RESEARCH ARTICLE

The Development of an Automatic Environment Control System in Greenhouses for Phoenix Oyster Mushrooms using the Internet of Things

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Article Information

Article History:
Received: 1 September 2023
Revised: 15 November 2023
Accepted: 26 December 2023
Published: 19 October 2025

Keywords:
Automatic Environment Control System
Internet of Things (IoT)
Phoenix Oyster Mushroom

Abstract

Mushrooms are rich in protein, nutritional substances, and health-enhancing medicinal substances, making them a popular choice for consumption. This popularity has spurred a growing interest in mushroom cultivation. However, mushrooms thrive only within specific temperature and humidity ranges. Deviations from these conditions can adversely affect their growth and overall production. Therefore, this research aimed to develop an automatic environmental control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things and evaluated the system's performance by experts while also assessing user satisfaction. The system is designed to control temperature and humidity to be at the optimum level for mushroom growth. It sends alerts to users if the temperature exceeds a specified threshold. The system utilizes NodeMCU to connect with temperature and humidity sensors and controls equipment such as water sprayers, ventilation fans, heat bulbs, and lights inside the greenhouse. Accessible via a web application, the system employs software development tools, including Arduino IDE, Firebase real-time database, LINE Notify, and Google Sheets. Statistical analysis relied on mean and standard deviation. The results showed that the system could effectively control greenhouse conditions to cultivate Phoenix oyster mushrooms through web applications and send LINE notifications. This may help reduce damage to Phoenix oyster mushroom cultivation that could occur. Evaluation results from experts scored were at the highest level, with an average of 4.79, while user satisfaction evaluations were also at the highest level, with an average score of 4.80.

1. Introduction

Thailand's agricultural sector, the foundation of its national prosperity, is undergoing a pivotal transformation under the Thailand 4.0 policy. Recognizing its significance, the government has strategically embraced technology as a key driver, propelling the economy towards a value-centric model where innovation reigns supreme and products and services acquire enhanced worth. This policy champions a critical shift from traditional practices to a modern, technology-driven approach known as "smart farming." This paradigm leap leverages cutting-edge tools like autonomous harvesting systems, autonomous water monitoring systems, and unmanned aerial vehicles. Valuable data generated from field demonstrations employing these technologies fuels a comprehensive Big Data platform, serving as a crucial decision-making engine and guiding the future of smart agriculture initiatives (Kwanmuang et al., 2020).

Mushrooms are a type of fungus that begins their growth within the mycelium of the fungus and gather in clusters over time in a few hours in a suitable environment (Arreerard and Arreerard, 2020). Mushrooms are rich in protein, nutritional substances, as well as medicinal substances that are beneficial for health. Thus,

ISSN 3088-1803 |

the consumption of mushrooms tends to grow in line with the trend of a healthy food market, both domestically and internationally. This is economically important. Phoenix oyster mushrooms, for instance, are popular for consumption as ingredients in many types of cooking because of their fragrant aroma, firm flesh, and sweet taste (Onprasonk et al., 2022; Pennate et al., 2024). Consequently, their cultivation thrives due to their health benefits, including cold prevention, antioxidants, and potential anti-cancer properties. Additionally, their high protein content aids muscle repair and overall tissue health, making them a valuable dietary source. Furthermore, their immune-boosting properties are promising for various health conditions (Sriputta and Khummanee, 2022; Jareanpon et al., 2023). In mushroom cultivation, weather conditions are influential on mushroom growth. The suitable temperature for the growth of Phoenix oyster mushrooms is in the range of 15 to 35°, and a humidity of not less than 80–85% (Fokngern et al., 2018). Therefore, mushroom farmers are more likely to grow mushrooms during the summer and rainy seasons due to these periods being suitable for their growth (Suksawang et al., 2018). If planting Phoenix oyster mushrooms outside of this season, the environment in the mushroom greenhouse must be properly controlled in terms of water and temperature. Otherwise, it will affect the growth of the mushrooms. In addition, cultivation of Phoenix oyster mushrooms requires manual labor to take care of the Phoenix oyster mushrooms, which affects production costs.

