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Design and Development of A Rice Straw-Based Mushroom Growing Substrate Pasteurizing and Cooling System

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ABSTRACT: This study employed an engineering design, planning and analysis to achieve the objectives of the study. The established operating time for the chemical pasteurization, cooling, and substrate discharging processes were 30 minutes, 90 minutes and 30 minutes, respectively. The temperature range for the chemical pasteurization process was 55°C - 60°C. The draining time after the cooling process was 30 minutes. The established acceptable proportion of rice straw to volume of water was 5 kg of rice straw to 200 liters of water. The pasteurization rate of 0.5 kg/min, cooling rate of 0.167 kg/min and discharging rate of 0.5 kg/min were recorded during the performance testing. The over-all production rate was 0.1 kg/min. The time needed for spawn to colonize the substrate depends on the spawning rate and its distribution, the substrate moisture and temperature, and the nature and quality of the substrate.

Keywords*: chemical pasteurization, rice straw-based mushroom substrate, incubation time, inoculation time*

I. INTRODUCTION

Mushroom production is one of the promising and viable agri-businesses in the Philippines. Today, the cultivation incessantly gaining more attention as a possibility to use agricultural wastes, thus, help to alleviate poverty and food security. It generates livelihood and income to people both in rural and urban areas. Currently, there are several methods of mushroom cultivation utilizing various technologies to improve the process. Mushroom can be grown on commercial or small scale using either highly urbane equipment or low cost materials and agricultural wastes. The demand of straw mushrooms is growing because of people's preference of eating food which is pesticide-free. The potential of straw mushroom culture is high not only because of health benefits and nutritional values but as well as the availability of indigenous raw materials, small area requirement for growing, less capital needed for investment and potential profits.

Usually, mushroom mycelia can be grown on the nutritious media, taking from it the nutrients necessary for their growth. Mycelium is a thread-like collection of cells that represent the vegetative growth of a fungus. There are commonly used substrate materials to facilitate the mushroom cultivation such as sawdust, cottonseed hull, rice straw, corncob, sugarcane bagasse, and other plant fibers with high cellulose contents. These agri-waste materials used as substrates are very inexpensive and sometimes free from agricultural sites, one of the merits of mushroom growing. Moreover, oyster mushrooms can be grown on a wider variety of agricultural wastes than any other cultivated mushrooms.

Pasteurization is a process by which amounts of microscopic competitors in a substrate are reduced, which gives the mycelium an advantage over harmful organisms, allowing it to take over the substrate and eventually produce mushrooms. It is basically the reduction of the amount of harmful competing organisms, when the process is over, there is still some micro-activity going on in the substrate, usually in the form of beneficial bacteria. Mycelium will colonize smaller pieces of straw much faster and easier.

Mushrooms are fungi characterized by the presence of gills under the umbrella-shaped cap called pileus. Some grows in mass or in clusters; others develop in singles or in pairs. Like plants, mushrooms have seeds responsible for propagating the species. Some varieties thrive well on cool weather, others in warm places. Mushroom growing requires little space and time and farmers can make use of their rice straws

following harvesting. Mushroom can be grown the whole year round provided a good storage of rice straw is prepared.

Mushroom cultivation is a promising way to recycle organic waste into a valuable product. The abundant amount of organic waste produced each year has been a problem all over the world, especially in developing countries. Rice straw, as the one of the largest amounts of agricultural residues, can be converted into mushroom with technologies ranging from very simple to a highly developed one. Mushroom cultivation gives some benefits to farmers as well. Mushroom can be used as an alternative source of protein, which is more affordable than other sour
ces such as meat and milk. The spent mushroom can be used as soil consolidation, animal fodder and components of mushroom substrate (Afrizal, Rahmad, 2009).

The mushroom industry is a potential market in Batangas City since there is no mushroom-growing farm in the locality. Mushroom production can be a profitable business, as proven by establishments and organizations such as the San Pedro Multi-Purpose Cooperative located at San Pedro, Batangas City. The cooperative has started its mushroom production using the conventional method. But due to financial instability, the cooperative is currently not engaged in mushroom production, but has gained experience in backyard cultivation of mushrooms and is willing to start for a small – scale production. Their products reach the market through public markets within the vicinity of Batangas City.

