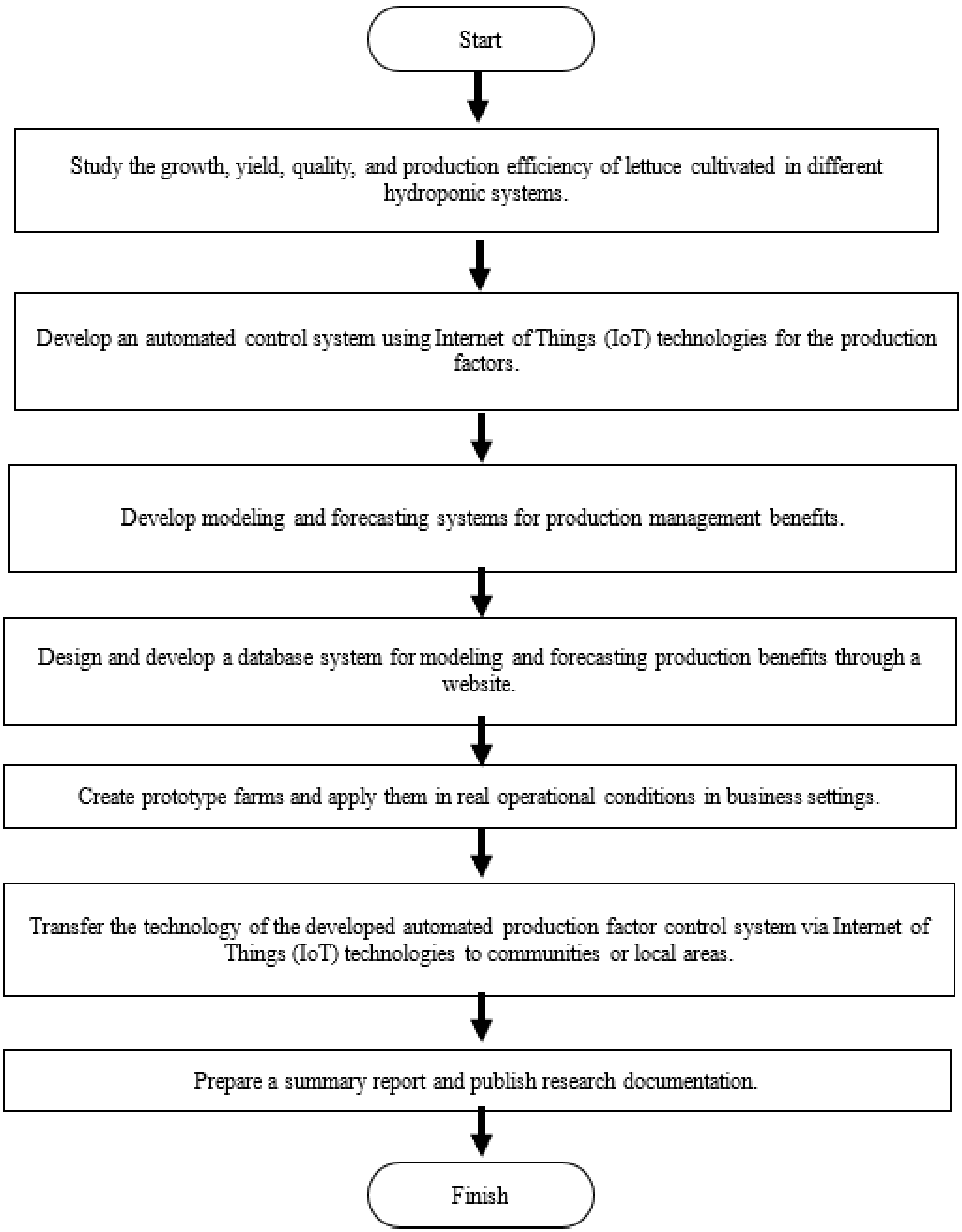


Figure 1. Flowchart for steps of the research process.

Research Framework

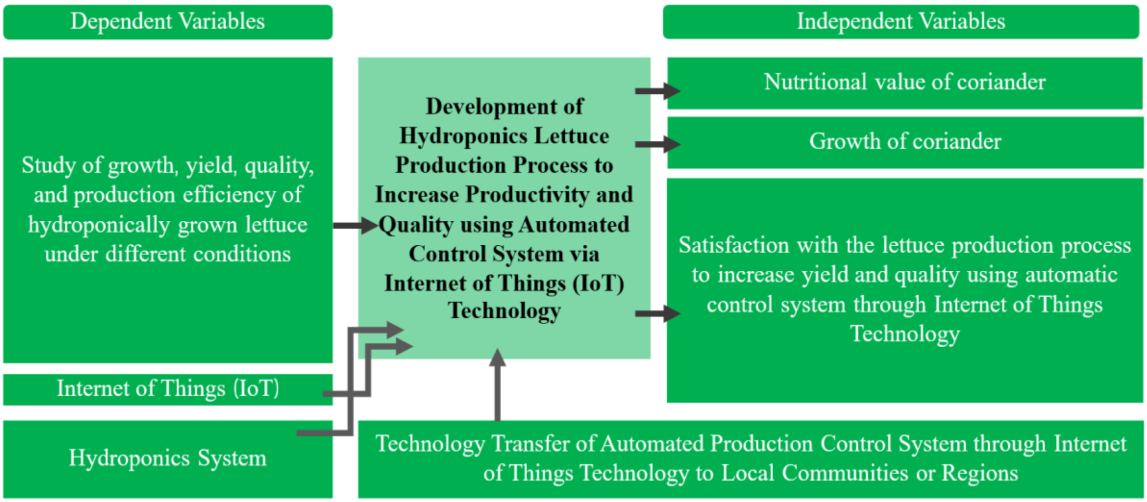


Figure 2. Conceptual Framework

Research Result

1) Growth, Yield, Quality, and Production Efficiency of Lettuce Cultivated in Different Hydroponic Systems

The study on the growth, yield, quality, and production efficiency of lettuce cultivated in different hydroponic systems yielded the following results:

1.1 Effects of Equipment Preparation and Methods

Table 1. Equipment Used for Studying the Growth of Lettuce Cultivated in Different Hydroponic Systems