These challenges prompted researchers to develop an automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things. This system enables farmers to manage their greenhouse environments either manually or remotely through the Internet of Things. Whenever the temperature surpasses the predetermined threshold, the system immediately sends an alert notification via LINE to farmers, urging them to take immediate action to minimize potential damage. This not only reduces labor costs but also enhances the overall efficiency of greenhouse management. The system relies on humidity and temperature sensors to monitor the environment and send data values to the cloud for storage in Firebase‘s real-time database. Additionally, farmers can access the collected data using Google Sheets. This innovative system has significantly improved greenhouse efficiency by providing easier environmental management, resulting in increased yields and heavier Phoenix oyster mushrooms compared to traditional methods.

2. Objectives

- To develop and evaluate the efficiency of an automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things (IoT).
- To assess the user's satisfaction with the automatic environment control system in greenhouses for Phoenix oyster mushrooms using the IoT.

3. Related Work

Mushrooms are rich in protein, nutritional substances, as well as medicinal substances that are beneficial for health. Phoenix oyster mushrooms, for instance, are popular for consumption as ingredients in many types of cooking because of their fragrant aroma, firm flesh, and sweet taste. Consequently, they are popular for commercial cultivation due to their health benefits, such as helping prevent colds, containing antioxidants, and anti-cancer properties. They have high levels of protein, which helps repair muscles or worn parts of the body. They help fight inflammation that can lead to diseases or damage to other tissues, help nourish the heart and improve its function, and stimulate body immune function. In mushroom cultivation, weather conditions are influential on mushroom growth. The suitable temperature for the growth of Phoenix oyster mushrooms is in the range of 15 to 35°, and humidity is in the range of 80–85% (Fokngern et al., 2018).

The IoT refers to a network of physical devices embedded with electronics, software, sensors, and connectivity. It allows these devices to connect and exchange data (Brown, 2016). This technology has become a powerful tool in the world of technology. Integrating various sensors allows for real-time data collection from a wide range of applications. And this information can be used to control the device remotely with precision and efficiency (Aggarwal and Singh, 2022).

NodeMCU is a platform designed to facilitate the creation of IoT projects. It consists of a Development Kit (the board itself) and open-source Firmware (software on the board), allowing programming in various languages. Notably, Lua offers enhanced ease of use. Built-in WiFi (ESP8266) provides the key to internet connectivity. NodeMCU enables the programming of device drivers for input/output control, and this programming can be done using C/C++ language through the program Arduino IDE (Arkapati and Embamrung, 2018).

The DHT22 is a budget-friendly digital temperature and humidity sensor known for its simplicity and accuracy. Utilizing a capacitive humidity sensor and thermistor, it measures the surrounding air and transmits a digital signal on the data pin, eliminating the need for analog input pins. Compared to its predecessor, the DHT11, the DHT22 boasts superior precision, wider operating range, and improved accuracy (Arkapati and Embamrung, 2018).

LINE Notify is a notification service offered by LINE, providing a channel for sending a variety of notifications. Designed for programmers and software developers, it utilizes API calls via HTTP POST to enhance projects and connect to web services. Notifications are sent selectively to individuals who request the service or to members of designated groups. For example, in a mushroom growth tracking system, if a fungal disease is detected, LINE Notify can immediately notify farmers via their smartphones through the LINE application (Sriputta and Khummanee, 2022).

4. Research Methodology

4.1 Research Procedures

The Development of an automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things consisted of 8 steps, as shown in Figure 1.

4.2 Research Tools

- The equipment used to develop the automatic environment control system in the Phoenix oyster mushroom greenhouses using the IoT included a relay, DHT22/AM2302 sensor, NodeMCU ESP8266 microcontroller, water sprayer, heat lamp bulbs, light bulbs inside the greenhouses and ventilation fan.

