IoT-Based Climate Control System for Cultivation of Oyster Mushroom (Pleurotus ostreatus) Fruiting Bag

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IoT-based climate control system for cultivation of oyster mushroom (Pleurotus ostreatus) fruiting bag

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Abstract: *Traditional oyster mushroom cultivation requires significant manual labor and precise environmental control for optimal growth. The study developed a system that combines soil moisture, temperature and humidity control, and an automated misting system with an IoT-based climate control system for the indoor cultivation of oyster mushroom fruiting bags, which is a smart urban farming system. The controlled system significantly increased mushroom yields, averaging 328.57g per harvest compared to 181.43g with traditional methods. Maintaining temperatures of 25°C – 30°C, humidity levels of 70% – 90%, and soil moisture between 60% and 90% in the mushroom chamber ensured consistent productivity. Comparative analysis revealed superior performance in moisture, temperature, and humidity control with the automated system, validated by t-tests (P = 0.04). These results underscore the system's effectiveness in enhancing mushroom growth, yield, and overall profitability for farmers in smart urban farming settings.*

Keywords: Mushroom Cultivation; Substrate Bags; Misting System; Temperature Control System; IoT-based climate control system

1. INTRODUCTION

The advancement of technology in numerous industries motivates people to mix agriculture and technology [1]–[3] as part of the Information and Communication Technologies that are directed towards smart industries [4] to enhance agricultural crop production worldwide by improving its productivity [5]. Agriculture technology is currently utilizing an integrated automation system based on the Internet of Things (IoT). This technology is considered appropriate for use in this industry because it can improve data collection, automation and monitoring [6][7]. One of the things currently being worked on in this area of research is the cultivation of mushrooms.

Oyster mushrooms (Pleurotus ostreatus) are a species of edible fungus with high nutritional value and notable pharmacological effects. These mushrooms are known to contain a variety of compounds with anticancer, antioxidant, antitoxic, antiplatelet aggregating, antihyperglycemic, antimicrobial, and antiviral properties. [8]. Moreover, among mushroom varieties, oyster mushroom species, Pleurotus ostreatus possesses anticancer action [9] while Pleurotus cystidiosus has potent antioxidant capabilities [10].

Oyster mushroom cultivation has risen globally due to its medicinal benefits and ability to grow in a wide temperature range and on various agro-based leftovers. The species also adapts to diverse agro-climatic conditions and various types of agricultural waste [11]. Many elements including temperature, humidity, and the sterility of the substrates, work singly or in concert to influence mushroom cultivation [12] and mushroom infections are aided by the conditions in which they are grown and the presence of a pest [13]. Bacterial and fungal-originated diseases and fungal viruses, specifically mycoviruses, are the most prevalent problems mushroom producers encounter, and they frequently have a substantial effect on mushroom phenotype [14] and aggressive mushroom cultivation may also result in significant product loss due to increased pests and infections [15].

The cultivation of oyster mushrooms will depend on the temperature and humidity of the room where these plants are grown. Oyster mushrooms of high quality will be gathered if the temperature and humidity were maintained at their set point. Initially, most mushrooms grow outdoors in certain regions of the world. As a result, the mushroom farmer relies solely on the condition of the natural environment. However, farmers in certain regions are authorized to manage mushroom growth for commercial and personal uses. Today's farmers are no longer just reliant on the natural growth of mushrooms; they can now cultivate their mushrooms. Using technology that automatically regulates temperature and humidity, it is possible to prevent mold formation in space [16].

There was a related study last 2019 by E. Li et. all, titled “Solar-Powered Multi-Network Greenhouse: Automated Mushroom Monitoring and Management System Using Microcontrollers and IoT-Based Applications” that employed the Solar-Powered Multi-Network Greenhouse, microcontrollers, and an IoT-based application to develop an automated monitoring and management system for mushrooms. This work develops an automated system whose composition is controlled by a microcontroller and monitored by Arduino IDE, as fungi are more susceptible to the adverse effects of rising temperatures in tropical regions such as the Philippines. The greenhouse monitoring gadget utilized a variety of highly capable sensors, providing accurate parameters for monitoring systems and improved cultivation control management. Many options for controlling parameters and preserving stability values suited for mushroom production were discussed. Thus, the prototype underwent a series of trials and tests to confirm its operation and precision. Similarly, testing was undertaken for temperature, relative humidity, and light to control and monitor the mushroom's needs. The analysis indicates that the greenhouse might be enhanced by installing a CCTV system to monitor the interior and outdoors constantly. In addition to locating the greenhouse in a more secluded location, some of the application's capabilities might be enhanced [17].