No.	Item	Quantity	Unit
1	NFT (Nutrient Film Technique) Hydroponic System	1	System
2	Water Pump 2500AP	2	Unit
3	Plastic Trays for Vegetable Seed Propagation	4	Set
4	Water Tanks for Nutrient Solution	4	Tank
5	Lettuce Vegetable Seeds	200	Set
6	Planting Cups (5 cubic centimeters)	200	Unit
7	Nutrient Solution Formula Phra Nakhon	2	Set
8	Perlite	2	Set
9	Vermiculite	2	Set
10	pH Meter	2	Set
11	EC Meter	2	Set
12	Power Plugs	2	Unit
13	Nitric Acid (HNO3)	2	Set
14	Potassium Hydroxide (KOH)	2	Set

1.2 Preparation of Phra Nakhon Nutrient Solution

The Phra Nakhon nutrient solution can be prepared by arranging the concentrated Phra Nakhon nutrient solution (Kong Ek, 2557) by weighing each chemical substance according to the specified quantities. For this experiment, the concentrated solution A consists of 500 milligrams per liter (125 grams) of Calcium Nitrate [Ca(NO3)2.4H2O] and 20 milligrams per liter (2 grams) of trace elements. On the other hand, the concentrated solution B consists of 125 milligrams per liter (31.25 grams) of Potassium Dihydrogen Phosphate [KH2PO4], 125 milligrams per liter (31.25 grams) of Potassium Nitrate [KNO3], 125 milligrams per liter (31.25 grams) of Magnesium Sulfate [MgSO4.7H2O], and 20 milligrams per liter (3 grams) of trace elements. Next, dissolve each solution with distilled water until they are homogeneously mixed and reach a volume of 5 liters, and store them in light-proof containers. After that, take 1 liter of the concentrated Phra Nakhon nutrient solution A and 1 liter of the concentrated Phra Nakhon nutrient solution B, and mix them in a plastic container to form a homogeneous mixture. Adjust the volume of the nutrient solution to reach 50 liters with water. Then, adjust the pH value of the nutrient solution to be within the range of 5.5-6.5 and the electrical conductivity (EC) to be 0.80-1.00 milliSiemens per centimeter (mS/cm) using Potassium Hydroxide (KOH) and Nitric Acid (HNO3). This pH and EC adjustment is performed three times per week.

1.3 Hydroponic Cultivation of Lettuce in NFT System

The hydroponic cultivation of lettuce in the NFT system begins with sowing the seeds of lettuce, the Green Oak variety, in planting cups with a volume of 5 cubic centimeters, one seed per cup. After that, place the planting cups in plastic trays sized 30 x 45 centimeters filled with water to a depth of approximately 1/4 of the cup's volume, and keep them at a temperature of 25±2 degrees Celsius. Once the seedlings start to germinate and grow into young seedlings with 2-3 true leaves and a height of about 5 centimeters, transfer the seedlings into the NFT system with a nutrient solution circulation (control experiment), and the lettuce seedlings of the Green Oak variety grown in the NFT system with a nutrient solution circulation controlled by IoT sensors. Maintain a planting distance of 20 centimeters between each plant. Subsequently, adjust the pH value of the nutrient solution to be within the range of 5.5-6.5 and the electrical conductivity (EC) to be 0.80-1.00 milliSiemens per centimeter (mS/cm) in both experiments. For this experiment, change the Phra Nakhon nutrient solution once a week, three times in total.

Figure 3 Lettuce Cultivation

1.4 Data Recording

The data on the growth of lettuce 'Green Oak' at 28 days after transplanting was recorded as follows:

1) Height (cm): Measured from the base of the plant to the topmost point of the plant.

2) Leaf count (leaves): Counted the fully expanded and undamaged leaves free from diseases and pests.

3) Canopy width (cm): Measured from one widest side of the leaf to the opposite widest side of the leaf.

4) Fresh weight of the plant (grams): The fresh weight of the plant was measured using a digital scale with two decimal places. Then, the plant was dried at 110°C in a hot air oven (Memmert, Model 500, Germany) for 72 hours.

5) Dry weight of the plant (grams): After drying the plant at 110°C in a hot air oven (Memmert, Model 500, Germany) for 72 hours, the plant's dry weight was recorded after it reached a constant weight.

6) Chlorophyll content: A 100 mg sample of lettuce leaves was ground and mixed with 95.5% acetone in a 10 mL volumetric flask. The mixture was then stored at 5°C for 48 hours. Afterward, the chlorophyll content in the leaves, including chlorophyll-a (Chla), chlorophyll-b (Chlb), and total chlorophyll (TC), was determined by measuring light absorbance at wavelengths of 662 and 644 nm using the method described by Shabala et al. (1998) and Lichtenthaler (1987).

$Chl_a = 9.784D_{662} - 0.99D_{644}$

$Chl_b = 21.42D_{644} - 4.65D_{662}$

$TC = Chl_a + Chl_b$

1.5 Research Result Recording

The recording of lettuce growth progress can be done using the following data table:

Table 2 Height (cm) of Green Oak Lettuce at 7, 14, 21, and 28 days after transplanting in the conventional hydroponic and hydroponic systems controlled by the Internet of Things (IoT).

Control System	Number of Days after Transplanting (days)			
	7	14	21	28
Normal Hydroponic System	1.12±0.04	1.92±0.01 b	4.00±0.01 b	7.44±0.06 b
IoT-controlled hydroponic system	1.17±0.01	2.83±0.01 a	4.79±0.04 a	11.37±0.07 a
t-test	ns	*	*	*
CV (%)	6.23	4.20	1.44	1.61

ns means no statistically significant difference.

* Statistically significant differences at the 0.05 significance level.

[1/]Mean ± standard deviation followed by different letters indicate statistically significant differences at the 0.05 significance level based on t-test comparisons

Table 3 Number of leaves of Green Oak lettuce at 7, 14, 21, and 28 days after transplanting in conventional hydroponic and hydroponic systems controlled by the Internet of Things (IoT).

Control System	Number of Days after Transplanting (days)			
	7	**14**	**21**	**28**
Normal Hydroponic System	3.48±0.02 b	5.20±0.03 a	6.58±0.03 b	10.95±0.08 a
IoT-controlled hydroponic system	3.60±0.03 a	4.73±0.02 b	6.70±0.03 a	9.75±0.09 b
t-test	*	*	*	*
CV (%)	1.55	4.03	1.06	1.86

* Statistically significant differences at the 0.05 significance level.

