Research article

Experiment on Smart Mushroom Cultivation Using an Environmental Control System

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Abstract The purpose of this research was to implement smart mushroom cultivation by applying a sensor network and control algorithm to test the performance of the cultivation system and yield obtained compared to the conventional method. This research introduced innovative automated methods to the cultivation of rice-straw mushrooms by utilizing sensor technology and a controller with a control algorithm. The control algorithm automatically controlled the environment in the mushroom house based on feedback from the sensors to maintain the environment in an optimum condition for mushroom growth. The experimental setup included two cycles for growing the rice-straw mushrooms in different control environments, with three stages per cycle. The first stage was used during the vegetative phase, the second stage was used to control mushroom growth during the spawn-run phase, while the last stage was applied during the pinhead and cropping phases. The first cycle of the experiment was implemented to verify the circumstances surrounding mushroom growth under automated control based on three parameters: ambient temperature, relative humidity, and carbon dioxide (CO_2). The experiment utilized one controller with four pieces of equipment to automate control based on those parameters, which included the ventilation fan, exhaust fan, sprinkler, and motor pump for the cooling pad. During the first cycle, some problems with the CO_2 sensor and the exhaust fan were encountered, so it was necessary to implement a combination of manual control and automated control in the controlling algorithm for the second cycle. After completing these experiments, we determined that utilizing a combination of automatic and manual control, mushroom farmers will be able to save time, money, and labor while also increasing mushroom yield to satisfy market demand.

Keywords smart mushroom cultivation, rice-straw mushroom, automation control system, automation technology, environmental control system.

INTRODUCTION

Agriculture is the most critical sector of the Cambodian economy in terms of its contribution to the Gross Domestic Product (GDP) because most of the population are farmers (Encyclopedia Britannica, 2021). Nowadays, most farmers in Cambodia are trying to evolve farming into modern agricultural techniques (Fosbenner, 2018). With the help of various technologies, agriculture has gotten more convenient while also producing higher yields to meet the demand for supplies. Among other agriculture sectors, the mushroom industry is still done in a very traditional way, which restricts production capacity and prevents it from producing enough yield to support both the farmer and the country's economy. As a result of these factors, it is essential to modernize the facilities to maximize production through the most efficient use of resources.

The main purpose of this research is to apply automation technology to the production of rice-straw mushrooms by utilizing sensor technology such as a Temperature sensor, Humidity sensor, CO_2 sensor, and a controller with a control algorithm that can control the devices in the mushroom house and automatically based on feedback from the sensors to maintain the environment in an optimum condition for mushroom growth. This experiment's goal is to test the performance of the system and the yields obtained compared to the conventional method.

MATERIALS AND METHODS

Experimental Setup

The smart mushroom house is constructed with dimensions of 5 meters by 6 meters (5 m × 6 m) which is equal to 30 square meters (32 m^2). The bamboo trees used to build the mushroom trays are 1.6 meters by 4 meters (1.6 m × 4 m) or 6.4 square meters (6.4 m^2), and there are ten trays altogether as shown in Fig. 1. One motor pump, one cooling pad, one exhaust fan, a shrinker system, a control panel, and monitoring sensors such as a temperature and humidity sensor and a CO_2 sensor were all included in the smart mushroom house's control equipment. The surrounding area is constructed of plastic. The ventilation fan is placed against the mushroom house wall above the door and faces the exhaust fan on the other side. The motor is mounted over the cooling pad that leans up against the wall, and the shrinker system is equipped around the mushroom house's corner.