- The software used to develop the system included the Arduino IDE for programming the system's microcontroller, Firebase Realtime Database for data storage and retrieval, LINE Notify integrated with the LINE application for real-time alerts, and Google Sheets for data analysis and report generation.

- In this research, the opening and closing of ventilation fans, water sprayers, heat lamp bulbs, and light bulbs inside the greenhouses was controlled by the Internet of Things using sensors, which were used to measure temperature and humidity in the Phoenix oyster mushroom greenhouses. In addition, the temperature and humidity data were sent to the Firebase Realtime Database. Then the data was displayed through a web application and retrieved as reports in the form of Google Sheets. If the temperature exceeded the specified value, the system would alert the farmers via Line notification, showing an overview of the system as shown in Figure 2.

- This research used questionnaires to collect data from experts and farmers in Ban Bing Community, Non Sung District, Nakhon Ratchasima Province, Thailand.

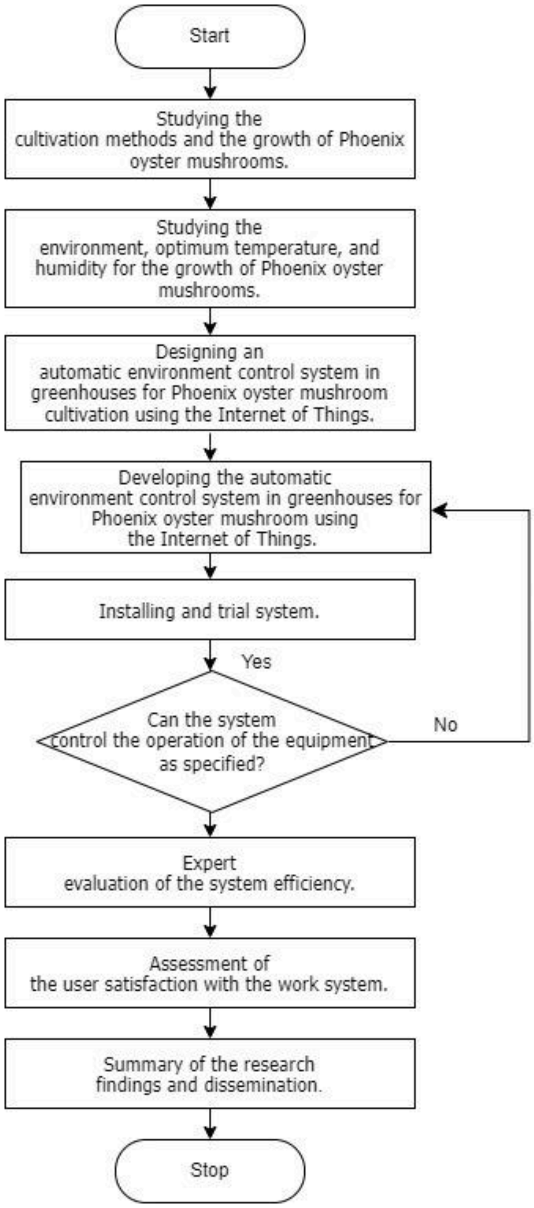

Figure 1. The flowchart of the system development process.

4.3 Target Group

- Three experts with proficiency in computers or expertise in agriculture were selected using a purposive method.

- Twenty users were selected using a purposive method from farmers in Ban Bing community, Non Sung District, Nakhon Ratchasima Province.