1/Mean ± standard deviation followed by different letters indicate statistically significant differences at the 0.05 significance level based on t-test comparisons

Table 4 Canopy width (centimeters) of Green Oak lettuce at 7, 14, 21, and 28 days after transplanting in conventional hydroponic and hydroponic systems controlled by the Internet of Things (IoT).

Control System	Number of Days after Transplanting (days)			
	7	**14**	**21**	**28**
Normal Hydroponic System	2.98±0.01 b	8.46±0.07 b	16.66±0.13 b	25.34±0.22 a
IoT-controlled hydroponic system	3.58±0.01 a	10.22±0.06 a	17.03±0.03 a	24.09±0.06 b
t-test	*	*	*	*
CV (%)	0.98	1.50	1.22	1.44

* Statistically significant differences at the 0.05 significance level.

1/Mean ± standard deviation followed by different letters indicate statistically significant differences at the 0.05 significance level based on t-test comparisons

Table 5 Fresh weight (grams) and dry weight (grams) of Green Oak lettuce at 28 days after transplanting in a conventional hydroponic system and hydroponic system controlled by the Internet of Things (IoT).

Control System	Fresh weight (grams)	Dry weight (grams)
	17.41±1.66 a	11.18±0.01 a
Normal Hydroponic System	8.71±0.09 b	5.82±0.01 b
IoT-controlled hydroponic system	*	*
t-test	20.07	0.01
CV (%)		

* Statistically significant differences at the 0.05 significance level.

1/Mean ± standard deviation followed by different letters indicate statistically significant differences at the 0.05 significance level based on t-test comparisons

Table 6 Amount of chlorophyll-a (Chl a), chlorophyll-b (Chl b), total chlorophyll (TC), and carotenoids (Cx+c) (micrograms per gram fresh weight) within the leaves of Green Oak lettuce at 28 days after transplanting in a conventional hydroponic system and hydroponic system controlled by the Internet of Things (IoT).

Control System	**The quantity of substance (micrograms per gram fresh weight)**			
	Chl *a*	**Chl *b***	**TC**	**C_{x+c}**
Normal Hydroponic System	27.57±1.07 b	9.23±0.66 b	36.80±1.67 b	10.15±0.65 b
IoT-controlled hydroponic system	43.97±1.51 a	14.51±0.29 a	58.48±1.65 a	15.46±0.46 a
t-test	*	*	*	*
CV (%)	8.18	9.57	7.80	9.80

* Statistically significant differences at the 0.05 significance level.

[1/]Mean ± standard deviation followed by different letters indicate statistically significant differences at the 0.05 significance level based on t-test comparisons

2. Development of a Growth Control System for Lettuce Cultivation in a Hydroponic System under Different Conditions Using Internet of Things (IoT) Technology

2.1 Greenhouse Design for Hydroponic Lettuce Cultivation

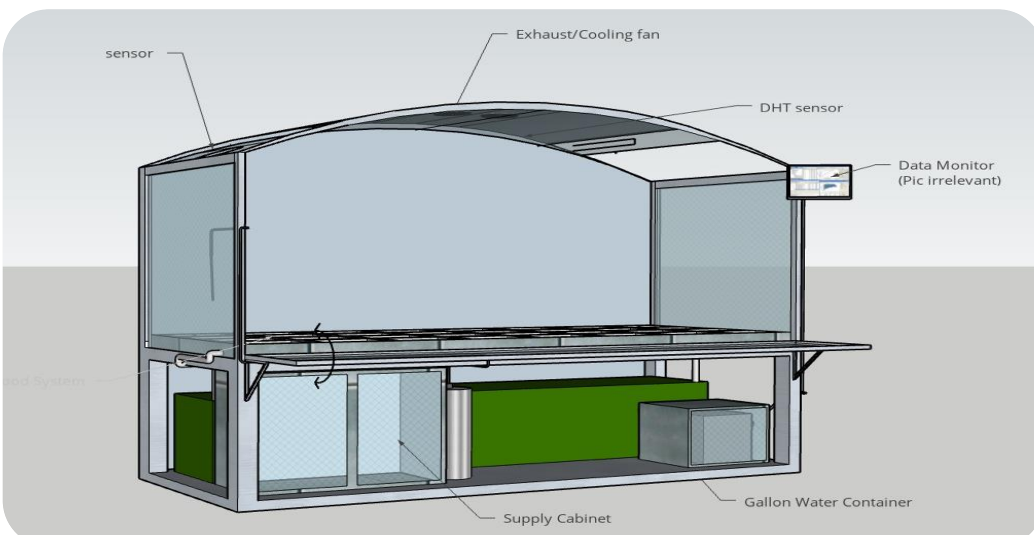


Figure 4. Components of the Greenhouse

From Figure 4, the greenhouse design has dimensions of 5.5 meters in length, 1 meter in width, and 1.8 meters in height. The frame is made of rubberwood, and the walls are made of 1-millimeter-thick transparent plastic. The control box is located at the bottom, and various sensors are installed, as shown in the above image.