This paper developed an enhanced internet of things (IoT)-based climate control system for the indoor cultivation of oyster mushroom fruiting bags, which is a smart urban farming system that requires less maintenance, less labor, and saves a significant amount of space. In addition, using an IoT platform will improve the capability of existing equipment for remote monitoring while simultaneously logging data for analysis and future reference.

2. METHODOLOGY

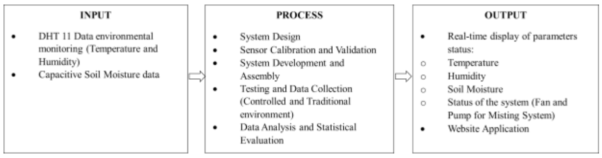

Fig. 1. General Framework

The general framework of the study, as shown in Figure 1, was segmented into a series of logical stages. The study aimed to establish a comprehensive system using environmental monitoring data from DHT 11 sensors (for temperature and humidity) and capacitive soil moisture sensors as input components. The goal was to integrate these elements to develop a real-time monitoring climate control system for the indoor cultivation of oyster mushroom fruiting bags. The process commenced with system design, which defined the functions and interactions of all system components, including communication protocols and data flow between sensors, the control system, and the cloud server. Following this, all selected sensors underwent calibration and validation tests in various conditions to ensure accuracy and reliability. The next phase involved the development and assembly of both hardware and software components. This included integrating the sensors into the system and creating a user interface for data display. Data was collected through both controlled and traditional environments to evaluate the system's performance and accuracy. Testing involved assessing data transmission and reception between sensors and the cloud-based services, as well as evaluating the system's capability to monitor and report environmental parameters. To assess the system's effectiveness and identify significant patterns in environmental data, data analysis and statistical evaluation were performed.

The output includes real-time display of environmental parameters: Temperature and Humidity.

2.1 System Overview

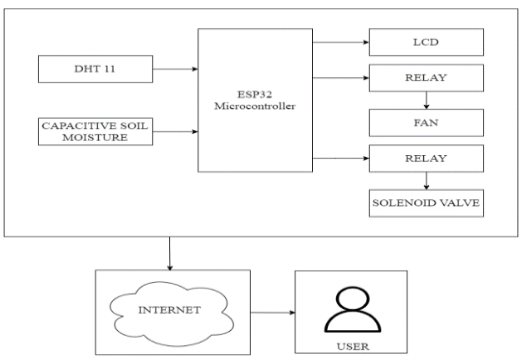

Fig. 2. Block Diagram of the System

The ESP32 is the system's central component, responsible for all decision-making, as illustrated in Figure 2. The system comprises a sensor unit, which includes the DHT11 for monitoring temperature and humidity, as well as a capacitive soil moisture sensor to measure or infer soil water content. Additionally, an LCD panel will display data from each sensor, and a button will allow for the activation and deactivation of the sensor node. A relay is also present, which uses low-voltage impulses to operate high-voltage circuits, enabling the opening and closing of a solenoid valve to mist oyster mushrooms if the desired temperature is exceeded. Upon receiving data from the sensor node, the base station will connect to the internet, allowing users to access an application that displays real-time information.

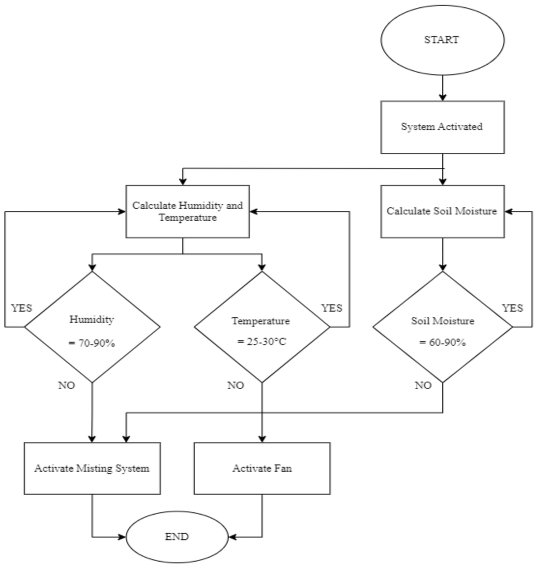

Fig. 3. System design and implementation

2.2 System Design and Implementation

As shown in Figure 3, when the system is activated, it will determine the oyster mushroom's soil moisture and the farmhouse's humidity and temperature. When relative humidity falls outside the range of 70% to 90%, the misting system will be activated. If the temperature falls below 25°C to 30°C, the fan will activate. When the soil moisture content falls 60% to 90%, the misting system will also activate. Subsection 2.2.1 shows a pseudo code for the algorithm implementation.