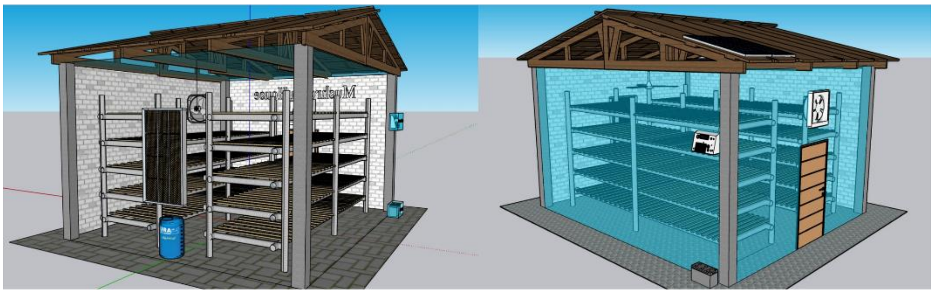

Fig. 1 Smart mushroom house simulation in 3D view

Environmental Requirement

Normally, the Rice Straw Mushroom grows in warm weather, typically in the tropics and sub-tropics. The optimal temperature for rice straw mushrooms to grow in mycelial is from 28°C to 30°C for its fruiting body production. where the ideal temperature for growing mushrooms is between 25°C and 40°C (Fasidi, 1996). The ideal humidity range for rice straw mushroom growth is between 70% and 90% (Bawis, 2014). While other research claimed that the mushroom's humidity might reach 99%. Additionally, the level of carbon dioxide ranges from 1000 to 2000 ppm.

Mushroom Substrate

In our case study, several materials, including rice straw, mung bean shells, rice bran, sugarcane (black sugar), limestone, and gypsum, have been employed to create the compost or substrate. The process of making this compost will take around six to seven days. First, the rice straw and mung bean shell will need to be soaked for at least a night to make them soft, then drain before mixing with limestone water. After combining these three ingredients, it must be fermented once more for a total of six days, with two days of re-mixing. The remaining components must be combined after six days and fermented for one night before use.

Table 1 Ingredients for substrate

Ingredients	Amount (kg)
Rice Straw	400.0
Mung Bean Shell	150.0
Rice Bran/ Wheat	50.0
Sugarcane (Black Sugar)	2.0
Limestone	5.5
Gypsum	3.0
Total	610.5

Table 2 Parameter requirements during each stage

Parameters	Stage I	Stage II	Stage III
Temperature (°C)	29-36	32-36	26-33
Relative Humidity (%)	100	92-96	86-92
CO_2 (ppm)	>1500	<1500	<1500

System Overview

The Smart Mushroom House has been equipped with all components and sensors, including a solar panel, a battery (Power Can), a circuit breaker, a transformer, a motor pump, a cooling pad, an exhaust fan, a ventilation fan, a sprinkler, a Honeywell ambient temperature and humidity sensor, a Honeywell carbon dioxide sensor, and a Honeywell controller (CIPer Model 50). To do the configuration, we must first ensure that the controller is powered with the appropriate current and voltage. Since the controller and the sensors require 24 VDC or VAC to work, but the standard range of electrical power is 220 VAC, a transformer is required to convert 220 VAC to 24 VAC for the controller.

The rice-straw mushroom grows in four stages, including the vegetative phase, spawn run, pin head initiation, and cropping mode. We have decided to divide the controlling stage into three stages. The first stage is to manage the vegetative phase which the temperature will stay between 32°C and 36°C. The second stage is to manage the system during the spawn run which the temperature will persist between 32°C and 36°C, the relative humidity stays between 92% and 96%, and the carbon dioxide stays at about 1500 ppm. The last is to handle the system during the pin head initiation and cropping mode, in which the temperature will stay between 26 and 33°C, the relative humidity will remain between 85% and 92% RH, and carbon dioxide will remain at about 1000 ppm. Also, we have decided to test in 2 cycles. The first cycle is in March, and the second cycle is in May because both months have similar weather and it is easier for us to study since both cycles use different configurations to test the differences between each condition.