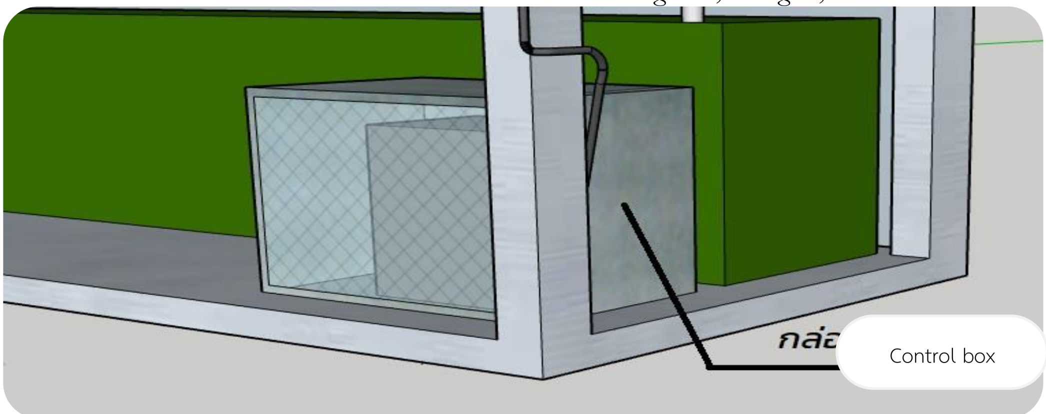


Figure 5. Control Box

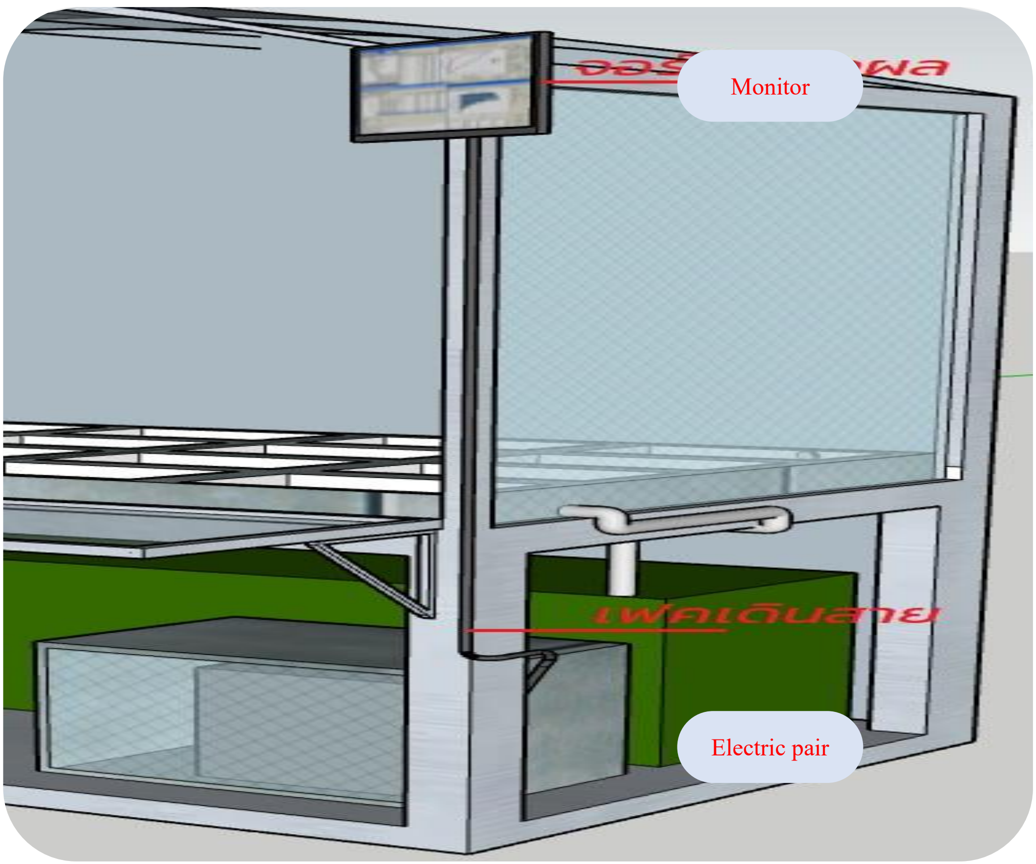


Figure 6. Display Screen

From Figure 6, the display screen is located at the top and connected to the control box using a cable to control the system automatically.

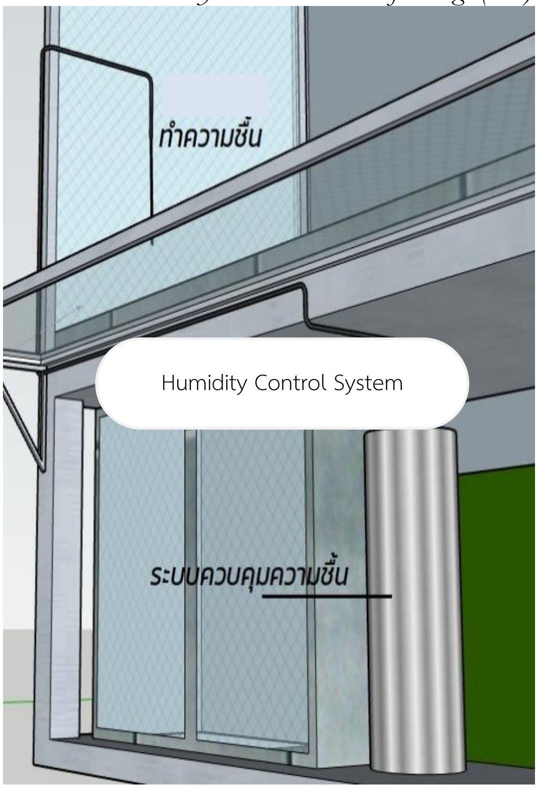


Figure 7. Air Humidity Control System

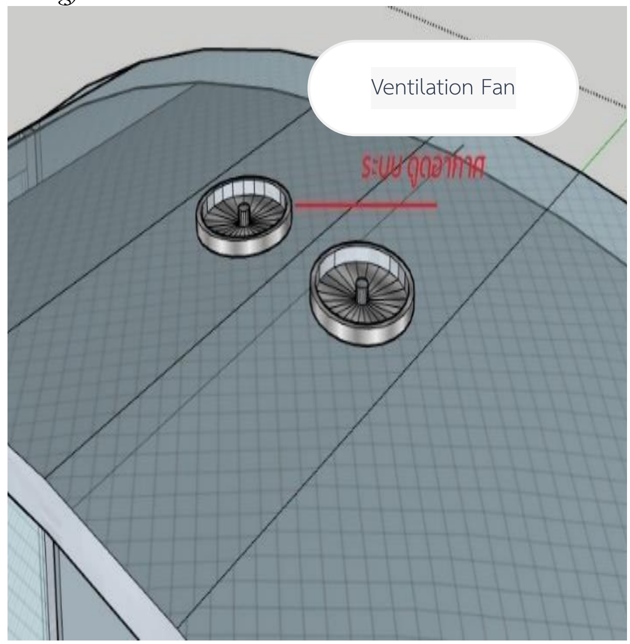
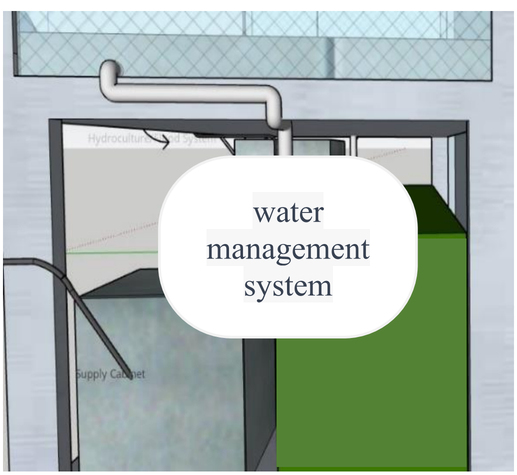


