Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

Special Issue 2022, Volume 35, Page 53-67

Engineering interventions and their effects on oyster mushroom cultivation- A systematic review

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ARTICLE INFO

Article history:
Received: 13 May, 2022
Revision: 24 August, 2022
Accepted: 03 September, 2022

Key words: Oyster Mushroom, productivity, internet of things (IoT), Sensor, Machine learning.

DOI: 10.56678/iahf-spl2022.8

ABSTRACT

Oyster mushrooms are rich in protein, minerals, and fibre with no cholesterol content. It also has medicinal properties. The consumption of oyster mushrooms is increasing, and their production is far below its demand. Oyster mushrooms' yield and nutrient content depend on the substrate, environmental conditions, quality of spawn, stage of mushroom at the time of harvest, etc. Different engineering methods are used in various operations during oyster mushrooms cultivation. This review paper aims to identify engineering systems or techniques used in oyster mushroom cultivation to improve the quality and yield of mushrooms and reduce drudgery, time, and human resource requirement. The available literature is extensively analysed to determine the different engineering inputs and their effects on oyster mushroom cultivation. Adopting the internet of things (IoT), automatic temperature and humidity control systems, machine learning, LED lights, etc., reduced the drudgery and human resources requirements. Also, the oyster mushroom's quality and yield are improved compared to the conventional cultivation practice. The present paper provides scope for developing new machines/equipment for a particular operation in oyster mushroom cultivation.

1. Introduction

Mushroom is a type of fungi and does not have chlorophyll (Soares et al. 2022). All the nutrients required for the growth of mushrooms are taken from nearby decomposed materials rich in organic matter. Mushroom is also known as "boneless vegetarian meat" because of its palatability, nutritive value, and peculiar taste (Panjikkaran and Mathew 2013). Cultivation of mushrooms has the solution to ever-growing food demand, unemployment, and environmental pollution (Nongthombam et al. 2021; Menon et al. 2021). It might be only the biological process which directly convert organic waste such as agricultural waste/lignocellulose, organic kitchen waste, forest waste, etc. into nutrient-rich products for human consumption. Even though more than 300 mushroom genera are available, only a few species are adapted for cultivation commercially. Oyster mushroom (*Pleurotus ostreatus*) is an *Agaricaceae* family having *Basidiomycetes* class (Nongthombam et al. 2021). The Oyster mushroom is second in cultivation after the button mushroom (Sánchez 2010; Shrestha et al. 2021).

Oyster mushroom is one of the best foods for the human body as it contains nutrients, particularly proteins, minerals, dietary fibre, and vitamins B, C, and D (Gregori et al. 2007; Panjikkaran and Mathew 2013). The nutritional value of mushrooms can be compared with meat, egg, and milk (Sánchez 2010). Oyster mushrooms can be used to reduce malnutrition problems (Akter et al. 2022). It has 56% carbohydrate, 30% protein, 10% ash, and 2% fat based on dry weight along with minerals such as potassium, phosphorus, calcium, copper & iron, (Nongthombam et al. 2021). The total energy obtained from the mushroom cap is between 250 and 350 cal/kg of fresh mushrooms (Sánchez 2010). This mushroom also has medical properties such as antioxidant, anti-tumour, antihypertensive, anti-nociceptive, and hypocholesterolemic/antiatherogenic properties and is also suitable for diabetic patients (Panjikkaran and Mathew 2013). It is an ideal diet for people suffering from heart disease and hypertension due to its high potassium to sodium ratio. It can be used in curing anaemia as it contains folic acid. The food prepared from mushrooms is well suited for

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different age groups as it has no cholesterol content (Nongthombam et al. 2021).

Because of its usefulness, the market demand for mushrooms increased in the world market (Panjikkaran and Mathew 2013). Cultivating oyster mushrooms can improve livelihood as they can be used as a reliable source of income (Menon et al. 2021). It can also manage agricultural waste by converting them into edible protein-rich products (Panjikkaran and Mathew 2013; Menon et al. 2021; Akter et al. 2022). Oyster mushrooms can be cultivated in various agro-climatic conditions (Nongthombam et al. 2021) as well as different substrates such as sawdust, composting materials, paddy straw, wheat straw, natural product from woodland and industries, organic kitchen waste, agro-industrial residue, etc. (Sánchez 2010; Phuong 2016; Popovych et al. 2019; Aguiar et al. 2021; Nongthombam et al. 2021; Akter et al. 2022). The cultivation of mushrooms requires simple technique and returns higher biological efficiencies (Oseni et al. 2012). Mushroom cultivation involves many unit operations which should be performed with much care (Sánchez 2010). The quality and productivity of the mushroom depend on these unit operations, substrate material, spawn quality, and the environmental conditions of mushroom cultivation (Gregori et al. 2007). The best cultivation technique should be adopted as per the available substrate and agroclimatic requirements. The use of machinery and technology reduced time, human resources, and cost-effectiveness. Oyster mushrooms' growth is most suitable at temperature and humidity of 20° to 30° C and 55 to 85%, respectively (Panjikkaran and Mathew 2013; Nongthombam et al. 2021). This environment condition can be maintained precisely by adopting machine learning techniques, microcontrollers and microprocessors, and other peripheral systems with reduced human resources involvement. The yield achieved from mushroom cultivation is diminished by the contamination of the spawn, and the contaminated spawn should be isolated from the others as early as possible. But, the segregation process is tedious and time-consuming work. This work can be executed with the machine learning technique. The growth of the mushroom fruits can be enhanced by using the electrocution technique and sound in addition to the supplement provided in the substrate. Different engineering systems are adopted or adapted in various operations during cultivations of oyster mushrooms. But there is always an option for developing a new engineering system that can be used in the mushroom cultivations to reduce drudgery, time, and cost. The present literature review explores the applications of engineering systems in cultivating oyster mushrooms.

2. Materials and Methods

A systematic review was done to understand the current status of the application of engineering systems in the cultivation of mushrooms and the future scope for engineering intervention in mushroom cultivation.