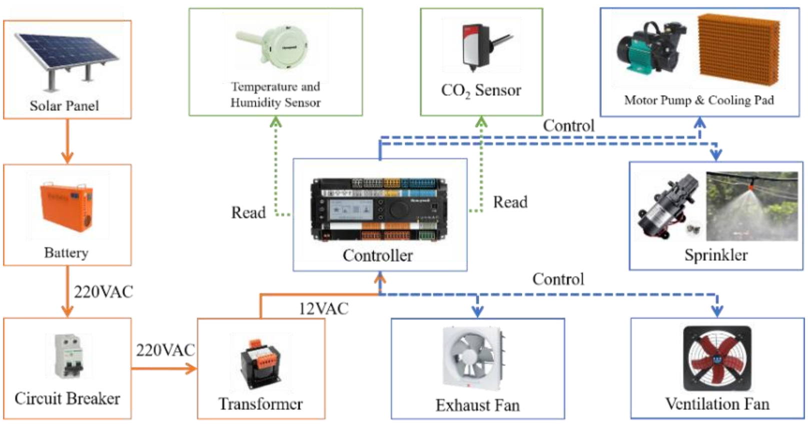

Fig. 2 System architecture of smart mushroom house

Experiment for 1st Cycle

After setting up all the controllers and assigned points, it needs to configure each step of mushroom cultivation to obtain and control the environment inside the mushroom home to its excellent condition during its growth stage.

The mushroom must be in stage I (vegetative phase), where the temperature must range from 29°C to 36°C, the humidity must range from 92% to 96%, and the CO_2 level must be less than 10000 ppm. In this case, the configuration follows the flowchart as shown in Fig. 3. below. It indicates that the Exhaust Fan and Sprinkler will activate whenever the temperature rises above 36°C and remain on until the ambient temperature falls below 36°C. The time required for this stage is approximately 3-4 days before we can see the spawn running through the compost and appearing as a thin white thread.

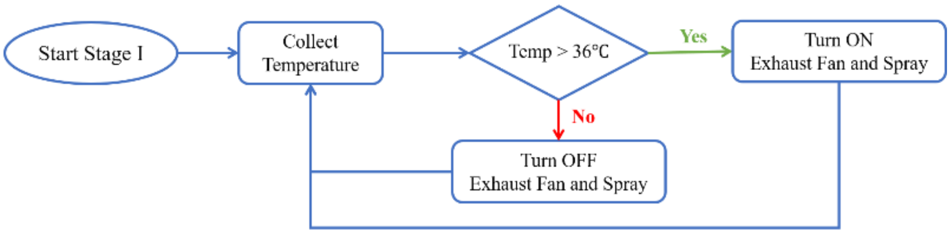

Fig. 3 Flowchart of stage I configuration

Under stage II (spawn run), the mushroom must grow in conditions with a CO_2 level of less than 1500 ppm, a temperature range of 29°C to 36°C, and a relative humidity range of 92% to 96%. In this case, the system configuration follows the flowchart as shown in Fig. 4. In this stage, the controller will read data from all three sensors, and based on that data, it will control the system. For example, if the temperature rises above 36 °C, the sprinkler and exhaust fan will turn on until the temperature falls below 36 °C. Additionally, if the relative humidity rises above 96% RH, the system will automatically switch on the ventilation and exhaust fans until the humidity returns to its typical range of 92-96%. In this situation, if the relative humidity falls below 92%, the system will automatically turn on the spray and motor for the mushroom house to hydrate the compost and moist the air, as too much dryness will prevent the compost from producing much output. The controller will also read information from the CO_2 sensor when the CO_2 level rises above 1500 ppm, the system will activate the exhaust fan to draw in the fresh air and the ventilation fan to circulate the air inside the mushroom house so that it is all the same. The time required for this stage is approximately 3-4 days before we can see the little thread that will eventually grow into a mushroom leg rising from the spawn that spread during the earlier stage.