Figure 8. Air Ventilation Fan



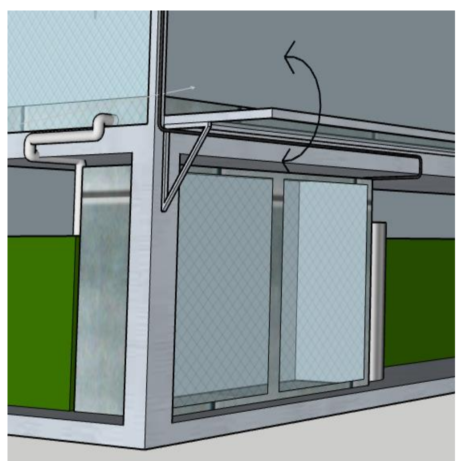


Figure 10. Equipment Storage Cabinet

From Figure 8, the fan is installed to ventilate the air when the temperature exceeds the predetermined value, controlling both temperature and humidity.

From Figure 9, the water management system is installed with sensors to measure the water level in the automated control system.

Figure 11. Mid-Sized Experimental Setup without a Roof

Table 7. Summary of Estimated Cost for Medium-Large Sized Greenhouse (Approximately 200 - 300 plants)

Size (Medium-Large)	Quantity	Price	Total
Greenhouse Frame	1	6550	6550
Fogging System	1	2300	2300
Clear Plastic	1	1000	1000
Water Tank	1	250	250
PVC Pipe (1/2")	1	53	53
PVC Elbow (1/2")	2	10	20
PVC Tee (1/2")	3	10	30
Sonic AP3500 Water Pump	1	400	400
Water Distributor	1	320	320
PE Pipe Set	1	123	123
Total			**11046**

3. Automated Control System with Internet of Things (IoT) Integration

3.1 Internet of Things (IoT) Integration System

This research developed a smart farm system for lettuce cultivation by controlling essential production factors. The crucial factors included 1) relative humidity at 70-90%, 2) temperature at 28-32°C, 3) carbon dioxide (CO2) concentration not exceeding 1,500 ppm, and 4) light intensity not exceeding 100 lux. The design and layout of the equipment for controlling these production factors were based on the specified dimensions of the greenhouse, which were 3.0 m wide, 4.ถ m long, and 2.40 m high. The installed equipment consisted of 1) a humidification system, 2) two 12-inch exhaust fans mounted on the greenhouse wall at a height of 2.0 m, 3) two 12-inch ventilation fans for CO2 removal, mounted at a height of 30 cm from the greenhouse floor, and 4) two sets of LED lights for illumination. Additionally, the research team installed DHT22 sensors to measure relative humidity, temperature, and CO2 concentration and LD-JX-655 sensors to measure light intensity. The architectural diagram of the system is presented in Figure 12.

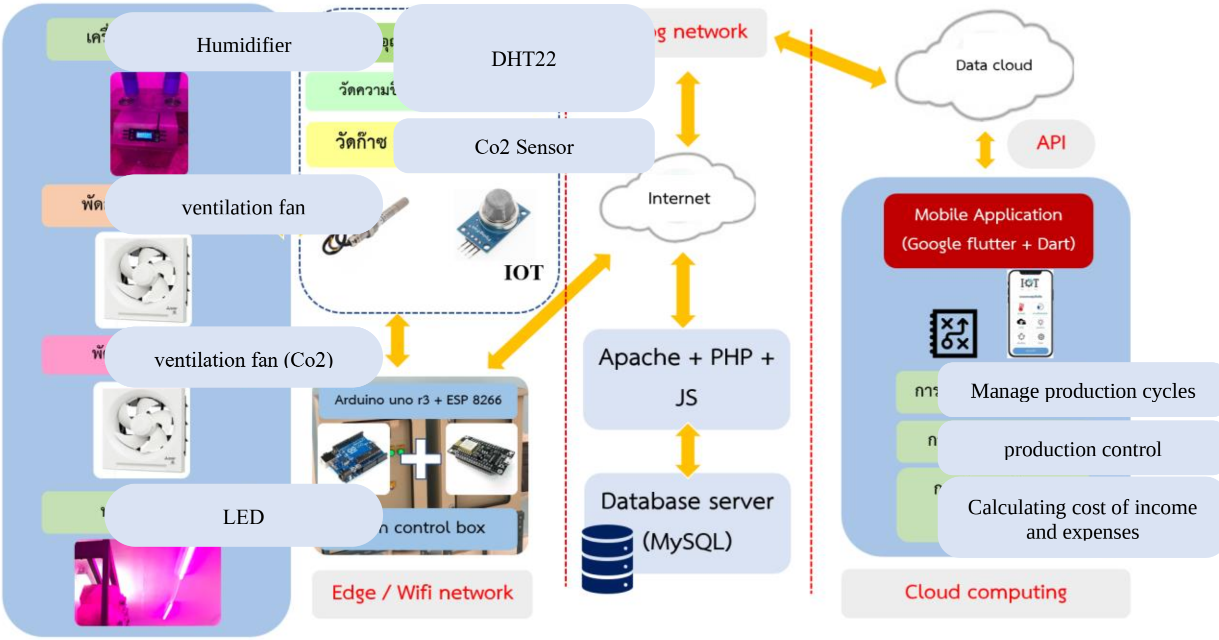


Figure 12 System Architecture

The IoT system control devices have the following details:

1. Temperature: It is defined on pin V0.
2. Humidity: It is defined on pin V1.
3. MotorFan1: This switch automatically controls the fan based on temperature and humidity conditions, such as if the temperature is... and humidity is...
4. MotorFan2: This is a switch to control the fan manually.

Figure 13. Hydroponic greenhouse controlled by IoTS

Figure 14. Hydroponic greenhouse controlled by IoTS and the conventional system.