2.2.1 Pseudocode of the System

Data: Sensor Readings
Return: Control Signals for Cooling System and Data for Cloud Server

```
Initialize System
Loop:
  #Read and Calculate Soil Moisture
  if soil_mstr > 60 && soil_mstr < 90:
      if misting_system == ON:
        turn_off(misting_system)
  else:
      turn_on(misting_system)

  #Read Humidity Sensor
```

```
if humidity > 70 && humidity < 90:
if misting_system == ON:
turn_off(misting_system)
else:
turn_on(misting_system)

#Read Temperature Sensor
if temp > 25 && temp < 30:
if fan == ON:
turn_off(fan)
else:
turn_on(fan)

Send All Sensor Data to Cloud Server
Repeat Loop
```

2.3 System Enclosure Design with LCD Readings

Fig. 4. System Enclosure Design with LCD Readings

As shown in Figure 4, the LCD of the system displays relevant information such as the current temperature and humidity of the room, the soil moisture content of the mushroom, and the current operational status of the Fan and Pump.

2.4 Data Gathering

The study used the ThingSpeak website to collect and store data gathered by the system. The system transmitted data every 10 minutes throughout the day, resulting in 144 data points per day. For 50 days, it has gathered a total of 7,200 data points. Next, the researcher computed each day's mean temperature, humidity, and soil moisture values, resulting in 50 data points for each variable. The same process was also applied to the traditional system.
Mushrooms were harvested on a weekly basis as soon as they reached optimal maturity. This was carried out by carefully inspecting the growth of the mushrooms and identifying the optimal time for harvest. Once the mushrooms were deemed ready for harvest, they were carefully harvested and weighed in grams using a weighing scale. This process was repeated weekly throughout the duration of the experiment.

2.5 DHT 11 Sensor Testing Method

To assess the accuracy of the DHT11 sensor in our system, as shown in Figure 5, A Lutron PM-1064SD Air Quality Monitor & Recorder was used as the reference device. By comparing the measurements from the DHT11 sensor to those obtained from the Lutron device, the level of agreement between the two sensors could be determined, and the overall accuracy of the system's temperature and humidity readings could be evaluated.

Fig. 5. DHT11 Sensor Testing

Data was collected by recording measurements every 10 minutes over a 1-hour period, resulting in 12 data points - 6 from the controlled system and another six from the comparative systems. After collecting the data, the researcher calculated the mean absolute percentage error (MAPE) to evaluate the accuracy of the forecasting model. MAPE is a commonly used metric for measuring the accuracy of prediction models. It measures the average percentage difference between actual and predicted values.
First gets the APE of each data using Equation 1 below, then get the overall mean APE using Equation 2,

$$APE = \left|\frac{A-F}{A}\right| x100 \quad (1)$$

$$MAPE = \left(\frac{100}{n}\right) - \sum_{i=1}^{n} \left|\frac{A-F}{A}\right| \quad (2)$$

where, A is the actual value, F for the forecast value, and n for the total number of observations.
To interpret the MAPE results, Lewis's (1982) guidelines were followed. which provides a way to assess the accuracy of the forecast. According to this interpretation, a MAPE of less than 10% indicates a highly accurate forecast, while 11% to 20% suggests a good forecast. A 21% to 50% MAPE is considered reasonable, while a 51% or higher MAPE suggests an inaccurate forecast.