The cooperative, during their backyard operation, used composting as a means of growing mushroom. The preparation of substrate materials were done manually. The quantity of mushroom they harvested ranged from 20 to 30 flushes per 2 m^2 of compost pile. The means of preparing the compost substrate were labor-intensive and time consuming, and the substrate was prone to contamination that hindered viable growth of mushrooms. To solve the problem, advanced methods of producing substrate was introduced. This involves chemical pasteurization and cooling process for substrate treatment, and then stuffing the processed substrate to substrate bags ready for spawning and incubation. This ensures the quality of the substrate and the edibility of the mushroom produced, requiring less labor and time. With this idea in mind, the researchers thought of utilizing all year round available agro industrial wastes such as rice straw to be used as substrate material.

It is therefore in this context that this study seriously considered the design and development of a rice straw-based mushroom growing substrate pasteurizing and cooling system which can be utilized by small mushroom growers in San Pedro, Batangas City.

II. OBJECTIVES OF THE STUDY

The main thrust of this study was to design and develop a rice straw-based mushroom growing substrate pasteurizing and cooling mixer. Specifically, this aimed to:

1. Design and fabricate the proposed machine taking into account the following requirements:
1.1 system components;
1.2 dimensions; and
1.3 material specifications.
2. Conduct performance testing of the developed machine to establish the following parameters:
2.1 operating time for chemical pasteurization, cooling and substrate discharging processes;
2.2 hot water bath temperature; and
2.3 acceptable proportion of the mass of rice straw to the volume of water.
3. Evaluate the actual performance of the machine in terms of:
3.1 pasteurization rate;
3.2 cooling rate;
3.3 discharging rate; and
3.4 over-all production rate.
4. Determine the properties of the processed substrate in terms of:
4.1 pH level;
4.2 moisture content; and
4.3 substrate temperature.
5. Utilize the processed substrate in oyster mushroom production and monitor the spawn run of inoculation.

III. MATERIALS AND METHODS

Research Design

This study employed the process of engineering design, thorough planning and comprehensive analysis to attain the objectives of the study. It also considered the performance and experimental testing to evaluate the performance of the fabricated machine. This covered the following stages:

Design Stage

This stage was focused on engineering calculations to determine the sizes and dimensions of materials that were used for fabrication, as well as the target capacity of the machine. Schematic layout of the proposed machine was presented specifying the different system components and dimensions.

Development Stage

This stage covered the fabrication of the machine taking into consideration the design specifications. Proper selection of materials was considered in terms of availability and cost.

Preliminary Testing Stage

Preliminary testing of the machine was conducted to establish the operating parameters of the fabricated machine. These included the operating time for chemical pasteurization, cooling and substrate discharging processes; hot water bath temperature; and acceptable proportion of the mass of rice straw to the volume of water. During this stage, some modifications were incorporated to rectify the problems encountered during initial operation. It also included several trial runs to come up with the desired operating conditions of the machine.

Final Performance Testing Stage

In the final testing stage, the performance of the machine was tested in terms of pasteurization rate, cooling rate, and discharging rate. Over-all production rate was also determined using the initially obtained parameters.

Experimental Testing Stage

The samples of the final product collected during the performance evaluation were tested to determine the properties of the treated substrate. This experimental method considered the following parameters such as pH level, moisture content and substrate temperature.

After rice straws were already processed, the preparation of fruiting bags followed. Other growing materials were mixed with the processes rice straw. Spawn was scattered evenly on one end. Tissue culture of oyster mushroom was used. After planting, these substrate bags were incubated in a housing in which temperature and humidity were controlled. Temperature and humidity were monitored through measuring devices such as mercury thermometer equipped with humidity measuring function. The time of harvesting the mature mushroom varied, depending on the condition of the space. After full inoculation, mushrooms started to grow after three (3) to four (4) days, but still varied depending on the room condition. Daily monitoring, which included keeping the housing damped and attaining the desired temperature and humidity level was done. Proper hygiene was practiced every time monitoring was done through the use of safety personal clothing.

Preparation of Raw Materials

Rice straw was collected from various agricultural farms in the province of Batangas. This served as a raw material in the production of mushroom substrate. Approximately, 120 kilograms of sun-dried rice straw were utilized in order to successfully meet the number of trials needed for the testing.