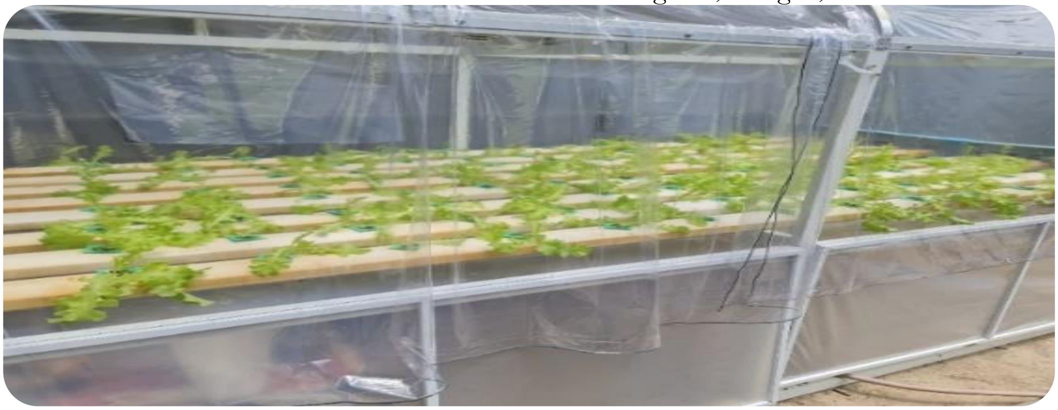


Figure 15. Hydroponic greenhouse controlled by IoTS

Figure 16. Hydroponic greenhouse controlled by IoTS and conventional system.