2.6 Capacitive Soil Moisture Sensor Testing Method

To determine the accuracy of the capacitive soil moisture sensor, its readings were compared with those obtained from the oven drying method.
First, soil samples were collected from the oyster mushroom fruiting bag and weighed. The capacitive soil moisture sensor was then used to measure the moisture content of each sample. The soil samples were then dried in an oven until completely dry, weighed again, and their moisture content was calculated using Equation 3.

$$\%MC = \frac{(w-d)}{w} x100 \quad (3)$$

where MC= moisture content, w is the weight of soil while wet, and d is the weight of the soil while dry. Then, it compares the moisture content readings obtained from the sensor with those calculated using the oven drying method. Lastly, the study used MAPE to analyze the data and note that significant discrepancies may require sensor calibration or replacement. The Capacitive Soil Moisture Sensor will be used for soil moisture content measurements if its accuracy suits the condition.
Figure 6 shows the soil samples used in the oven drying process and the oven used for drying them.

Fig. 6. Capacitive Soil Moisture Sensor Testing

2.7 Evaluating Growth Rate

The website Thingspeak was utilized to collect and store the data gathered by Oyster mushroom fruiting bags typically do not grow simultaneously. Mushroom growth in each bag can vary based on factors such as temperature, humidity, soil moisture, and other environmental conditions. Variations in nutrient levels and other factors between bags can also influence growth rates. Consequently, it is typical for the fruiting process to progress at slightly different rates across different bags. To assess the growth rate of the mushrooms, their weight was recorded each time they reached harvest readiness. Each week, the weight of the harvested mushrooms was recorded and compared with the weight of mushrooms grown in the traditional system over the same period. Figure 7 was used to determine which system had a better growth rate.

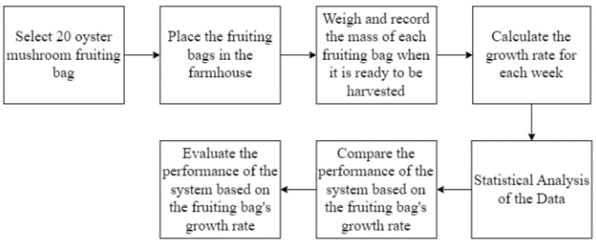

Fig. 7. Growth Rate Evaluation

2.8 Statistical Tool

The aim was to enhance oyster mushroom cultivation by developing a new climate control system for fruiting bags and evaluating its effectiveness compared to the traditional system. The new system was designed and developed to provide optimal growing conditions for the mushrooms. To thoroughly evaluate the two cultivation methods, 50 samples were collected for each parameter of interest, including temperature, humidity, soil moisture, and mushroom weight. By collecting numerous samples, the study's findings were enhanced in terms of reliability and accuracy.

The null hypothesis (H_0) for the study posited that the climate control system did not exert a statistically significant effect on temperature, relative humidity, soil moisture, or mushroom biomass in relation to the growth rate of oyster mushrooms. The alternative hypothesis (H_1) posited that the climate control system had a statistically significant effect on temperature, relative humidity, soil moisture, and mushroom biomass, thereby influencing the growth rate of oyster mushrooms.

To test the hypotheses, an independent two-sample t-test was employed to determine if there was a significant difference in means between the climate control group and the traditional group. The t-test formula was used to calculate the t-value, which measures the difference between the means of the two groups in terms of standard error. The assumption of unequal variances was used because the variance in each group might not be the same. The degrees of freedom were calculated using the formula (n1 + n2 - 2), where n1 and n2 are the sample sizes of the two groups being compared. The critical value for the t-test statistic was determined using a t-distribution table or a statistical software program, in this case, Microsoft Excel.

If the calculated t-value is greater than the critical value, then the null hypothesis is rejected, and it is concluded that there is a significant difference in means between the two groups for that variable. If the calculated t-value is less than the critical value, then the null hypothesis cannot be rejected, and it is concluded that there is not a significant difference in means between the two groups for that variable.

To compare two groups with unequal variances, the t-Test: Two-Sample Assuming Unequal Variances tool in Excel's Data Analysis add-in was used. First, the date entered for both groups into separate columns in an Excel worksheet. Next, the Data Analysis tool was accessed, and the t-Test: Two-Sample Assuming Unequal Variances option was selected. The appropriate input ranges for the two groups were then specified, along with the significance level and whether the test was one-tailed or two-tailed. Excel then automatically performed the t-test, calculating the t-statistic, degrees of freedom, and p-value. Based on the results, it was possible to determine whether to reject the null hypothesis and conclude whether there was a significant difference between the means of the two groups. By using the Data Analysis tool in Excel, a t-test with unequal variances was easily performed, providing reliable insights from the data.