The rice straw was cut into small pieces with a length of 1 to 3 inches before introducing it to the system. This was done in order to loosen the material so that the water would be evenly absorbed by the fibers of the rice straw. In this case, the rice straw would not entangle into the mixing shafts of the mixer and would be easily discharged by the machine. The rice straw was also soaked in water for 8 hours and then air dried. The solution composed of carbendazium, formaldehyde and water was prepared. For 100 liters of water, 7.5 grams of carbendazium and 50 milliliters of formaldehyde were added and supplied initially to the chamber. The said solution was premixed and preheated approximately for 5 minutes at 55°C - 60°C through the mixer, until carbendazium was evenly dissolved and was followed by the rice straw input.

IV. RESULTS AND DISCUSSION

System Components of the Machine

The final set up of the fabricated rice straw-based mushroom growing substrate pasteurizing and cooling mixer is presented in Figures 1 and 2.

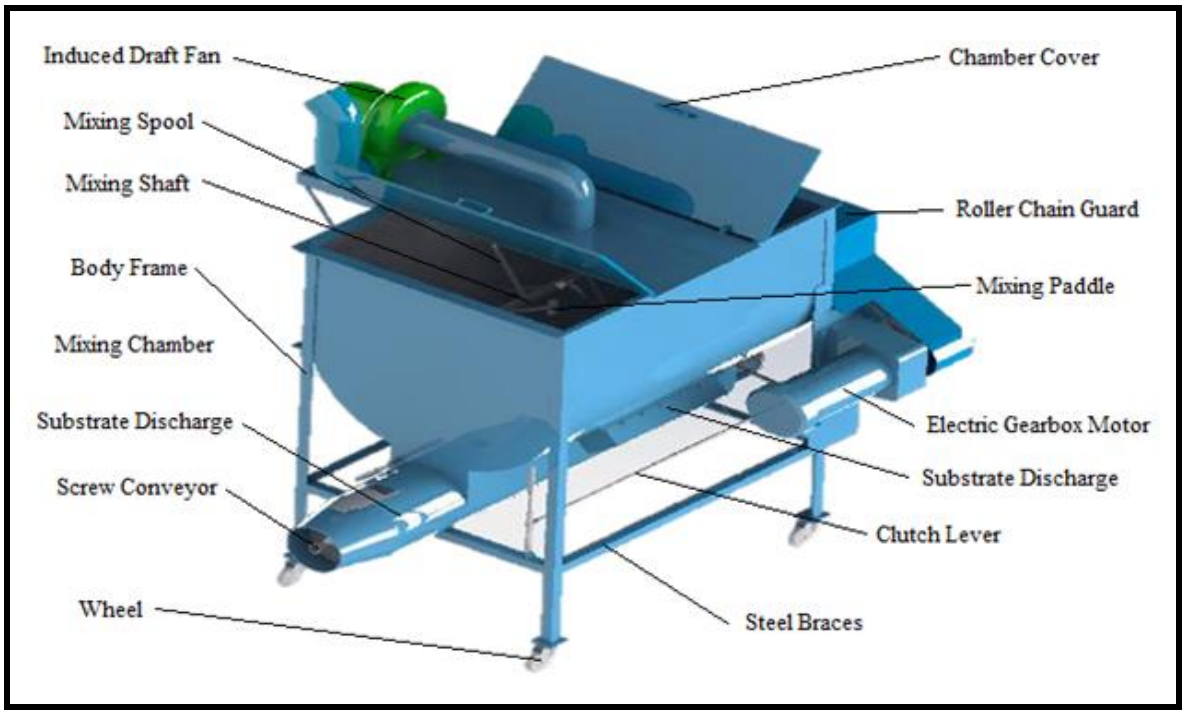

Figure 1. Front Isometric View of the Fabricated Machine

The machine is composed mainly of the mixing chamber, mixing shafts and mixing paddles, heating element, induced draft fan, screw conveyor, substrate discharge, flexible transmitting elements and prime mover. The mixing chamber is a U-shaped cylindrical vessel which can handle up to 200 liters of water. It is made up of stainless steel plate with a thickness of 3mm. The rice straw contains a certain amount of moisture when processed inside the mixing chamber, thus, the mixing shafts help loosen the rice straw fibers and prevent them from clumping. The mixing shafts both measure 915mm in length and 32mm in diameter. Moreover, the mixing paddles are welded along the length of the mixing shaft and are arranged in an alternate manner in such a way that no mixing paddles would clash each other. The mixing paddle is in the form of a spool having a length of 152mm, in which the mixing plate is welded at its tip measuring 50mm x 25.4mm. This ensures that the rice straw is well-blended inside the mixing chamber.