Figure 17. Demonstrating the technology transfer to the community

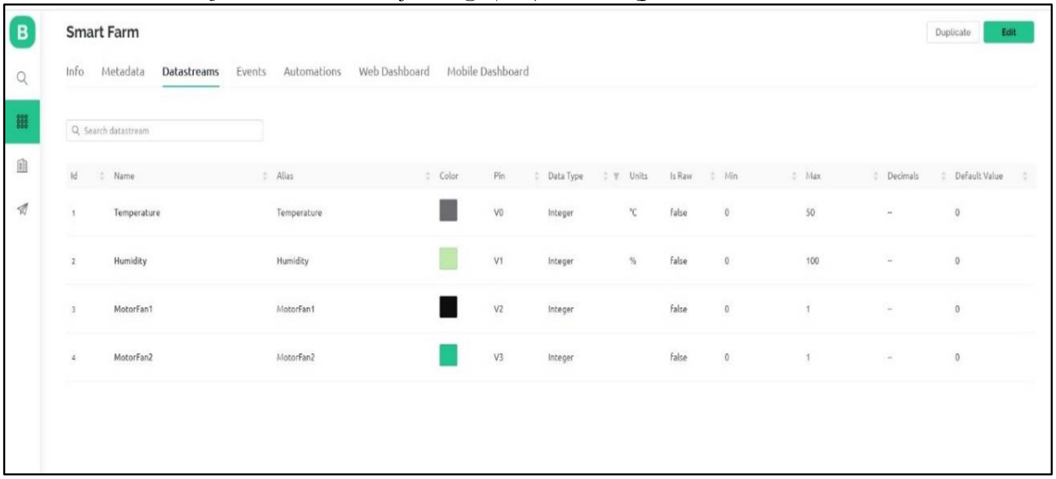


Figure 18. Blynk control interface via the website

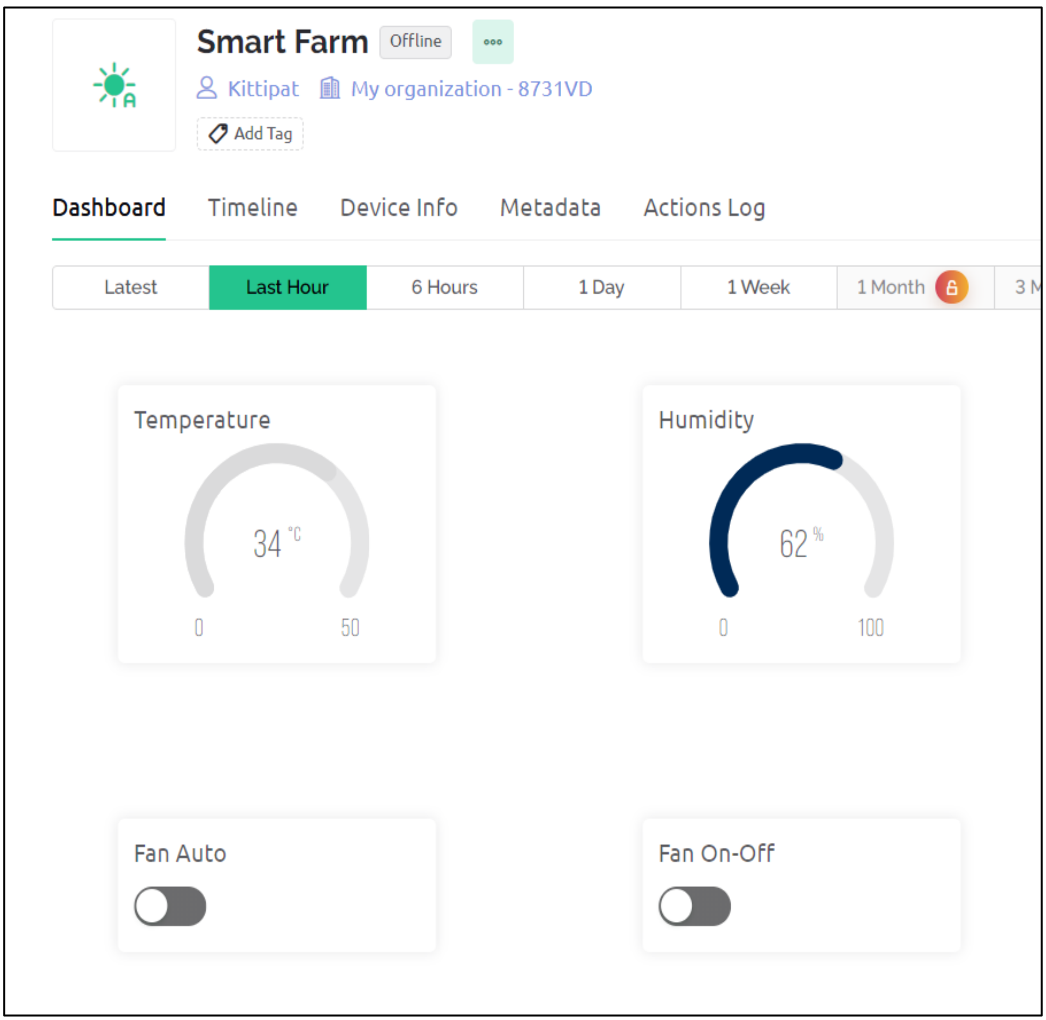


Figure 19. Blynk control interface via the website

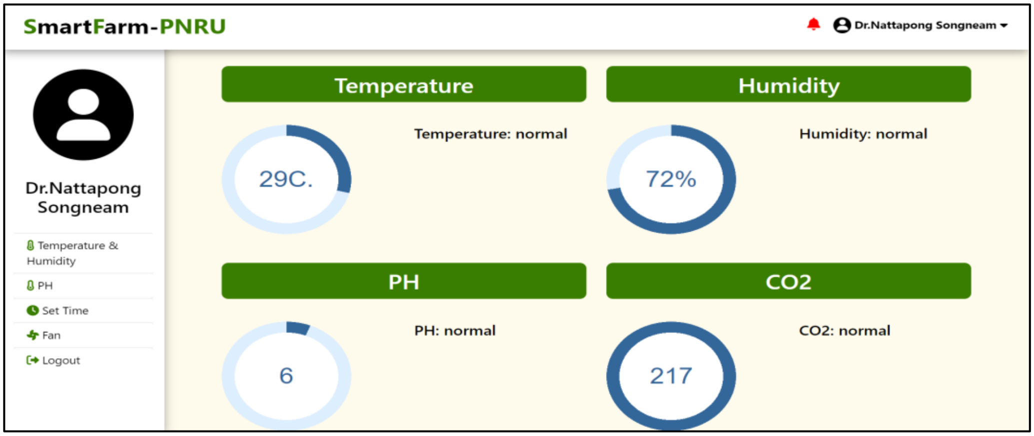
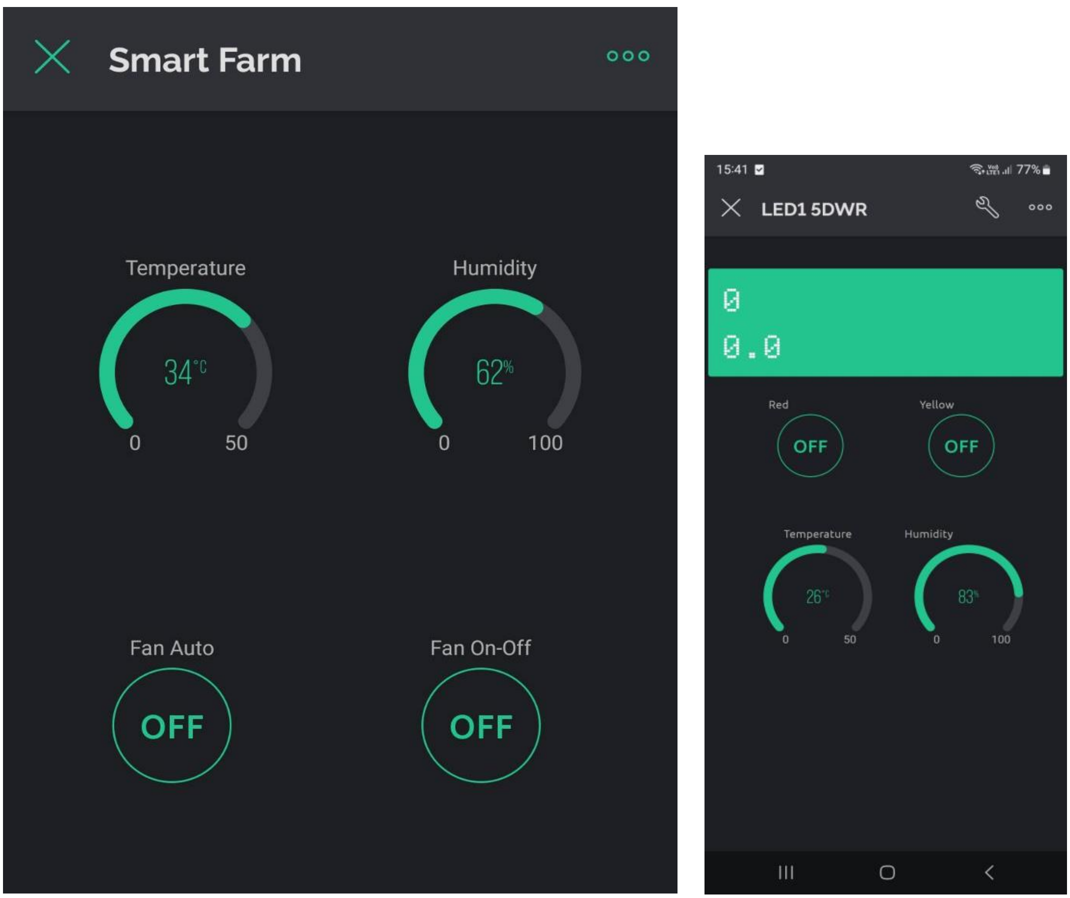


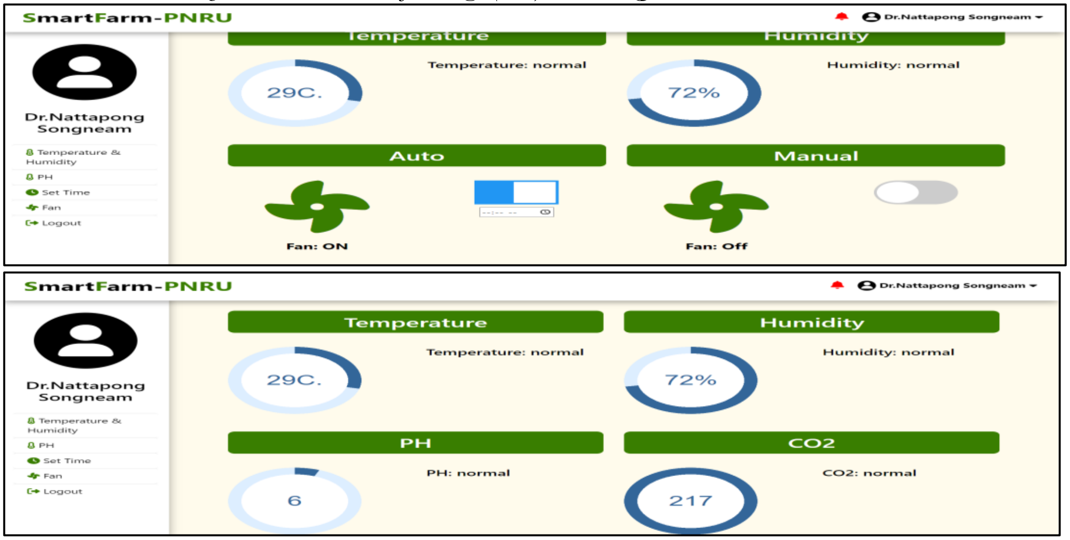
Figure 20. Blynk control interface via the website