The materials were searched on the Scopus, Web of Science, and Pub Med database by using the combination of keywords "Oyster Mushroom" AND cultivation OR plantation OR Machines OR tools AND "Oyster Mushroom". The keywords were searched in title, keyword, and abstract. The documents available only in English are considered with no limit on year. Nine hundred twenty-two articles were listed in the database.

The inclusion and exclusion of an article in the present study were decided after reading the title and abstract by the reviewers. In some reports where confusion arose, full articles were studied for inclusion/exclusion. The information on the engineering system used in mushroom cultivations, different cultivation techniques of oyster mushrooms, and different treatment or substrate preparation methods are selected for the review. Due to the limited article available in our study, all the conference articles and peer reviewed articles are included. Out of Nine hundred twenty-two documents, two hundred forty-fives are duplicates, and six hundred eighteens are not related to the current study. Only Fifty-nine articles are associated with the present study. Among fifty-nine articles one cannot retrieve, two are book chapters, and one doesn't have information about the journal in which it is published. The remaining fifty-five articles are considered in the current study. A literature survey flow chart and inclusion/exclusion criterion is given in figure 1.

3. Literature Review

More than 70 oyster mushroom species exist, but only a few are cultivated commercially (Agun et al. 2021). Cultivation of oyster mushrooms is becoming popular because of its nutritional content, mediational value, and versatility for cultivation in a wide range of substrate and agro-climatic conditions (Saritha and Pandey 2010). Quality spawn, suitable substrate and their treatment process, and climatic conditions during the cultivation process are essential steps that must be appropriately maintained depending upon mushroom species to obtain quality and productive mushroom cultivation (Sánchez 2010; Soares et al. 2022). The different mycological terms for oyster mushrooms are shown in figure 2

The caps of oyster mushrooms are shell-shaped, semi-circular to elongate. The margins are smooth and sometimes wavy and whitish to greyish or tan; the texture is velvety, the flesh is thick and white, the gills are narrow, the stalk is short, wide, and white, with the broad base being hairy. The spores look narrowly elliptical, smooth, and colourless when

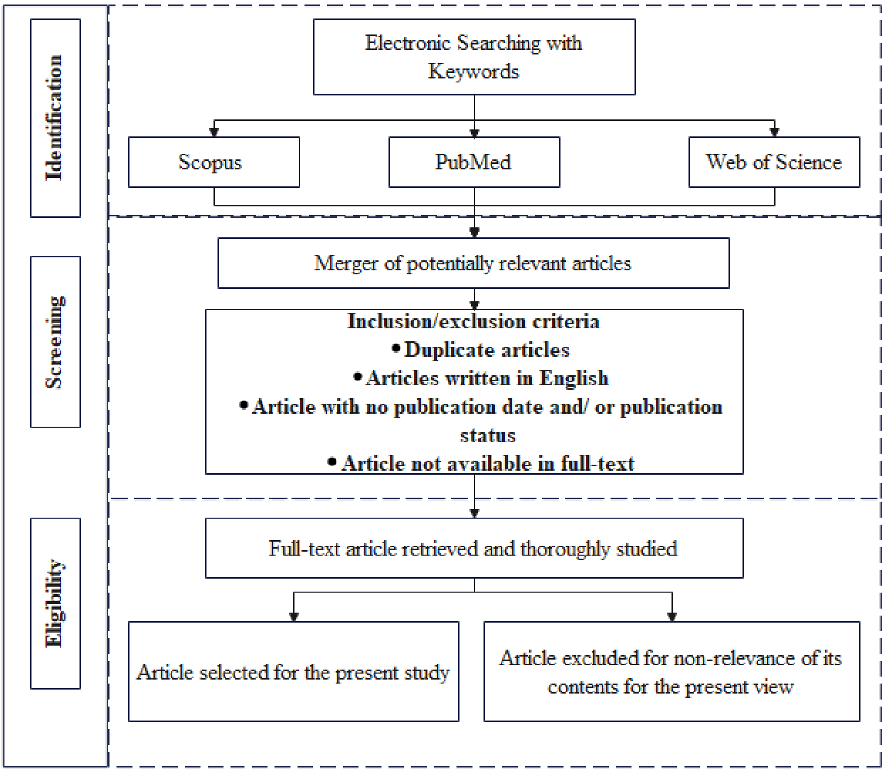

Fig 1. Flowchart for inclusion/exclusion criterion from literature survey

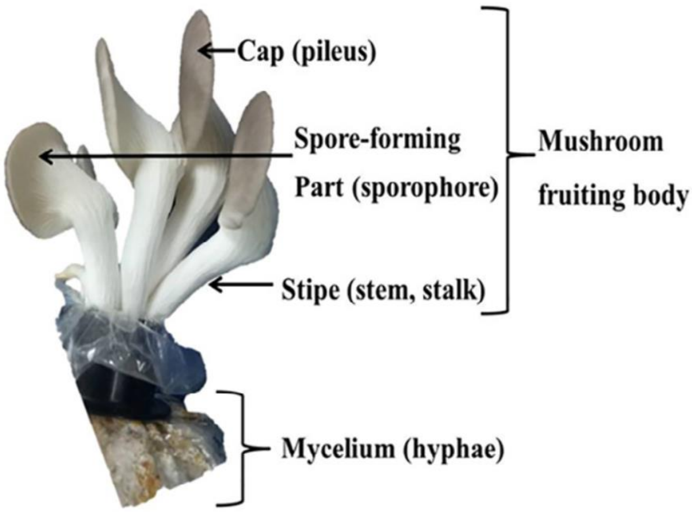

Fig 2. Mycological terms of oyster mushroom (Agun et al. 2021)

magnified. On average, the cap width ranges between 2-15 cm, stalk length is around 4 cm, and stalk width is approximately 2 cm (Menon et al. 2021).