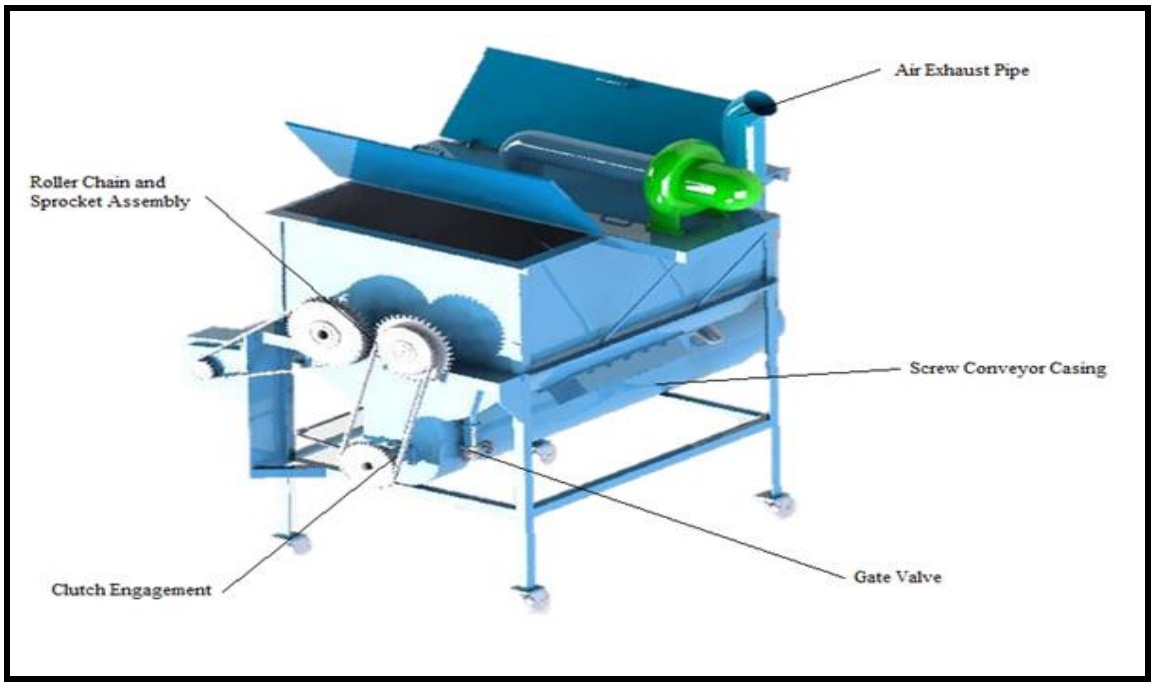

Figure 2. Rear Isometric View of the Fabricated Machine

The heating element is used for the pasteurization process of the rice straw substrate. The machine is composed of two pairs of heating coil, one pair on each side, enclosed in a rectangular casing. It is located at the lower left and right sides of the mixing chamber. It has a rated capacity of 920W per coil and is made of copper tubing. The coil is able to heat the chemical mixture up to 60^{o}C. The induced draft fan with a power rating of 550W is used to cool down the rice straw substrate after pasteurization process. Basically, it is a blower in which the flow of air is reversed. It has a 102mm intake having three blades which rotate at 3600 rpm.

The screw conveyor helps the processed rice straw to be extruded out the substrate discharge. It has a diameter of 203mm and rotating at 40 rpm. It is enabled by engaging the clutch on the sprocket coupled on the mixing shaft. The substrate discharge is a frustum-shaped opening with a diameter at the end of 150mm, where the processed substrate is released from the machine.

The electric gearbox motor serves as the prime mover of the machine, which drives the mixing shafts and the screw conveyor. It is a 3-phase, 60 Hz motor that operated up to 1800 rpm. The roller chain and sprocket assembly serves as the main flexible transmitting element that guides the motion through the machine. The driving sprocket, which has 16 teeth, is directly coupled to the gearbox motor. This is driven by a 50-tooth sprocket aligned with 68-tooth gear in one mixing shaft. The other shaft also is a 68-tooth gear aligned with a sprocket containing 38 teeth.