4.4 Statistics

The statistics used in this research included the mean ($\bar{x}$) and standard deviation (σ). The mean obtained was

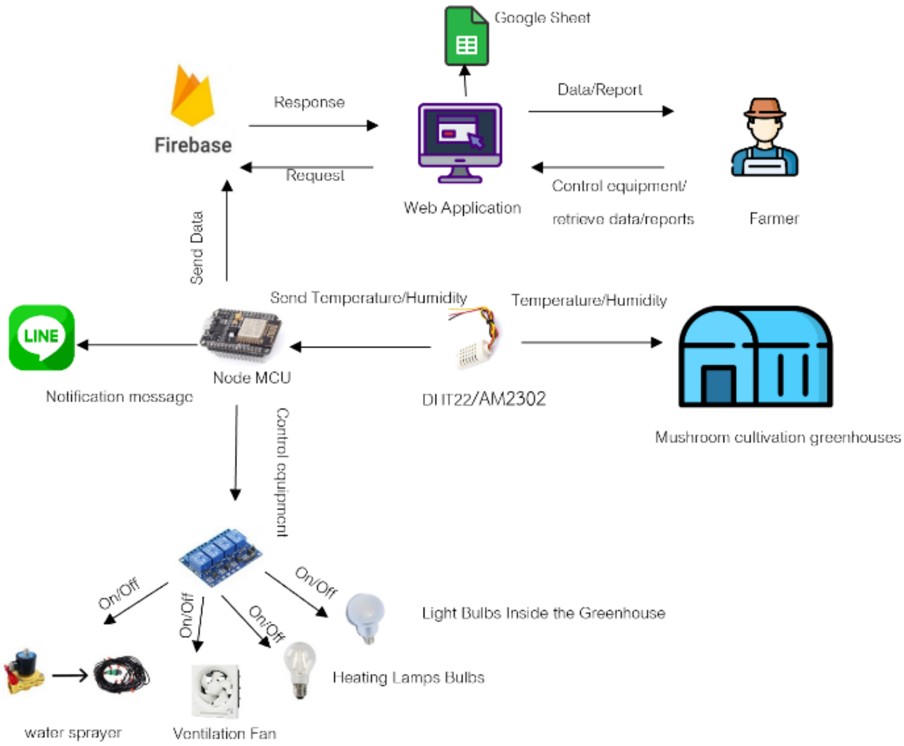

Figure 2. Overview of the system.

compared with the evaluation criteria as follows (Srisa-ard, 2002):

4.51 - 5.00 means the highest level.
3.51 - 4.50 means the high level.
2.51 - 3.50 means the moderate level.
1.51 - 2.50 means the low level.
1.00 - 1.50 means the lowest level.

5. Results

5.1 Development of Environmental Control Equipment for Cultivating Phoenix Oyster Mushrooms in Greenhouses

The Development of an automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things. The equipment used in this system is shown in Figure 3.

Figure 3 shows the assembly of the control equipment system, consisting of a NodeMCU ESP8266 connected to a DHT22/AM2302 sensor for temperature and humidity measurement, and a relay, which was connected to the ventilation fan, heat lamp bulbs, and light bulbs in the greenhouses, and a solenoid valve for turning the water sprayer on and off. After connecting the devices, a program to control the operation of various devices was written, as shown in Table 1.

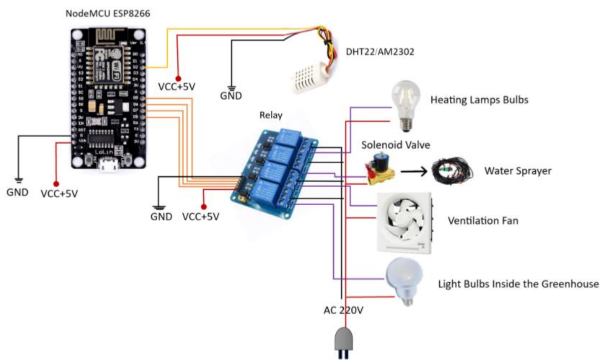

Figure 3. Equipment used in system.

Table 1. Operation of the device control system (Fokngern et al., 2018).