3.1 Substrate

The substrate is the material on which mushrooms grow and provides necessary nutrients to the mushroom. Oyster mushrooms can be cultivated with materials containing carbohydrates (cellulose, hemicellulose, and lignin), protein, fat, minerals, and vitamins (Soares et al. 2022). So, it is cultivated on a wide range of materials, i.e., agro-waste from fields and industries, waste material from the forest, organic kitchen waste, etc. (Sánchez 2010; Phuong 2016; Popovych et al. 2019; Aguiar et al. 2021; Nongthombam et al. 2021; Akter et al. 2022). Mushroom cultivation can thus recycle agro-waste material (Panjikkaran and Mathew 2013; Menon et al. 2021; Akter et al. 2022). It may be the only biological method to convert agro-waste material into protein-rich food products (Sánchez 2010). The nutrient content of mushrooms is affected by the type of substrate used, and also yield achieved has a positive correlation with the carbohydrate and nitrogen ratio of the substrate (Gregori et al. 2007). Mycelial growth also depends on the nutrient content of the substrate (Menon et al. 2021). Selection of a particular substrate for oyster mushroom cultivation depends on available materials in the area, species of the mushroom, desired quality of the product, and ultimately, the profit or income in the cultivation. The following materials in table 1 are the substrate used in the literature collected.

The pie chart shown in figure 3 shows the different substrates used in the literature. Paddy/rice straw is the most commonly used substrate (24%), followed by Sawdust (16%). Paddy straw yields 10% higher oyster mushrooms than wheat straw (Zhang et al. 2002). Supplements are sometimes used to improve yield potential and increase mushrooms' protein and mineral contents (Gregori et al. 2007). Rice bran and calcium carbonate are the most commonly used supplement in cultivation.

Table 1. Substrate used for cultivation of oyster mushroom

Substrate	Authors
1. Agar	(Nakano et al. 2011)
2. Banana leaves	(Menon et al. 2021)
3. Brachiaria straw	(Iossi et al. 2018)
4. Brazil nut shell	(Aguiar et al. 2021)
5. Coconut coir	(Menon et al. 2021)
6. Corn Cob	(Akter et al. 2022)
7. Cotton stalks	(Balasubramanya and Kathe 1996)
8. Cotton waste	(Phuong 2016)
9. Horse manure	(Oseni et al. 2012)
10. Malt	(Nakano et al. 2011)
11. Paddy straw	(Shrestha et al. 2021), (Saritha and Pandey 2010), (Panjikkaran and Mathew 2013), (Menon et al. 2021), (Bisaria et al. 1989), (Balasubramanya and Kathe 1996), (Akter et al. 2022), (Cruz-del Amen and Flores Villaverde 2019), (Bandura et al. 2021)
12. Residues (seeds) of açaí	(Aguiar et al. 2021)
13. Rice husk	(Akter et al. 2022), (Cruz-del Amen and Flores Villaverde 2019)
14. Sawdust	(Roshita and Goh 2018), (Soares et al. 2022), (Akter et al. 2022), (Roshita et al. 2017), (Aguiar et al. 2021), (Ibrahim et al. 2017)
15. Sugarcane bagasse	(Oseni et al. 2012), (Akter et al. 2022)
16. Sunflower seed husk	(Soldatenko et al. 2019), (Bandura et al. 2021)
17. Tucumã palm trees	(Aguiar et al. 2021)
18. Wheat straw	(Balasubramanya and Kathe 1996), (Sharma et al. 2020), (Akter et al. 2022), (Bandura et al. 2021)
19. Wood log	(Popovych et al. 2019)

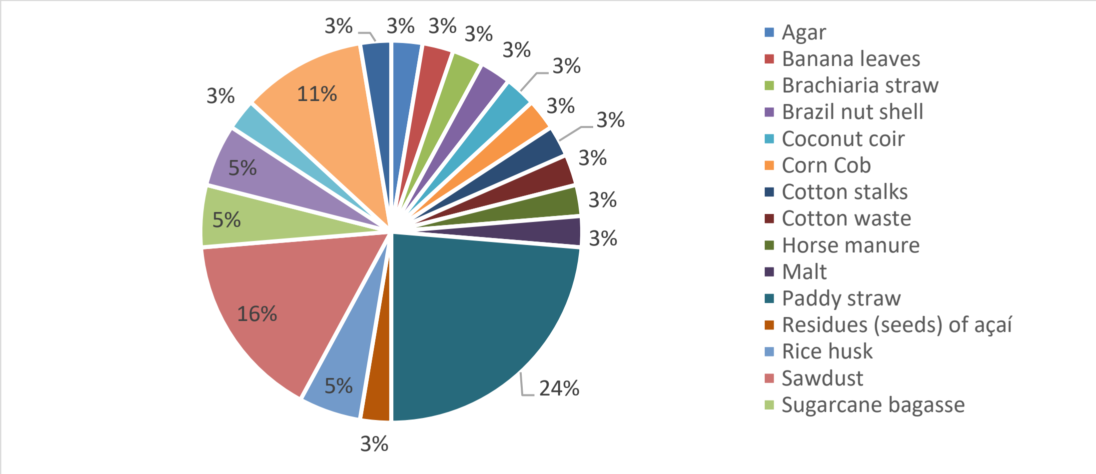

Fig 3. Pie chart for the substrate used in the cultivation of oyster mushroom

The number of days required for mycelium growth, first harvest day, total yield, and body parts size of mushroom fruit depends on the substrate. In contrast, type of seeds affect only the number of days required for mycelium growth (Soares et al. 2022).

3.2 Substrate preparation and planting

After the selection of substrate, next is substrate preparation. The substrate preparation methods consist of two-step, i.e., size reduction and pasteurization or sterilization. The size reduction of the substrate is made in all the substrates except in the case of sawdust which is in powder form. Different researchers in the literature used various length of size reductions in the range of 2 cm to 10 cm as per the type of substrate. The main reasons for size reduction may be the ease of handling the substrate and the reduced time required for mycelial growth due to the large surface area available for microorganisms (Bellettini et al. 2019). A higher yield was obtained on ground straw than on chopped straw with less crop cycle (Zhang et al. 2002; Gregori et al. 2007). But grinding of substrate needed a considerable amount of energy compared to chopping. Oyster mushrooms can also be cultivated on the typical water-treated substrate, but cellulolytic moulds in the substrate compete with mushrooms and destroy their growth and quality (Sharma et al. 2020). Substrate pasteurization or sterilization is one of the most critical steps in oyster cultivation as it destroys different pathogens which may damage or compete with the mushroom (Saritha and Pandey 2010; Iossi et al. 2018). It is also the most expensive operation in mushroom cultivation(Aguiar et al. 2021). There are different methods of treatment available. Chemical sterilization, steam, and hot water pasteurization are the most common forms. Hot water and chemical treatment may not eliminate harmful microorganisms, but it reduces them to the level suitable for mushroom cultivation (Aguiar et al. 2021).