Results of Preliminary Testing

Various operating conditions were established during the preliminary testing of the fabricated machine. These parameters included the operating time for chemical pasteurization, cooling and substrate discharging processes; the hot water bath temperature; and the acceptable proportion of the mass of rice straw to the volume of water.

1. Operating time for Chemical pasteurization

Chemical pasteurization is simply the process by which amounts of microscopic competitors in a substrate are reduced. This gives the mycelium an advantage over harmful organisms, allowing it to take over the substrate and eventually produce mushrooms (mushroom-appreciation .com). When the process is over, there is still some micro-activity going on in the substrate, usually in the form of beneficial bacteria. Pasteurization occurred between 55°C and 60°C. Anything more than that would kill good bacteria, Along with the acceptable pasteurization temperature, the operating time of 30 minutes was established.

2. Operating time for Cooling Process

The 25°C to 30°C was the appropriate temperature range for the cooling process. The cooling time was monitored against the temperature of substrate which enabled to determine the appropriate time of cooling.

Table 1 Temperature of Substrate and the Observed Cooling Time

Substrate Temperature (^{o}C)	Cooling Time (min)
52	0
48	5
46	10
44	15
43	20
41	25
40	30
38	35
37	40
35	45
33	50
32	55
32	60
30	65
30	70
29	75
27	80
26	85
25	90

To attain the temperature of substrate at 30 ^{o}C, it required 65 minutes cooling time. At a minimum acceptable temperature of 25 ^{o}C, 90 minutes was required. Thus, the cooling time was set to 90 minutes to allow the possible temperature increase of substrate after discharging.

3. Water Bath Temperature

The water bath temperature during the chemical pasteurization of 30 minutes was monitored and the variation is presented on Table 2.

Table 2 Pasteurization Time and Hot Water Bath Temperature

Pasteurization Time (minutes)	Hot Water Bath Temperature (°C)
5	57
10	59
15	58
20	60
25	60
30	60
35	61
40	62
45	64
50	64
55	65
60	67

It can be gleaned from Table 2 that at 30-min pasteurization time, the hot water bath temperature was recorded to be 60 ^{o}C. Thus, the hot water bath temperature was set to 60 ^{o}C.

4. Acceptable Proportion of Mass of Rice Straw to Volume of Water

In establishing the acceptable proportion of mass of rice straw to volume of water, the standard properties of substrate to be produced were considered. These include the pH level ranging from neutral to slightly basic, i.e., 7.0 to 8.0; the moisture content from 60 to 65% and substrate temperature from 25 to 30 ^{o}C. Various tests were conducted considering varying amounts of the mass of rice straw at constant volume of water.

Table 3 Result of Preliminary Test using Varying Amounts of Rice Straw at Constant Volume of water

Trial	Feed Mass of rice straw (in kilograms)	pH Level	Moisture Content (%)	Substrate Temperature (°C)
1	5	7.94	62.15	27
2	6	8.47	62.77	28
3	7	8.99	63.39	28

Table 3 shows the results of the chemical pasteurization process and cooling system using varying amounts of rice straw such as 5, 6 and 7 kg feed with a constant volume of water of 200 L. The data that were recorded in terms of their respective pH levels, moisture content and substrate temperature are presented in Table 3. It can be noted that the values of pH, moisture content and substrate temperature using the 5 kg feed conform to the standard ranges set for the substrate properties. Hence, the acceptable proportion of rice straw to volume of water was 5 kg of rice straw and 200 L of water.

Results of Final Performance Testing

After the establishment of the operating conditions of the fabricated machine, final performance testing was conducted to evaluate the following parameters, which include pasteurization rate, cooling rate, discharging rate, and over-all production rate.

Using the maximum capacity of the machine which is 15 kg of rice straw with a total volume of water of 600 L, 45 grams of carbendazium and 300 milliliters of formaldehyde were used to pasteurize, cool and discharge producing the desired mushroom substrate.

The following data were recorded to determine the final testing parameters.

Table 4 Results of Final Performance Testing of the Machine based on Established Parameters

Process	Mass of Mushroom Substrate Produced (kg)	Processing Time (min)	Processing Rate (kg/min)
Pasteurization	**15**	**30**	**0.500**
Cooling	**15**	**90**	**0.167**
Discharging	**15**	**30**	**0.500**

Table 4 depicts the results of the final performance testing enumerating the processes involved, processing time, and processing rate. The pasteurization rate of 0.5 kg/min, cooling rate of 0.167 kg/min and discharging rate of 0.5 kg/min were recorded during the final performance testing. Using the total processing time of 150 minutes, the over-all production rate was found to be 0.1 kg/min.