To compare the efficiency of the controlled and traditional systems in terms of oyster mushroom growth rate, weekly weight data in grams and percentage weight were collected for mushrooms from both systems. The weight percentage was calculated by dividing the total weight of harvested mushrooms per week by the overall weight of the mushroom harvest during the experiment, and then multiplying the result by 100. This data enabled the calculation of the growth rate for each system and facilitated their comparison. By comparing growth rates, the goal was to identify which system was more effective for oyster mushroom cultivation.

3. DATA RESULTS AND ANALYSIS

This section provides valuable insights into the performance of sensors and the importance of carefully monitoring environmental conditions in mushroom cultivation.

3.1 DHT 11 Temperature and Humidity Sensor Testing

Four tables will be presented to compare the accuracy of the DHT11 sensors used in the controlled and traditional systems against the reference standard, the Lutron PM-1064SD Air Quality Monitor & Recorder.

Table 1. Temperature Testing of the Controlled System

Temperature from DHT11 Sensor (◦C)	Temperature from Lutron (◦C)	Absolute Error (◦C)	Absolute Percentage Error (%)
31.0	30.8	0.8	2.58
29.9	29.7	0.2	0.67
29.6	29.5	0.1	0.34
29.9	29.5	0.4	1.34
29.4	29.0	0.4	1.36
29.5	29.6	0.1	0.34
		MAPE	1.10

Table 1 compares the temperature measurements obtained from the Lutron PM-1064SD Air Quality Monitor & Recorder and the temperature and humidity sensor (DHT11) of the controlled system, with the former treated as the reference standard. The maximum absolute error observed was 0.8◦C, while the minimum absolute error was 0.1◦C. The maximum absolute percentage error was 2.58%, while the minimum percentage error was 0.34%. The MAPE, a metric used to assess the accuracy of the measurements, was calculated as 1.10%.

Table 2. Temperature Testing of the Traditional System

Temperature from DHT11 Sensor (◦C)	Temperature from Lutron (◦C)	Absolute Error (◦C)	Absolute Percentage Error (%)
30.2	30.8	0.6	1.99
29.4	29.7	0.3	1.02
29.8	29.5	0.3	1.01
29.9	29.5	0.4	1.34
29.6	29.0	0.6	2.03
29.8	29.6	0.2	0.67
		MAPE	1.34

In addition, Table 2 compares temperature measurements obtained from the traditional system's temperature sensor with the reference device. The maximum absolute error observed was 0.6◦C, while the minimum absolute error was 0.2◦C. The maximum absolute percentage error was 2.03%, while the minimum percentage error was 0.67%. The MAPE was calculated as 1.34%.

Table 3. Humidity Testing of the Controlled System

Humidity from DHT11 Sensor (%RH)	Humidity from Lutron (%RH)	Absolute Error (◦C)	Absolute Percentage Error (%)
97.0	99.1	2.1	2.16
95.2	93.8	1.4	1.47
92.6	91.5	1.1	1.19
96.8	94.5	2.3	2.38
93.1	92.9	0.2	0.21
91.5	90.3	1.2	1.31
		MAPE	1.45

Table 3 compares humidity measurements obtained from the controlled system's DHT11 sensor with the reference device. The maximum absolute error observed was 2.1◦C, while the minimum absolute error was 0.2◦C. The maximum absolute percentage error was 2.38%, while the minimum percentage error was 0.21% with a resulting MAPE of 1.45%.

Table 4. Humidity Testing of the Traditional System

Humidity from DHT11 Sensor (%RH)	Humidity from Lutron (%RH)	Absolute Error (◦C)	Absolute Percentage Error (%)
96.8	99.1	2.3	2.38
95.7	93.8	1.9	1.99
93.8	91.5	2.3	2.45
96.4	94.5	1.9	1.97
94.4	92.9	1.5	1.59
91.9	90.3	1.6	1.74
		MAPE	2.02

Lastly, Table 4 compares humidity measurements obtained from a traditional system's DHT11 sensor with the reference device. The maximum absolute error observed was 2.3◦C, while the minimum absolute error was 1.5◦C. The maximum absolute percentage error was 2.45%, while the minimum percentage error was 1.59%. The MAPE was calculated as 2.02%.

Overall, the results show that the DHT11 sensors are accurate, as all MAPE values fall below 10%, which is generally considered an acceptable range.