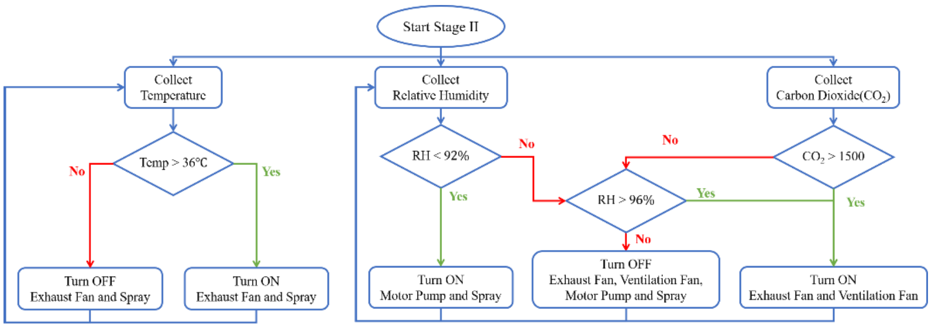

Fig. 4 Flowchart of stage II configuration

Stage III includes the pin head initiation and cropping mode. The ambient temperature must be between 29°C and 33°C, the relative humidity must range from 92% to 96%, and the CO_2 level must be less than 1000 ppm for the mushroom to thrive. The flowchart illustrates the system configuration in this condition as shown in Fig. 5. The configuration for this stage is the same as the previous stage, but there are differences between the fixed static variables that we input in the temperature, humidity, and CO_2 sensors. The controller will read the parameters from all three sensors and control the system based on those data. For example, if the temperature rises above 33°C, the sprinkler and exhaust fan will turn on until the temperature drops below 33°C. When relative humidity rises above 92%, the system automatically turns on the ventilation and exhaust fans until the humidity falls below the typical range of 85% to 92%. In this condition, the system will automatically turn on the spray and motor for the mushroom house if the relative humidity falls below 85% in exchange for hydrating the compost and moistening the air, as too much dryness will prevent the compost from producing much yield. The controller will also read data from the carbon dioxide sensor, and when the CO_2 level rises above 1000 ppm, the system activates the exhaust fan to filter out the fresh air and the ventilation fan to circulate the air inside the mushroom house so that it is equally heated and cooled. The time required for this stage is approximately six to seven days since the little mushroom must first grow to the point where its head is an egg shape.

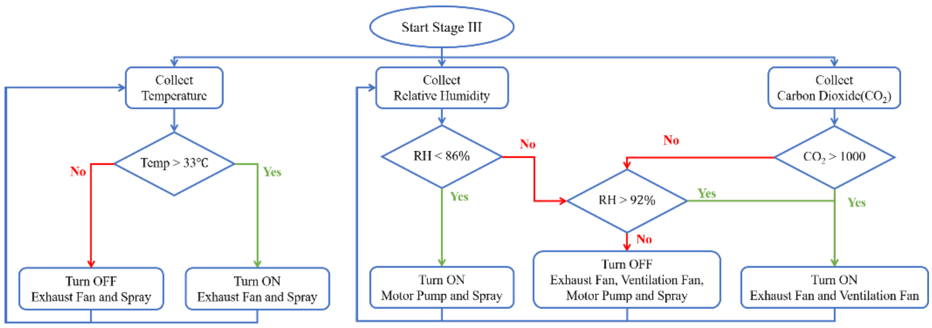

Fig. 5 Flowchart of stage III configuration

Experiment for 2nd Cycle

Based on the results from the first cycle of the experiment, we encountered some problems with the carbon dioxide sensor and the exhaust fan, which caused the compost to become excessively dry and provide less yield than expected. To find a solution, we come up with another configuration in which we will use scheduling time to regulate the exhaust fan to turn on for five minutes and three times a day during stage II (spawn run) because in stage II the mushroom does not require too much oxygen from outside and the air does not require to ventilation much. Additionally, because mushrooms need frequent ventilation during stage III and require more fresh air to grow, the scheduling time for these stages was adjusted to five minutes every hour or 24 times per day. In addition to fixing the problem, we also have installed another two sensors, including an ambient temperature and relative humidity sensor and a carbon dioxide sensor outside the mushroom house to compare the environment outside and inside the mushroom house.