Properties of Processed Substrate

The properties of processed substrates were tested in terms of their pH level, moisture content and temperature. The standard ranges for the substrate were considered as follows: the pH level from 7.0 to 8.0; the moisture content, from 60 to 65%; and the substrate temperature, from 25 to 30°C. After the processed substrates were discharged, five (5) random samples were tested as presented in Table 5.

Table 5 Properties of Processed Substrate

Sample	pH level	Moisture Content (%)	Temperature (^{o}C)
1	**8**	**56.5**	**28**
2	**7.7**	**73.7**	**31**
3	**7.5**	**59.5**	**27**
4	**7.8**	**65.2**	**29**
5	**7.8**	**67.9**	**28**
Average	**7.76**	**64.56**	**28.6**

The obtained average values of the three (3) desired properties of the processed substrate conformed to the standard ranges as shown in Table 5. This means that the processed substrates using the developed machine can be used for mushroom production.

Results of Mushroom Cultivation using Processed Substrate

The processed substrate was then utilized in the actual mushroom cultivation at San Pedro Multi-purpose Cooperative. The fruiting bags of substrate were prepared and incubated at the designated site where the condition space was monitored in terms of temperature and humidity. These conditions are vital in the successful growth of the mushroom. Twelve (12) fruiting bags using oyster mushroom spawn were tested for this purpose.

The growth of oyster mushroom requires high humidity (80-90%) and high temperature (25-30 ^{o}C) for the vegetative growth called spawn running and lower temperature (18- 25 ^{o}C) for fruit body formation (Buah et al. 2010). The correct temperature enables them to grow well in the growing house.

Table 6 Space Temperature and Humidity Data

Day	Temperature (°C)			Humidity (%)		
	AM	**Noon**	**PM**	**AM**	**Noon**	**PM**
1	24	28	25	86	80	84
2	25	29	26	84	80	84
3	24	28	24	84	80	86
4	24	29	26	86	82	84
5	25	28	26	82	80	84
6	25	28	25	84	80	82

7	24	29	25	84	82	84
8	25	29	26	84	82	84
9	24	29	26	82	80	84
10	25	28	26	82	80	84
11	25	28	25	82	80	82
12	24	28	25	84	82	84
13	24	29	26	84	80	82
14	24	29	26	84	82	84
15	25	29	25	84	82	86
16	24	28	25	84	80	84
17	25	29	26	84	80	84
18	24	28	26	82	82	84
19	24	28	26	84	80	84
20	25	29	26	82	80	82
21	25	28	26	82	80	84
22	24	29	26	84	82	84
23	25	29	26	84	80	84
24	25	28	26	84	84	82
25	24	29	25	84	82	82

Table 6 shows the data obtained during the monitoring of the condition space during the first twenty five (25) days incubation at San Pedro, Batangas City. The required temperature and humidity were achieved yielding a temperature range from 25 to 30°C and a humidity of 80 to 90%. These conditions are therefore suitable for the cultivation process.

The pasteurized rice straw or the processed substrate was inoculated with mycelium
The mushroom started from thin, thread-like cells called mycelium. Fungus mycelium is the white, thread-like plant often seen on rotting wood or moldy bread. Mycelium was propagated vegetatively, known as spawn. The time needed for spawn to colonize the substrate depends on the spawning rate and its distribution, the substrate moisture and temperature, and the nature and quality of the substrate.

Table 7 shows the results of the spawn run monitoring in order to determine the inoculation process of the twelve (12) fruiting bags.

Table 7 Spawn Run Length Monitoring

Day	**Bag Number and Spawn Run Length (mm)**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
5	**30**	**32**	**40**	35	**25**	**30**	**25**	**20**	**25**	**30**	**30**	35
10	**60**	**60**	**75**	65	**60**	**55**	**65**	**50**	**60**	**70**	**55**	55
15	**85**	**90**	**100**	80	**105**	**85**	**95**	**95**	**75**	**95**	**80**	70
20	**125**	**110**	**120**	100	**115**	**105**	**110**	**115**	**125**	**115**	**120**	95
25	**150**	**135**	**145**	110	**135**	**150**	**135**	**140**	**145**	**140**	**145**	105

Table 7 shows the monitoring of spawn run of inoculation. The spawn run length as measured every five (5) days were recorded. After four (4) days, the first flashes were occurred in the fruiting bags. It can be noted that out of 12 fruiting bags, there were ten (10) bags that were started to bear pin heads on the 20th day. The mushroom grew in these fruiting bags (1, 2, 3, 5, 6, 7, 8, 9, 10, and 11) regardless of the full mycelium spawn run length of 180 mm.