Temperature	Humidity	Heat Lamp Bulbs	Water Sprayer	Ventilation Fan
<15	<80	On	Off	Off
<15	80–85	On	Off	Off
<15	>85	On	Off	On
15–35	<80	Off	On	Off
15–35	80–85	Off	Off	Off
15–35	>85	Off	Off	On
>35	<80	Off	On	On
>35	80–85	Off	Off	On
>35	>85	Off	Off	On

5.2 The Results of Web Application Development

The Development of an automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things. Users of the developed automatic environment control system are divided into two groups: administrators and regular users. Administrators must log in to the system via the web application. Upon logging in, the home menu serves as the main page, and the control menu allows the switching on/off of various devices. The Dashboard menu displays reports for temperature, humidity, and the working status of the DHT22/AM2302 sensors. The Manage User Menu allows administrators to manage user information, including adding, deleting, editing, and searching for user details. The Contact Us menu enables users to contact the system developer, and the Log Out menu allows users to log out of the system, as shown in Figures 4 - 9. In addition, within the Dashboard menu, administrators can click the “Export to Google Sheets” button to export temperature and humidity values as Google Sheets (Figure 10). If the temperature exceeds the specified limit, a real-time online notification will be prompted, as shown in Figure 11. Regular users have the same access as administrators but lack the Manage User menu page. For IoT equipment and greenhouse, as shown in Figure 12.

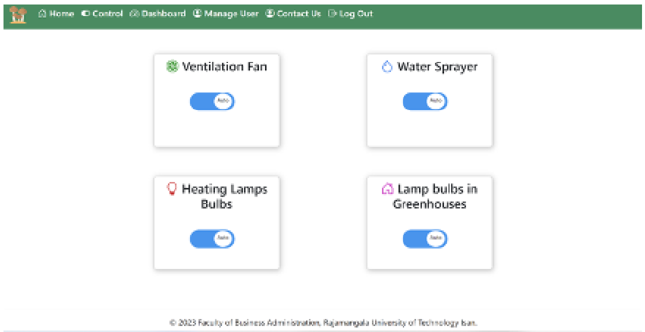

Figure 6. Control page.

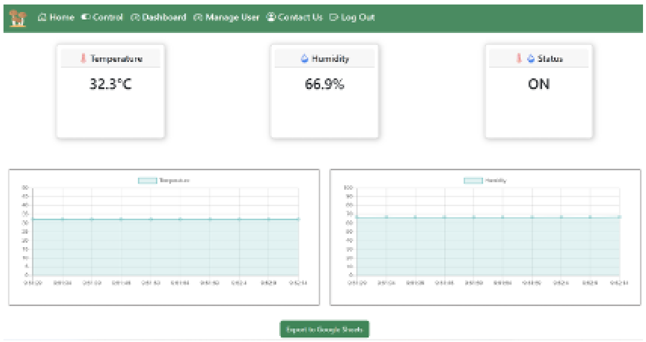

Figure 7. Dashboard page.

Figure 4. Login page.

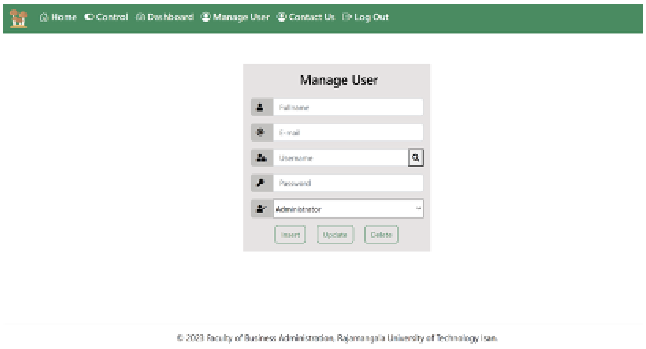

Figure 8. Manage user page.

Figure 5. Login page.