The hot water or steam treatment is usually performed at a temperature above 60°C as common bacterial and fungal spores cannot survive at a temperature greater than 50 to 60°C (Saritha and Pandey 2010). This treatment is a combination of temperature and duration. Different authors adopt different combinations of this temperature and time as per their requirements. Tables 2 and 3 provide various combinations of temperature and duration for hot water and steam treatment.

Table 2. Temperature and duration combinations of hot water treatment

Temperature (°C)	Duration (min.)	Authors
60	180	(Oseni et al. 2012)
80	120	(Balasubramanya and Kathe 1996)
80	90	(Jaramillo Mejía and Albertó 2013)
80	120	(Gowda et al. 2014)
80 ± 2	60	(Saritha and Pandey 2010)
80 to 90	90	(Aguiar et al. 2021)
90	90	(Soares et al. 2022)
100	30	(Shrestha et al. 2021)
100	30	(Panjikkaran and Mathew 2013)
100	60	(Akter et al. 2022)

Table 3. Temperature and duration combination of steam treatment

Temperature (°C)	Duration (min.)	Authors
80 ± 2	120	(Saritha and Pandey 2010)
120	120	(Jaramillo Mejía and Albertó 2013)
121	240	(Oseni et al. 2012)
121	180	(Soldatenko et al. 2019)
121	60	(Shrestha et al. 2021)
121	60	(Aguiar et al. 2021)
121	30	(Roshita and Goh 2018)

The combination of temperature and duration for hot water treatment varies from 60°C to 100°C with a minimum of 30 min to 180 min. In contrast, most of the temperature for steam treatment is 121°C, with duration varies from 30 min to 240 min. The different combinations of temperature and duration may be due to various substrates, oyster mushroom species, and additional biotic factors in respective areas. Steam sterilization is widely used, but the cost involvement is considerably higher (Aguiar et al. 2021). Due to this factor, hot water treatment is still recommendable in rural areas. Chemical treatment is an effective treatment for sterilization of substrate for mushroom cultivation. Some of the chemicals used in the sterilizing substrate for mushroom cultivation available in the literature are given in table 4.

The duration required for the chemical treatment is considerably more than the duration for hot water and steam treatment, except for 1% calcium hydroxide (Iossi et al. 2018) and 0.3% chlorine bleach (Zhang et al. 2002). The yield obtained through chemical treatment depends on the chemical used and its concentration (Iossi et al. 2018). In some cases, chemical treatment is done after heat treatment i.e. chemical sterilization is performed by spreading heat-treated straw for 30 min on a hessian cloth previously soaked in 1% potassium permanganate solution (Panjikkaran and Mathew 2013). Adoption of a particular treatment in the mushroom process depends on the substrate used, the economic condition of the farmer, biotic factors in the area, etc.

The yield obtained by steam sterilization at 121°C is higher than hot water and chemical treatment but statistically at par with hot water treatment (Shrestha et al. 2021). The lowest yield was obtained in chemical treatment as the residue effect of chemical inhibit the growth of mushroom (Shrestha et al. 2021). But these findings contradict the finding (Jaramillo Mejía and Albertó 2013), where chemical treatment has a higher yield, and hot water treatment produces the lowest yield. Chemical treatment should be discouraged as it has a negative environmental impact (Jaramillo Mejía and Albertó 2013). Instead of steam sterilization, substrate pasteurization with hot water is sufficient for oyster mushroom cultivation (Sánchez 2010).

In India, the commonly used treatment method is hot water pasteurization. Still, due to considerable labour and energy requirements, chemical sterilization is sometimes adopted, which is not recommendable due to its health hazard to the worker, environmental pollution, etc. (Saritha and Pandey 2010).

Apart from these treatments, some researchers try to find other treatment methods. The anaerobic treatment process for cultivating oyster mushrooms on cotton stalks, rice straw, and wheat straw was studied and compared it with the traditional hot water treatment (Balasubramanya and Kathe 1996). The yield obtained with anaerobic therapy for seven days was the same as that obtained with conventional hot water treatment at 80°C for two hours. However, the product obtained from anaerobic treatment decreased

Table 4. Chemical used in the treatment of substrate for oyster mushroom cultivation

Chemical	Duration	Authors
Water solution having 1.25 ml of formalin and 0.15 g Carbendazim per 1 L of water	18 h	(Shrestha et al. 2021)
A solution of Carbendazim (0.5%)	-	(Jaramillo Mejía and Albertó 2013)
Water solution having 75 ppm Bavistin and 500 ppm formaldehyde	18 h	(Saritha and Pandey 2010)
Water solution having 2% calcium hydroxide	24 h	(Aguiar et al. 2021)
Enzyme *Ctec2* at the rate of 0.45% concerning substrate	60 h	(Phuong 2016)
A water solution containing 1% of calcium hydroxide	20 min	(Iossi et al. 2018)
Water containing thiophanate-methyl 50 ppm and formalin 500 ppm	12 h	(Sharma et al. 2020)
A water solution containing 0.3% chlorine bleach	10 min	(Zhang et al. 2002)

when the number of days in anaerobic treatment was more than 14 days. Anaerobic treatment is an economical way of cultivating mushrooms where there is no need for additional labour and equipment. Cold plasma technology was used to treat substrate for oyster mushroom cultivation (Agun et al. 2021). Sterilization by cold plasma for 25 min reduced the bacterial colonies, and the substrate treated with cold plasma technology formed pinhead and harvested ahead of traditional methods of substrate sterilization.