3.2 Capacitive Soil Moisture Sensor Testing

Table 5. Soil Moisture Testing for the Controlled System

Moisture Content from Capacitive Soil Moisture Sensor (%)	Moisture Content from Oven Drying Method (%)	Absolute Error (◦C)	Absolute Percentage Error (%)
86.9	84.90	2.00	2.30
86.6	88.30	1.70	1.96
87.2	85.20	2.00	2.29
90.9	88.77	2.13	2.35
		MAPE	2.23

Table 5 compares soil moisture measurements obtained from the controlled system's capacitive soil moisture sensor and the reference method of oven drying. The maximum absolute error observed was 2.13, with a minimum absolute error of 1.7. The maximum absolute percentage error was 2.35%, while the minimum percentage error was 1.96%. The resulting mean absolute percentage error (MAPE) was calculated as 2.23%. These results suggest that the capacitive soil moisture sensor in the control system is highly accurate, with only slight variations from the reference method.

In contrast, Table 6 compares soil moisture measurements obtained from the traditional system's capacitive soil moisture sensor and the reference method of oven drying. The maximum absolute error observed was 4.40, with a minimum absolute error of 2.00. The maximum absolute percentage error was 5.24%, while the minimum percentage error was 2.40%. The resulting MAPE was calculated as 3.78%.

These results indicate that the capacitive soil moisture sensor used in the comparative system is less accurate than the one used in the control system, with more significant variations from the reference method.

Table 6. Soil Moisture Testing for the Traditional System

Moisture Content from Capacitive Soil Moisture Sensor (%)	Moisture Content from Oven Drying Method (%)	Absolute Error (◦C)	Absolute Percentage Error (%)
82.5	84.90	2.40	2.91
83.9	88.30	4.40	5.24
83.2	85.20	2.00	2.40
84.9	88.77	3.87	4.55
		MAPE	3.78

Overall, these findings suggest that the accuracy of soil moisture sensors can vary significantly depending on the specific system used. While the capacitive soil moisture sensor in the control system produced highly accurate measurements with minor variations from the reference method, the one in the comparative system exhibited more significant errors and variability. It is essential to carefully evaluate and select the appropriate sensor for each system to ensure accurate and reliable measurements.

3.3 Comparison of Temperature Data between Controlled and Traditional Systems nalysis of Temperature, Humidity, and Soil Moisture between Controlled and Traditional Systems

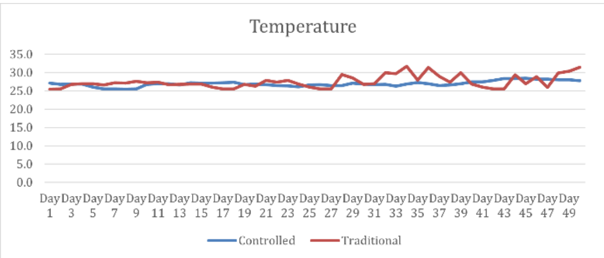

Fig. 8. Temperature Data Comparison

As shown in Figure 8, the temperature readings for both the controlled and traditional systems were recorded for 50 days. The temperature range specified for the mushroom farmhouse was 25-30°C, and the control system was equipped with a fan that activated when the temperature fell outside this range. The raw data table can be found in Appendix B.

According to the data, it can be observed that on most days, the controlled and traditional systems were within the specified temperature range. However, there were a few instances where the temperature exceeded the range, particularly in the traditional system.

On Day 28, the traditional system recorded a 29.5°C above the specified range. On Days 32 and 33, the controlled system recorded temperatures of 30.0°C and 29.7°C, respectively, which were also above the range. On Days 34 and 50, the traditional system recorded temperatures of 31.7°C and 31.5°C, respectively, significantly higher than the specified range. Overall, the controlled system effectively maintained the temperature within the specified range for most of the 50 days.

3.4 Comparison of Humidity Data between Controlled and Traditional System

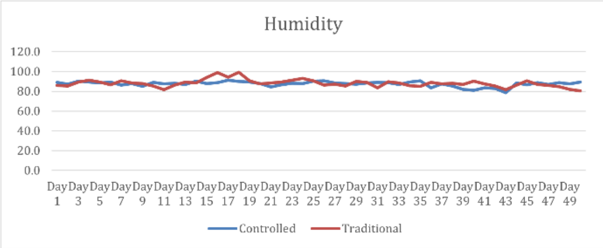

Fig. 9. Humidity Data Comparison

Figure 9 compares humidity data between the controlled and traditional systems over 50 days. The ideal humidity range for this system is between 70% to 90%, and when the relative humidity falls outside of this range, the misting system is activated to adjust it.