RESULTS AND DISCUSSION

Results of 1st Cycle

The stage I configuration has turned on and the system has been running based on the design algorithm. During this process, the temperature has never risen above 36°C which is the set point to turn on the exhaust fan and spray. It means that the environment inside the mushroom house has stayed under our control. When it reached the pin head stage, the stage II configuration system turned on, and we can see that the temperature during this stage increased by 36°C, allowing our control system to turn on the exhaust fan and spray. After both components were turned on, we observed that the temperature decreased below 36°C. The ventilation fan and exhaust fan have been turning on when the CO_2 level has risen above 1500 ppm and turning off when it has fallen below 1500 ppm.

However, this procedure has made both components run inexorably because the CO_2 level rarely stays below 1500 ppm. The problem with our sensor's response time is that it responded too late, which causes problems for our system. During stage III of the control process, the set points for temperature, CO_2, and relative humidity are 33°C, 1000 ppm, and 92%, respectively. However, the received data have all exceeded the set points of all parameters, which makes all of the mushroom house's components turn on unstoppable. With this issue, we have decided to turn off the automatic system and use the manual system instead.

With the results from the first cycle, we harvested a total yield of 80 kg with a total substrate weight of 610 kg, which represents a percent of 0.13%, or 0.13 kg of rice straw mushrooms per kilogram of the substrate. According to the standard, 10 kg of dried straw yields 2 kg. Our yield is less than 0.7 kg compared to the standard because some errors also happened during the growing process (Gummert, 2022). The CO_2 sensor that we utilized has caused errors in the data flow, causing the receiving data to be delayed and the ventilation and exhaust fans to operate automatically based on configuration, drying up the compost and producing less yield.

Results of 2nd Cycle

The only difference between the received data and the first cycle of control from stage I to stage III is that the relative humidity has reached 99%, causing our exhaust fan and ventilation fan to run nonstop following the stage configuration and causing the compost to become too dry. Regarding this issue, we have set the set point to 99% in stage II and stage III configurations in favor of activating the exhaust fan and ventilation fan. As previously mentioned, the second cycle's stage II temperature set point is the same as the first cycle, but the humidity only remains at 99%, which is higher than the set point of the first cycle, so we changed the set point of the second cycle to 99% instead to prevent the control the environment inside the mushroom better. The ventilation and exhaust fans were not directly controlled by the CO_2 level during this stage because we already had a schedule for when to turn them on and off. During stage III, the process is the same as the first cycle but we have only added the scheduled time to turn on and off the exhaust fan and ventilation fan every five minutes.

With the second cycle implementation, we harvested the rice straw mushroom with a total yield of 85 kg and a total substrate of 610 kg, which equals a percent of 0.14%, which means that one kilo of the substrate produces 0.14 kg of rice straw mushroom. There were still a few errors that happened between these stages where the humidity sensor reading was above 99% RH, causing the ventilation fan and exhaust fan to run continuously in accordance with the stage setting, drying out the compost.

CONCLUSION

Based on the results of both cycles, we can compare the configuration and yield and find that the second cycle is a little better than the first cycle, which generated more than 5 kg of rice straw mushrooms. With both results, we have discovered and faced some obstacles regarding the exhaust fan, ventilation fan, CO_2 sensor, and humidity sensor. Even though there were a few issues with the experiment, this is not the end of the research. We have recommended a different configuration to assist in resolving the issue. Since some sensors were not capable of the system, we will replace those and do another config algorithm to help upgrade the systems. This study is focused on figuring out the best control algorithm for the mushroom house. It is also possible to estimate and analyze the accuracy of real-time data using the data collected from all the sensors. The data achieved in this study have to be regarded as a significant input for subsequent research on the issue that cropped up during the testing phase to make the system more stable and dependable. Applying both automated control and manual control has helped local farmers save their labor, money, and time and create products of the mushroom to meet the demand of the market.

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