Inoculation or spawning is mixing spawn (mushroom seed) with the sterilized substrate. It is carried out in three different processes. In the first process, the desired spawn rate is mixed with treated substrate and filled the mixture into a suitable container (Sánchez 2010; Aguiar et al. 2021; Bandura et al. 2021). The treated substrate is first loaded in the container in different layers in the second process. In between consecutive layers, spawns are spread in the periphery to facilitate fruiting (Panjikkaran and Mathew 2013; Shrestha et al. 2021; Menon et al. 2021; Akter et al. 2022). In the third process, the sterilized substrate is filled in the container, and the desired quantity of spawns is injected (Soares et al. 2022). The container used is usually a plastic bag of different sizes suitable to the condition. Depending upon the container, there are various methods of mushroom cultivation like shelf, bag, bottle, tray, jar, grid-frame, wall-frame, and others. In practice, the most used are bag, bottle, and shelf cultivation, but bag cultivation is the most effective and has the highest biological efficiency (Gregori et al. 2007). The freshly prepared grain spawn, i.e., 20-30 days old, is best for spawning. The mixing of spawns should be done @ 2/3% of the weight of the substrate (Nongthombam et al. 2021), whereas increasing spawn rates from 1.25% to 5% (wet weight of the substrate) might result in increases of nearly 50% yield (Sánchez 2010). But it should not increase beyond 10% weight of substrate as there is no economic benefit beyond this point (Bellettini et al. 2019).

The polybags or containers filled with the substrate and spawn are kept in the incubation chamber. Holes or openings are usually provided on the poly bags or container to get proper aerations to the spawn. The exchange of O_2 and CO_2 is achieved through these holes or openings (Menon et al. 2021). The size and numbers of holes vary depending upon the size of the bag, mushroom species and substrate used, etc. In an experiment, 20 to 40 holes of approximately 0.3 cm diameter were provided (Panjikkaran and Mathew 2013), whereas in another experiment, 8 to 10 holes of 0.8 cm diameter were provided (Shrestha et al. 2021). Another method of providing aeration is the use of heat-resistant plastic neck while packing the plastic bag (Akter et al. 2022). This plastic neck is filled with cotton and used as means of aeration. The equipment used for making holes should be appropriately sterilized to prevent contamination (Menon et al. 2021).

When the mycelium growth is completed, and the pinhead is started, the bags are transferred to the cultivation chamber by providing cuts/ slits on the polybags for fructification (Oseni et al. 2012; Menon et al. 2021; Soares et al. 2022; Akter et al. 2022). The environmental factors such as temperature, humidity, aeration, and light required during incubation and cultivations vary depending upon the oyster mushroom species (Sánchez 2010; Nongthombam et al. 2021). But most oyster mushroom species grow well in a temperature range of 22 to 28°C and humidity of 70 to 90 per cent (Ariffin et al. 2020). Mostly incubation and cultivation are performed in the same room by varying environmental parameters required by the mushroom species (Bandura et al. 2021). The incubation and cultivation room should be adequately disinfected to prevent contamination during the cultivation (Shrestha et al. 2021).

Oyster mushrooms are harvested when the fruiting body is fully developed. The development stage of the fruiting body can be determined by observing the cap of the fruiting body. A mushroom is considered fully developed when the cap reaches optimal size but is not broken (Soares et al. 2022).

3.3 Pasteurizing system

Pasteurizing the substrate is an essential process in the cultivation of oyster mushrooms. It removes or deactivates all the harmful competitive microorganisms with the oyster mushroom. Even though hot water pasteurization is the most recommended one, conventional methods of hot water pasteurization lead to the contamination of the substrate, are time-consuming, are low efficiency, and are challenging to handle the hot substrate from the heating container. A pasteurizing system with 25 kg dry straw capacity with the compression and tilting mechanism provisions was designed and developed (Gowda N. A. and Kumaran 2014). The developed system has a controller for temperature and time combination by using contact relay TC544, electromagnetic contactor MNX-50, and temperature sensor PT100. This pasteurizing system required less water and time for pasteurizing the oyster mushroom substrate than conventional methods. The developed system performed best at the maximum compression with a temperature and time combination of 80°C and two hours (Gowda et al. 2014).

3.4 Quality assessment system

All the mushroom consumers, prefers good quality and fresh mushrooms for their consumption. The quality of the mushroom product depends on many factors, and the quality of spawn used in the cultivation is one factor. Spawn is very susceptible to contamination by various pathogenic moulds and pests. Pathogen-contaminated spawn inhibits mycelium growth and is contagious, leading to crop loss (Tongcham et al. 2020). This contaminated spawn must be separated and discarded. Usually, in the mushroom farm, segregation of contaminated spawn is carried out by manual labour, which is time-consuming, labour-intensive, and likely to make mistakes when engaged continuously for a more extended period. Microbial methods of detecting contaminated spawn inside the polybag are also unsuitable at the mushroom farm level. The machine-learning technique with a deep neural network algorithm was used to classify the contaminated spawn inside the polybag with 98.7% accuracy and 99.1% precision (Tongcham et al. 2020). Mushroom spoilage is another phenomenon that deteriorates mushroom quality in the market. Mushroom spoilage is due to water loss which leads to shrinkage, microbial infestation, aerial oxidation, and enzymatic browning. The stage and position of growth also affect the oyster mushroom's texture, shape, and size (Mukherjee et al. 2022). So, experience and trained human resources are required for decision making and inspection mushroom. Manual judgment of mushroom quality is labour-intensive, time-consuming, and inconsistent, leading to error (Mukherjee et al. 2022). To relieve this situation, machine vision for the quality assessment of oyster mushrooms was used (Mukherjee et al. 2022). In their experiment, two learning model support vector machines (SVM) and artificial neural network (ANN) were used with the accuracy of (93.4 ± 2.6%) and (94.7 ± 0.98%) respectively. The detection of mushroom disease can be performed using Convolutional Neural Network (CNN) with an accuracy of 99% (Surige et al. 2021).