The figure shows that the controlled system generally maintained humidity levels within the desired range, with some fluctuations. In contrast, the traditional system had more variability and often fell outside the ideal range.

On Day 3, the traditional system was within range but dropped below the ideal range on Day 11 and again on Day 21. It also exceeded the ideal range on Days 15, 16, 18, and 25. In contrast, the controlled system remained within range on all days except Day 7, which was slightly below the ideal range. This data suggests that the controlled system is more effective at maintaining the desired humidity range than the traditional system.

3.5 Comparison of Soil Moisture Data between Controlled and Traditional System

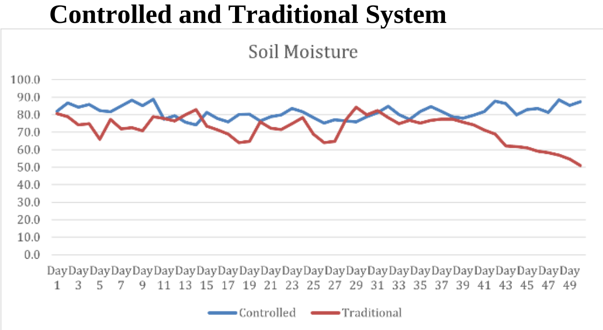

Fig. 10. Soil Moisture Data Comparison

Figure 10 depicts a comparison of soil moisture levels between the controlled and traditional systems over a period of 50 days. The optimal range for soil moisture in this study is between 60% and 90%, and the misting system is activated when the moisture falls outside of this range.

The graph shows that the controlled system generally sustained the desired moisture levels, albeit with minor fluctuations. On the other hand, the traditional system exhibited more fluctuations and frequently fell outside the optimal range, particularly in the last 20 days of the experiment. Based on this data, it is apparent that the controlled system is more effective in maintaining the desired soil moisture range than the traditional system.

3.6 Statistical Analysis of Temperature between Controlled and Traditional Systems

The table presents the results of a two-sample t-test assuming unequal variances for the temperature between a Controlled group and a Traditional group. The mean temperature for the Controlled group is 26.97, while the Traditional group has a slightly higher mean temperature of 27.55. The t-test resulted in a t-statistic of -2.22, indicating a significant difference between the groups. The one-tail p-value is 0.01, below the conventional threshold of 0.05, suggesting a statistically significant difference in temperatures. Additionally, the t-statistic is smaller than the t-critical value of 1.67, further supporting the rejection of the null hypothesis. In summary, the data suggests a significant difference in temperature. These findings suggest evidence of a meaningful difference between the two groups, controlled and traditional systems.

Table 7. t-Test: Two-Sample Assuming Unequal Variances for the Temperature

	Controlled	Traditional
Mean	26.97	27.55
Variance	0.54	2.97
df	66.0	
t Stat	-2.22	+
P(T<=t) one-tail	0.01	
t Critical one-tail	1.67	

3.7 Statistical Analysis of Humidity between Controlled and Traditional Systems

Table 8. t-Test: Two-Sample Assuming Unequal Variances for the Humidity

	Controlled	Traditional
Mean	87.56	88.87
Variance	6.78	12.28
df	90.00	
t Stat	-2.12	
P(T<=t) one-tail	0.02	
t Critical one-tail	1.66	

The table presents the results of a two-sample t-test assuming unequal variances for the humidity between a Controlled group and a Traditional group. The mean humidity for the Controlled group is 87.56, while the Traditional group has a slightly higher mean humidity of 88.87. The t-test resulted in a t-statistic of -2.12, indicating a statistically significant difference in humidity between the groups. The one-tail p-value is 0.02, below the conventional threshold of 0.05, further supporting the significance of the difference. Therefore, the null hypothesis can be rejected, and it can be concluded that there is a significant difference between the two groups.