Figure 3 shows the fruiting bags with flashes and pin heads.

Figure 3. Fruiting Bags with Flashes and Pinheads

Table 8 shows the respective masses of the first flashes of ten (10) fruitng bags. The total mass of the mushroom flashes harvested was 355 grams. Continuous flashing were observed on the following days.

Table 8 First Flash of Ten Fruiting Bags

Bag Number	Flashes (grams)
1	80
2	20
3	30
5	20
6	75
7	20
8	25
9	30
10	25
11	30
Total	355

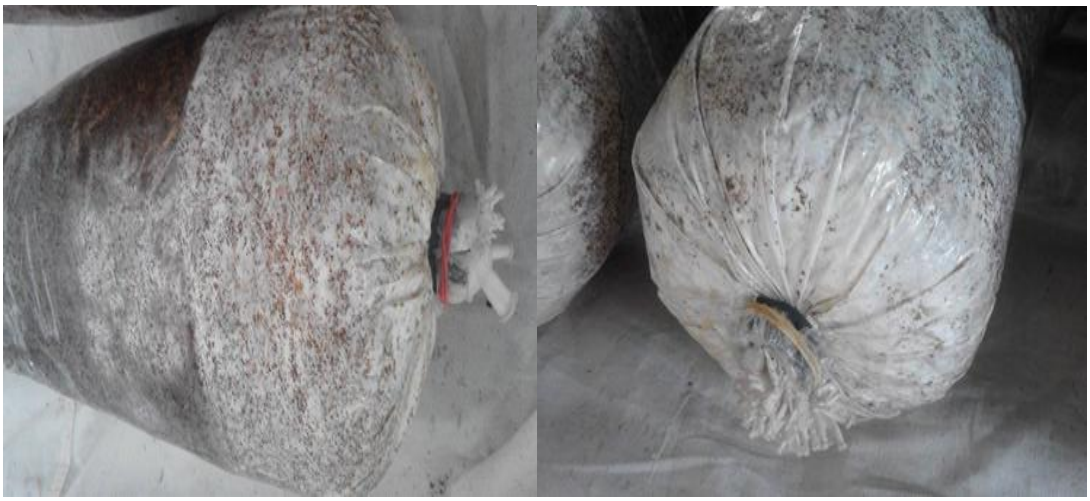

Figure 3. Mycelium Pin Heads

Figure 4. First Mushroom Flashes

Table 9 Mass of Mushroom Flashes for Each Harvest for a total of 25 days

Bag No.	Mass of Mushroom Flashes (grams)				
	1st Harvest	2nd Harvest	3rd Harvest	4th Harvest	5th Harvest
1	80	30	50	40	20
2	20	30	30	70	10
3	30	30	50	40	15
5	20	30	50	20	10
6	75	20	30	60	20
7	20	40	35	60	15
8	25	30	30	50	20
9	30	25	45	45	35
10	25	35	40	60	15
11	30	20	35	80	20
Total	355	290	395	525	180

Table 9 presents the data regarding the mass in grams of the flashes of mushroom that grew in each bag. For the first harvest, the bags produced a total of 355 grams of mushroom. For the second harvest, 290 grams of mushroom were collected. The third flashing had a total harvest of 395 grams of mushroom. For the fourth flashing, the bags produced a total harvest of 525 grams of mushroom. Lastly, for the fifth harvest, a total of 180 grams of mushroom were harvested. A total mass of 1745 g was produced for this testing. Figures 4, 5, 6, 7 and 8 show the flashings of the mushroom for five harvesting periods.