3.5 Yield improvement system

Demand for oyster mushrooms increases because of their high nutrition and medicinal value (Roshita et al. 2017; Bandura et al. 2021). The production of oyster mushrooms cannot meet its demand (Roshita and Goh 2018; Fauzi et al. 2020). One of the reasons for the low production of oyster mushrooms is the lack of research on improving production yield (Roshita and Goh 2018). Commercially oyster mushrooms are usually cultivated in the mushroom house. Oyster mushroom requires light during the fruiting stage. The necessary amount of light may not be sufficient or suitable during this stage due to the existing cultivation structure and climatic conditions. This fluctuation in the light amount hampered its yield (Roshita and Goh 2018). There is no benefit of light during mycelial growth; instead, blue light inhibits the growth of mycelia (Nakano et al. 2011; Bandura et al. 2021). Light plays an essential role in developing fruiting bodies, such as elongation of stipes and cap formation (Nakano et al. 2011; Roshita and Goh 2018; Bandura et al. 2021). Fertilizers and pesticides can also be used to improve the productivity of mushrooms. Still, from a bioethics point of view, the use of artificial light is safer in enhancing the productivity of the mushroom (Roshita and Goh 2018). Some researcher experimented by exposing the mycelial-filled bag to different LED (blue, green, and red) lights (Roshita and Goh 2018). All the light-treated bags completed pinhead emergence and fruiting body formation in less time than untreated. The blue light was the best (Nakano et al. 2011; Roshita and Goh 2018). The positive performance of mushrooms in blue light is due to blue-light photoreceptors. The yield is also more in the case of the blue LED light. The LED-treated products have higher moisture content than the other light treatment (Roshita and Goh 2018). The growth of mushrooms is also affected by the sound, and electrical treatment as thunderstorms and lightning strikes promote mushroom growth (Roshita et al. 2017). The mushroom yield can be increased by providing an electrical treatment of 9V for 10 seconds every five days during the mycelial growth stage (spawn running) (Roshita et al. 2017). The different acoustic sounds (hardcore music, soothing instrumental, Quranic recital, and thunderstorm) applied at 75 dB at the interval of 10 days after inoculation had a positive effect on the yield of oyster mushroom (Ibrahim et al. 2017). They found that thunderstorms are best suited for mycelial growth, whereas hardcore music enhances yield. A study to produce mushroom clusters suitable for packaging is conducted as the demand for packaged quality mushrooms is increased (Bandura et al. 2021). They observed the effect of substrate bag position (horizontal, vertical, and slant) and perforation hole size on the size of the mushroom cluster. The biological efficiency in the horizontal is less than in vertical and slant positions, but the maximum cluster size is found in the horizontal orientation. There exists a positive correlation between the perforation size and cluster size. The mushroom cluster produced from 50 mm perforation is best suited for commercial packaging and storage in their region. The yield from the mushroom can also be predicted by using the machine learning technique. developed A yield prediction for oyster mushroom cultivation was developed by using Long short-term memory (LSTMs) and predict the yield of oyster mushrooms with 95% accuracy (Surige et al. 2021).

3.6 Temperature and humidity control system

The world is now facing a severe issue of climate change which threatens agricultural cultivation and, ultimately, food security (Ariffin et al. 2020). Improving crop yield can also help to overcome food security. Like other crops, the oyster mushroom also requires a good range of environmental parameters like temperature, humidity, and air composition to produce a higher yield at different stage of its production cycle (Hendrawan et al. 2019; Najmurrokhman et al. 2019). The requirement of these environment parameters at the various stages of oyster mushrooms also varies depending upon their species. But in general, oyster mushrooms are cultivated well in cold and humid climates (Cruz-del Amen and Flores Villaverde 2019; Setiawati et al. 2021). Maintaining favourable environmental parameters for oyster mushroom cultivation is difficult with the weather change during the daytime (Akbar et al. 2020; Surige et al. 2021). In the conventional practice of oyster mushroom cultivation, these required favourable environment parameter is managed by manual watering in the morning and evening, which is a tedious, time-consuming, and requires a considerable amount of workforce (Adhitya et al. 2016; Fuady et al. 2017; Gajbhiye et al. 2018; Ariffin et al. 2020; Agustianto et al. 2021). Manual controlling of these environmental parameters is inaccurate (Hadi et al. 2021). Hence, it affects the yield and quality of the mushroom (Mohd Ariffin et al. 2021). With the advancement of technology, many researchers use different technologies such as the internet of things (IoT), microcontroller, microprocessor, sensors, machine learning, fuzzy logic, etc., to maintain the temperature and humidity inside the mushroom cultivation chamber favourable for the cultivation of mushroom. Table 5 shows different controllers, logic, and sensor used in the oyster mushroom cultivation house's automatic temperature and humidity control system. Arduino accounts for 78% of the controller used in developing automatic temperature and humidity control system of the oyster mushroom cultivation chamber. The main reason for the wide use of Arduino is its versatility to interface varieties of the peripheral device, open-source, low cost with sufficient memory and performance for the work. Figure 4 shows the share of Arduino in the controller used in the automatic temperature and humidity control system of the oyster mushroom cultivation chamber as per literature.

Table 5. Different controllers, logic, and sensors used in automatic temperature and humidity controls system in cultivating oyster mushrooms.

Controller	Logic	Sensor	Authors
Arduino	Data transfer and display	DHT22, BH1730 Sensor	(Mohammed et al. 2018)
Arduino	Feed-forward neural network	DHT11	(Adhitya et al. 2016)
Arduino	Feed-forward neural network	DHT11	(Gajbhiye et al. 2018)
Arduino	Fixed threshold	DHT11	(Setiawati et al. 2021)
Arduino	Fixed threshold	DHT11	(Najmurrokhman et al. 2020)
Arduino	Fixed threshold	DHT22	(Ariffin et al. 2020)
Arduino	Fixed threshold	HSM	(Sihombing et al. 2018)
Arduino	Fixed threshold	DHT11	(Akbar et al. 2020)
Arduino	Fuzzy	-	(Agustianto et al. 2021)
Arduino	Fuzzy	DHT11	(Najmurrokhman et al. 2019)
Arduino	Fuzzy	DHT11	(Sulistyanto et al. 2018)
Arduino	Fuzzy	DHT11, LDR	(Hadi et al. 2021)
Arduino	Fuzzy	DHT22	(Mohd Ariffin et al. 2021)
Arduino	Fuzzy	DHT22	(Cruz-del Amen and Flores Villaverde 2019)
Arduino	Fuzzy	SHT11	(Hendrawan et al. 2019)
Arduino	Fuzzy	SHT11	(Cikarge and Arifin 2018)
Arduino	Neuro-fuzzy	SHT11	(Anta et al. 2021)
Arduino and Lattepanda	Fixed Threshold	SHT11	(Nasution et al. 2019)
DOIT ESP32 DevKit V1	Fixed Threshold	DHT22	(Fauzi et al. 2020)
Intel Galileo	Extreme learning machine	DHT11	(Fuady et al. 2017)
Microcontroller 8051	Fixed Threshold	SHT75	(Goh et al. 2021)
PLC	Fuzzy	DHT22	(Thong-un and Wongsaroj 2022)