3.8 Statistical Analysis of Soil Moisture between Controlled and Traditional Systems

Table 9. t-Test: Two-Sample Assuming Unequal Variances for the Soil Moisture

	Controlled	Traditional
Mean	81.42	72.58
Variance	14.73	60.01
df	72.00	
t Stat	7.23	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.67	

The table provides the results of a two-sample t-test assuming unequal variances for the soil moisture between a Controlled group and a Traditional group. The mean soil moisture for the Controlled group is 81.42, while the Traditional group has a lower mean soil moisture of 72.58. The t-test yielded a t-statistic of 7.23, indicating a highly significant difference in soil moisture between the groups. The one-tail p-value is 0.00, below the conventional threshold of 0.05, further emphasizing the statistical significance of the difference. The results strongly suggest that the null hypothesis can be rejected, and the Controlled group has a significantly higher mean soil moisture compared to the Traditional group.

3.9 Evaluation of Oyster Mushroom Growth rate

Table 10 shows the weight measurements for the seven harvests over a 50-day duration in two mushroom cultivation systems, the controlled and traditional systems. The weight percentage was calculated by dividing the total weight of harvested mushrooms per week by the overall weight of the mushroom harvest during the experiment, and then multiplying the result by 100.

Table 10. Oyster Mushrooms Growth Rate Evaluation

50 days duration								
20 mushroom fruit bags each system								
Weight (grams)								
System	1st Harvest	2nd Harvest	3rd Harvest	4th Harvest	5th Harvest	6th Harvest	7th Harvest	Total
Controlled	450	550	320	250	330	150	250	2300
Traditional	350	200	150	180	250	80	60	1270
Weight (percentage)								
System	1st Harvest	2nd Harvest	3rd Harvest	4th Harvest	5th Harvest	6th Harvest	7th Harvest	Total
Controlled	19.57%	23.91%	13.91%	10.87%	14.35%	6.52%	10.87%	100.00%
Traditional	27.56%	15.75%	11.81%	14.17%	19.69%	6.30%	4.72%	100.00%

The weight measurements indicate that the controlled system produced a higher yield of mushrooms than the traditional system. In the first harvest, the controlled system produced mushrooms with an average weight of 450 grams with 19.57%, while the traditional system produced mushrooms with an average weight of 350 grams with 27.56%. The difference in average weight between the two systems continued to increase in all subsequent harvests. The controlled system produced mushrooms with higher average weights in each of the seven harvests. In the second harvest, the controlled system produced mushrooms with an average weight of 550 grams with 23.91%, while the traditional system produced mushrooms with an average weight of 200 grams with 15.75%. Similarly, in the third harvest, the controlled system produced mushrooms with an average weight of 320 grams with 13.91%, while the traditional system produced mushrooms with an average weight of 150 grams with 11.81%. The trend continued in all subsequent harvests, with the controlled system consistently producing mushrooms.

The weight measurements suggest that the controlled system may be more effective in producing higher yields of mushrooms than the traditional system.

3.10 Statistical Analysis of the Growth Rate Evaluation

Table 11. t-Test: Two-Sample Assuming Unequal Variances of the Growth Rate

	Controlled	Traditional
Mean	328.57	181.43
Variance	18014.29	9914.29
df	11.00	
t Stat	2.33	

	Controlled	Traditional
P(T<=t) one-tail	0.02	
t Critical one-tail	1.80	

Based on the information provided in table 11, it seems that the Controlled group had a higher mean growth rate compared to the Traditional group. The t-test indicates that this difference is statistically significant, with a p-value of 0.02 (less than the conventional threshold of 0.05). The t-statistic of 2.33 exceeds the t-critical value of 1.80, supporting the rejection of the null hypothesis that the means of the two groups are equal.

4. CONCLUSIONS

This study aimed to establish optimal environmental conditions for oyster mushroom cultivation and evaluate the effectiveness of a climate control system in enhancing growth rates. The control system maintained the chamber temperature between 25°C and 30°C, relative humidity at 70% to 90%, and soil moisture content of the fruit bags between 60% and 90%, which were crucial for consistent crop yields. The study found significant differences between the controlled and traditional systems in managing these conditions, demonstrating the control system's effectiveness in maintaining ideal parameters for improved mushroom growth.

Additionally, the impact of the climate control system on growth rates was assessed by weighing harvested mushrooms weekly. Statistical analysis revealed a significant difference in growth rates, with the controlled system outperforming the traditional system. The t-test results, with a P-value of 0.04 and a t Stat value of 2.33, confirmed that the controlled system led to higher growth rates as evidenced by the t-Test results and consequently, increased crop yields and profitability. These findings highlight the critical role of climate control in optimizing mushroom production.

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