(1) (2)

Figure 21. 1: Application for controlling temperature and humidity with a fan

2: Application for controlling temperature and humidity



(1) (2)

Figure 22. 1: Application for displaying pH and carbon dioxide (CO2) values

2: Application for displaying pH and carbon dioxide (CO2) values

4. To compare the efficiency between the conventional cultivation process of lettuce and the process with an automated control system using Internet of Things (IoT) technology, the evaluation data yielded the following results:

4.1 Population and Sample Group Data
4.1.1 Population: Farmers in the Chai Badan Phiphapphan District.
4.1.2 Sample Group: 20 farmers from the Chai Badan Phiphapphan District.
4.2 Criteria Used for System Satisfaction Evaluation
The criteria for scoring the system satisfaction were divided as follows:
Level 5: Indicates a very high level of satisfaction.
Level 4: Indicates a high level of satisfaction.
Level 3: Indicates an average level of satisfaction.
Level 2: Indicates a low level of satisfaction.
Level 1: Indicates the lowest level of satisfaction.

5. Nutritional Analysis of Hydroponically Grown Lettuce

Table 8 The results of the chemical composition analysis of hydroponically grown lettuce in two different systems: (A) Hydroponic system and (B) Hydroponic system controlled by the Internet of Things (IoT) technology in all aspects.

Item	Lettuce (A)	Lettuce (B)
Moisture Content	96.11 ± 0.75	96.43 ± 0.59
Protein Content (dry weight %)	32.24 ± 0.35	32.99 ± 0.33
Fiber Content (dry weight %)	16.69 ± 0.43	17.55 ± 0.59
Ash Content (dry weight %)	10.57 ± 0.54	10.61 ± 0.60
Fat Content (dry weight %)	2.23 ± 0.03	2.28 ± 0.03

Total Phenolic Compounds (mg gallic acid equivalents per gram fresh weight)	4.83 ± 0.06	4.95 ± 0.0.4
Antioxidant Activity (%)	80.67 ± 0.25	83.50 ± 1.10

Results of the chemical composition analysis, total phenolic compounds, and antioxidant capacity of hydroponically grown lettuce (Coriandrum sativum L.) were compared between two systems: a hydroponic system controlled by the Internet of Things (IoT) and a control hydroponic system without IoT as shown in Table 4.7. The moisture content, protein content, ash content, fiber content, and fat content showed no significant difference between the two systems, which is consistent with the research by Phornkid (2019) studying the automatic nutrient solution control system for hydroponic vegetable cultivation with IoT, which reported that vegetables grown in the IoT-controlled nutrient solution had similar values of height, leaf number, and canopy width as statistically compared to conventionally grown vegetables ($p > 0.05$). On the other hand, hydroponically grown lettuce controlled by the IoT showed higher total phenolic compounds and antioxidant capacity than the conventional hydroponic system. This finding may be due to the IoT-controlled system's ability to regulate nutrient solution, environmental conditions, and temperature, providing an optimal growth environment for lettuce, leading to increased levels of the mentioned compounds and enhanced antioxidant capabilities.

Conclusion and Discussion of Results

In the development of a growth control system for hydroponically grown lettuce (Coriandrum sativum L.) under different conditions, utilizing Internet of Things (IoT) technology, the main components of the system were as follows:

1) Hydroponic greenhouse for controlled lettuce cultivation using hydroponic technology.

2) Internet of Things (IoT) devices, including the following main components:

2.1 Temperature sensor (V0)

2.2 Humidity sensor (V1)

2.3 MotorFan1 for automatic fan control

2.4 MotorFan2 for manual fan control

3) Application for system control, with the following functionalities:

3.1) Temperature monitoring

3.2) Humidity monitoring

3.3) Light intensity measurement

3.4) Automatic operation of cooling fans

The study investigated hydroponically grown lettuce's growth, yield, quality, and production efficiency under different conditions. The results obtained were as follows:

1. Green Oak lettuce variety grown in a conventional hydroponic system showed the highest leaf count, canopy width, fresh shoot weight, and dry shoot weight.

2. Green Oak lettuce variety grown in the IoT-controlled hydroponic system demonstrated the highest height, chlorophyll content, chlorophyll b content, total chlorophyll content, and total carotenoid content.

Nutritional analysis revealed no statistically significant difference in height, leaf count, and canopy width between vegetables grown in the IoT-controlled nutrient solution and those grown conventionally by farmers ($p > 0.05$). However, hydroponically grown lettuce controlled by the IoT showed higher levels of all phenolic compounds and a greater antioxidant capacity than conventionally grown lettuce in hydroponics. This result could be attributed to the IoT-controlled system's ability to regulate nutrient solution supply, environmental conditions, and temperature, creating an optimal growth environment for lettuce. Consequently, the observed increase in phenolic compounds and antioxidant capacity indicates enhanced nutritional value and improved resistance to oxidative stress in hydroponically grown lettuce using the IoT-controlled system.

Recommendation

This research studies and develops a growth control system for hydroponically grown coriander (Coriandrum sativum L.) under different conditions, utilizing Internet of Things (IoT) technology. The experimental period occurred during Thailand's hot season, characterized by relatively high temperatures. Therefore, it is essential to investigate the effective management of heat dissipation, potentially leading to improved outcomes in the future.

Additionally, this study solely focuses on the production process of coriander. However, the findings from this research can be further extended and applied to various other vegetables within the same group.

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