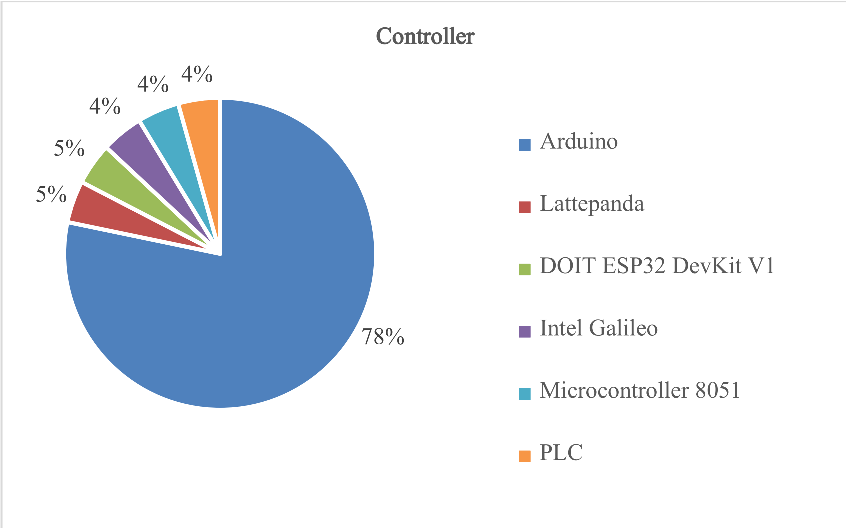

Fig 4. Controller used in developing automatic temperature and humidity control system of oyster mushroom cultivation chamber

Figures 5 and 6 shows the share of logic and sensor used to develop the oyster mushroom cultivation chamber's automatic temperature and humidity control system.

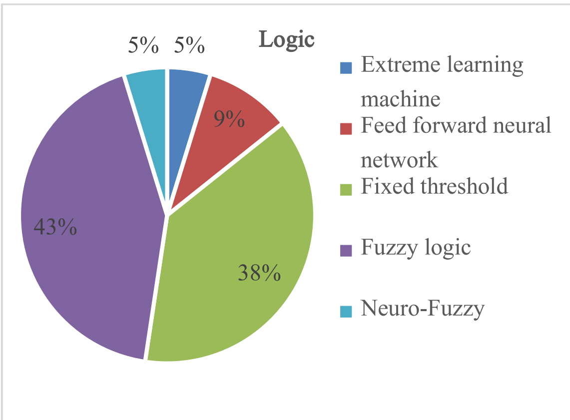

Fig 5: Logics used in the development of automatic temperature and humidity control system of oyster mushroom cultivation chamber

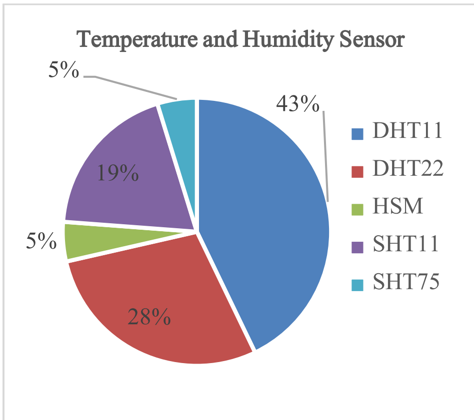

Fig 6: Temperature and humidity sensors used in the development of automatic temperature and humidity control system of oyster mushroom cultivation chamber

From figure 5, it is known that fuzzy logic (43%) and fixed threshold method (38%) are widely used methods in developing temperature and humidity control systems for oyster mushroom cultivation. The main reason for adopting fuzzy logic is its ability to deliver a precise solution from approximate or specific information (Cruz-del Amen and Flores Villaverde 2019). In contrast, the fixed threshold is used because of its simple nature. DHT11 and DHT22 account for 43% and 28% of the temperature and humidity sensor used to develop a temperature and humidity control system for oyster mushroom cultivation, as shown in figure 6. The main reasons for adopting DHT11 and DHT22 are their ease of interfacing with Arduino and reliable performance with sufficient accuracy and precision.

Some researchers experimented with comparing the performance of fuzzy logic, fixed threshold, and conventional cultivation methods by using manual watering (Hendrawan et al. 2019). They found that the quality of oyster mushrooms and yield achieved from fuzzy logic is superior, followed by the fixed threshold method. The lowest quality and yield of oyster mushroom are achieved from the conventional control system. This finding agrees with Cruz-del Amen and Flores Villaverde 2019 and Thong-un and Wongsaroj 2022. Feed-Forward Neural Network is more effective than fuzzy logic as it requires less average response time for conditioning (Adhitya et al. 2016). A comparison between fuzzy logic with neuro-fuzzy in humidity control was conducted and found that neuro-fuzzy took lesser time to reach steady-state conditions (Anta et al. 2021). Long short-term memory (LSTMs) was used to monitor environmental parameters and provide instruction to the environment parameter control equipment in the mushroom cultivation to the desired level with an accuracy of 89% (Surige et al. 2021) .