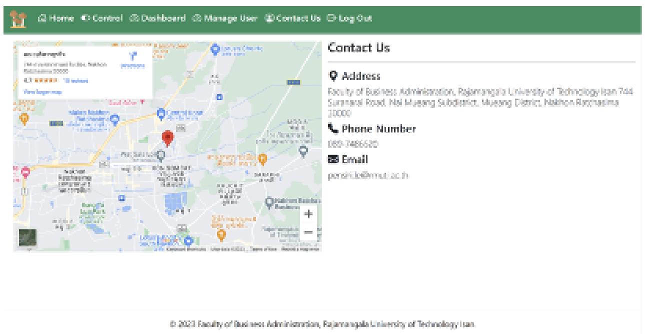

Figure 9. Contact us page.

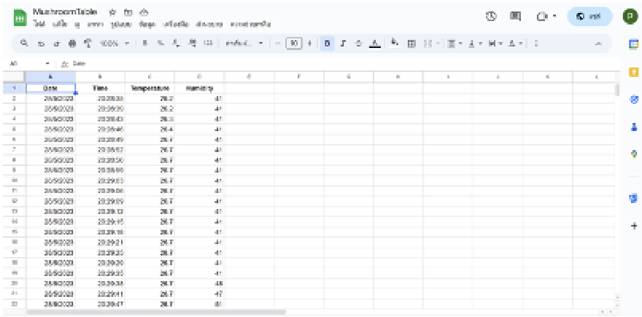

Figure 10. Google sheet page.

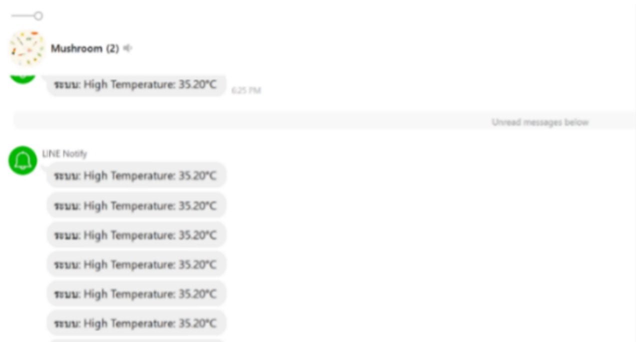

Figure 11. Line notification page.

Figure 12. IoT equipment and greenhouse.

5.3 Results of the Efficiency Evaluation of the Automatic Environment Control System in Greenhouses for Phoenix Oyster Mushroom using the IoT

Three experts assessed the suitability of the developed application. The results were subsequently analyzed using basic statistics in relation to the criteria, and the results were summarized as shown in Table 2:

Table 2. Evaluation results of the efficiency of the developed automatic environment control system in greenhouses for Phoenix oyster mushroom using the Internet of Things.

Assessed Aspect	$\bar{x}$	σ	Level
1. System usage	4.80	0.35	Highest
2. Material and device for installation	4.47	0.58	High
3. Security and accessibility of the system	4.87	0.12	Highest
4. Utilization of benefits for farmers	5.00	0.00	Highest
Total	**4.79**	**0.26**	**Highest**

Table 2 shows the results of the expert opinion inquiry on the efficiency of the overall system were at the highest level ($\bar{x} = 4.79, \sigma = 0.26$). When considering each item, it was found that the utilization of benefits for farmers was at the highest level ($\bar{x} = 5.00, \sigma = 0.00$), followed by the security and accessibility of the system was at the highest level ($\bar{x} = 4.87, \sigma = 0.12$), the system usage was at the highest level ($\bar{x} = 4.80, \sigma = 0.35$) and the material and device for installation was at the high level ($\bar{x} = 4.47, \sigma = 0.58$).

5.4 Assessment Results of User Satisfaction with the Developed Automatic Environment Control System in Greenhouses for Phoenix Oyster Mushrooms using the IoT

The researcher applied the developed application to 20 users to assess their satisfaction. The results were then analyzed using basic statistics in relation to the criteria, and the findings were summarized as shown in Table 3.

Table 3. Assessment of satisfaction results of the automatic environment control system in greenhouses for Phoenix oyster mushroom using the Internet of Things (IoT).