Figure 4. First Mushroom Flashing

Figure 5. Second Mushroom Flashing

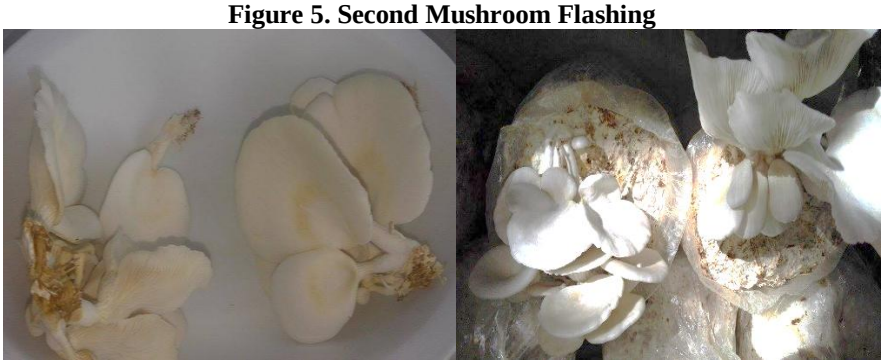

Figure 6. Third Mushroom Flashing

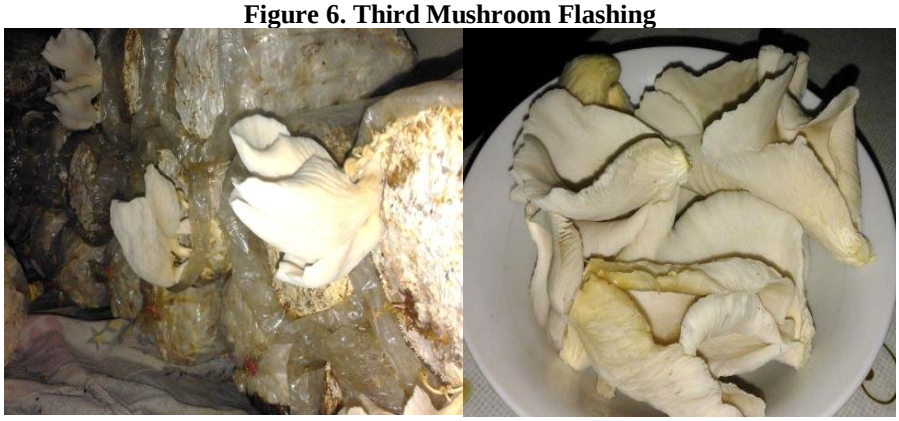

Figure 7. Fourth Mushroom Flashing

Figure 8. Fifth Mushroom Flashing

It was observed that the fully grown mushrooms were harvested from 20 to 25 days after incubation. Variation in the number of fully inoculated bags occurred in various trials. The fruiting bags that were not fully inoculated were contaminated.

Summary of Findings, Conclusions and Recommendations

The established operating time for the chemical pasteurization, cooling, and substrate discharging processes were 30 minutes, 90 minutes and 30 minutes, respectively. The maintaining temperature range for the chemical pasteurization process was 55°C - 60°C. The draining time after the cooling process was 30 minutes. The established acceptable proportion of rice straw to volume of water was 5 kg of rice straw and 200 L of water. This required 15 grams of carbendazium and 100 mL of formaldehyde to facilitate chemical pasteurization. The pasteurization rate of 0.5 kg/min, cooling rate of 0.167 kg/min and discharging rate of 0.5 kg/min were recorded during the final performance testing. Using the total processing time of 150 minutes, the over-all production rate was 0.1 kg/min. Fully grown mushrooms were harvested starting at 20^{th} day of incubation up to 25^{th} day. A total mass of mushroom flashes of 1745 grams was produced for five harvesting periods.

It can be concluded that rice straw can be a viable resource for mushroom substrate production using the fabricated machine. The availability and huge sources of rice straw make it sustainable for the purpose. The success of mushroom production depends on the space temperature and relative humidity that can be maintained in a particular location. The time needed for spawn to colonize the substrate depends on the spawning rate and its distribution, the substrate moisture and temperature, and the nature and quality of the substrate.

Other types of agri-waste materials can be tested using the developed machine to produce substrate and determine its effectiveness in mushroom cultivation. Likewise, other variety of mushroom can be tested using the rice straw substrate. Training of end-users of the fabricated machine can be done for them to gain knowledge and understanding on the operation and machine of the machine. An in-depth economic analysis can be done to determine the economic viability of the project. Continuous consultation to experts can be done to improve further the design of the machine. Further studies on mushroom cultivation can be pursued in the future.

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