Assessed Aspect	$\bar{x}$	σ	Level
1. User interface	4.85	0.39	Highest
2. Operation of the system	4.82	0.49	Highest
3. Design of the greenhouse model and various equipment	4.74	0.65	Highest
4. Utilization of benefits for farmers	4.79	0.48	Highest
Total	**4.80**	**0.50**	**Highest**

Table 3 shows the results of the user opinion inquiry on the satisfaction of the overall system were at the highest level ($\bar{x} = 4.80, \sigma = 0.50$). When considering each item, it was found that users had the highest level of satisfaction with the system in every item, with the user interface was at the highest level ($\bar{x} = 4.85, \sigma = 0.39$), followed by the operation of the system ($\bar{x} = 4.82, \sigma = 0.49$), the utilization of benefits for farmers ($\bar{x} = 4.79, \sigma = 0.48$) and the design of the greenhouse model and various equipment ($\bar{x} = 4.74, \sigma = 0.65$).

5.5 Comparison Results of the Effectiveness of Mushroom Cultivation Operations in 2 Greenhouses

This section compares the effectiveness of mushroom cultivation in 2 greenhouses. It was observed that Phoenix oyster mushrooms from the greenhouse using the Internet of Things were higher than conventional greenhouse, as shown in Table 4.

Table 4. Comparison results of the effectiveness of mushroom cultivation operations from 2 greenhouses.

Date	Greenhouse using IoT (100 cubes)		Conventional greenhouse (100 cubes)	
	Number of Mushrooms	Total Weight (g.)	Number of Mushrooms	Total Weight (g.)
1	8	402	3	149
2	14	813	8	354
3	23	1,244	14	802
4	35	2,312	28	1,423
5	53	3,359	46	2,640
6	71	4,480	66	3,785
7	86	5,354	75	4,297

6. Discussion and Conclusion

Mushroom cultivation is gaining popularity because mushrooms are in demand in the health-conscious market. Mushrooms are nutritious and possess medicinal properties. However, growing mushrooms requires proper control of water and temperature within the mushroom cultivation house to ensure the mushrooms grow properly. The objectives of this study were twofold: 1) to develop and evaluate the efficiency of an automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things and 2) to assess the user's satisfaction with the automatic environment control system in greenhouses for Phoenix oyster mushrooms using the Internet of Things. The research results showed that the developed system could control the environment in the greenhouses for Phoenix oyster mushroom cultivation. It could be used to increase productivity and reduce the burden of taking care of mushroom cultivation for farmers as it automatically adjusts watering and heating based on fluctuating temperatures and humidity. In addition, both the expert evaluation of the system ($\bar{x} = 4.79, \sigma = 0.26$) and the user satisfaction evaluation ($\bar{x} = 4.80, \sigma = 0.50$) were at the highest level. The implementation of this automated environmental control system significantly enhances farming efficiency, enabling growers to effortlessly maintain optimal conditions in their mushroom greenhouses, resulting in increased yields and heavier mushrooms compared to traditional methods. Furthermore, timely notifications via Line allow users to address potential issues promptly, further optimizing their mushroom cultivation. The results of this research are consistent with Fokngern et al. (2018) and Jareanpon et al. (2023), which has researched IoT systems and reported performance results, leading to increased yields and heavier mushrooms compared to traditional methods. Future research will explore the potential of this system for other types of mushrooms, valuable medicinal plants, and organic farming practices. Additionally, its principles could be applied to optimize animal husbandry environments for improved health and wellbeing.

Suggestions. The results of this research provide protection for system security. Installation and usage are limited to certain users. Thus, for those interested in utilizing the research outcomes, please contact the research team to request access credentials (username and password) and installation assistance.

Acknowledgments

This research project was financially supported by Faculty of Business Administration, Rajamangala University of Technology Isan, Nakhon Ratchasima, fiscal year 2023.

Declaration of Ethics

This study was ethically approved by the Ethics Committee for Research Involving Human Subjects, Rajamangala University of Technology Isan (HEC-01-66-026).

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