Implementation of IoT provides the benefit of monitoring and controlling environment parameters from a remote place and does not need the manager/farmer to be at the cultivation site physically. This feature benefits urban farming, which helps reduce food shortages (Mohammed et al. 2018; Ariffin et al. 2020). Oyster mushroom cultivation is among the top choice in urban cultivation as it requires less space due to vertical cultivation and short plantation cycle (Mohd Ariffin et al. 2021). The available literature frequently used ESP8266 module and ThingSpeak as WiFi modules and IoT platforms. Using ESP8266 module may be due to its low cost, compatibility with Arduino, and the ThingSpeak platform's ability to aggregate, analyze, and graphical display. The ThingSpeak platform also provides free service up to narrow channel, message, and computation sufficient for the work.

3.7 Substrate filling and compression system

The filling of the substrate into the bag or container is performed by human labour. A considerable amount of energy and time is required in the substrate filling process (Rizaldi et al. 2019). A filler and compactor is designed for the powder substrate of oyster mushroom cultivation (Rizaldi et al. 2019). Screw conveyor filled the mushroom substrate from the hopper into the mushroom bag with the help of a retaining pipe. The designed system is simulated in SolidWorks.

4. Discussion

The demand for oyster mushrooms increases because of their nutritional and medicinal value. Oyster mushrooms can be cultivated on readily available various agro-residue without any costly equipment. The nutrient content of the oyster mushroom depends on the composition, i.e., the carbon and nitrogen ratio of the substrate. Substrate type also affects the duration of the incubation period. Paddy straw is widely used as the substrate for growing oyster mushrooms among the agro-residue. The substrate is chopped except for the powder substrate and sterilized or pasteurized to kill or deactivate microorganisms present. Steam, hot water, and chemical treatment are most commonly used. For small-scale production, hot water treatment is sufficient for oyster mushroom cultivation even though it produces less yield than steam treatment due to the requirement of a considerable amount of investment. The yield and quality of oyster mushrooms are depending on various factors such as environmental parameters, substrate composition, spawn quality etc. Further, contaminated bags must be isolated immediately from the others to avoid contagious in the mushroom house. However, the identification of contaminated spawn can be done by skilled person in the early stage. The process of isolating contaminated spawn is tedious, time-consuming, and there is likely to have a more chance of human error in identifying contaminated spawn in the long run. Machine learning techniques with deep neural networks can be used to identify contaminated spawn inside the mushroom cultivation house. Oyster mushroom is perishable, and also the mushroom texture and shape size vary depending upon the stage at which it is harvested. Judgment of the right stage for mushroom harvesting and segregating deteriorated mushrooms required trained human resources. This human resource requirement can be reduced and provide greater work efficiency by adopting machine vision. Machine vision along with deep learning technique can also be used to detected the deteriorated mushroom in the market. Various species of oyster mushrooms are cultivated in different agro-ecological regions having different environmental parameters. Like other crops, oyster mushrooms require a specific range of environmental parameters at different stages of their cultivations. Maintaining these ecological parameters manually inside the mushroom house is inaccurate and requires a considerable workforce. With the advancement of technologies, automatic temperature and humidity control systems with IoT are widely implemented to control environmental parameters. IoT provides an opportunity for remotely monitoring and controlling the environmental parameters inside the mushroom house as and when required. Arduino is the most implemented control system for this work because of its versatility in working with various sensors, low cost, and open source. DHT11 and DHT22 have been commonly used temperature and humidity sensors. The ESP8266 module and ThingSpeak are widely utilized as WiFi modules and IoT platforms in environmental parameters control systems.

The yield of the mushroom cultivation can be increased by applying supplements to the substrate, but engineering interventions like LED light, sound, and electrocution can also improve the yield. Blue LED light during the fruiting stage accelerates the maturity of the fruit and also increases the yield. Applying electrical treatment of 9V during the incubation period and sound treatment after inoculation can also improve the yield. Prediction of the yield of a crop provides information to the farmer ahead of harvesting to perform necessary treatments and arrangements. Oyster mushroom yield can also be predicted using Long short-term memory (LSTMs). Adopting engineering technologies can reduce human resource requirements, execute the work smoothly and precisely and improve the quality and yield of oyster mushrooms. But there is only one article related to the substrate filling for powder substrate. There is no technology, machine, or tools available to fill and compact paddy straw substrate. This substrate filling requires a considerable workforce and time. So, there is a need to develop substrate (paddy straw) filling and compacting machines for oyster mushroom cultivation.

5. Conclusion

Some remarkable progress has been achieved in applying engineering knowledge in oyster mushroom cultivation in the last decades. However, the engineering systems or techniques used in oyster mushroom cultivation are still not up to the mark (Rizaldi et al. 2019). Only one article is available for substrate filling and compression for oyster mushroom cultivation. The substrate filler and compactor mentioned in the article is for powder substrate. As per available literature, there is no system for substrate filling and compression for substrates like paddy and wheat straw, the primary material used as substrates in oyster mushroom cultivation in rural areas in India. In India's northeastern state, the oyster mushroom is cultivated using paddy straw as a substrate. During the cultivation, straws were chopped, sterilized, inoculation the substrate with spawn, filled in a polybag, and placed in the mushroom cultivation room. Usually, inoculation of the substrate with spawn and filling in polybag is carried out in two different processes: mixing spawn and substrate before filling into the bag or filling substrate layer by layer in the bag and proving spawn in between. In both cases, one must manually put the sterilized straw or mixture of straw and spawn into the polybag and compress it to a certain degree as required during the oyster mushroom cultivation. This operation is performed manually. Manual compression of straw into the polybag is time-consuming, labour-intensive, and tedious. If the degree of compression of substrate and spawn is less than the desired amount, the substrate or bed's shape may disintegrate or damage during harvesting, leading to a low number of flush. Also, if the degree of compression is more, there may be chances that the mushrooms may not grow well due to the inability to germinate. Both cases lead to a lower yield. So, there is a need to develop a paddy straw substrate compressor or filler for oyster mushroom farmers, which will provide an optimum compression and shape as far as yield is concerned and reduce drudgery and time requirements.

6. Reference

Adhitya RY, Ramadhan MA, Kautsar S, Rinanto N, Sarena ST, Munadhif I, Syai'in M, Soelistijono RT, Soeprijanto A (2016) Comparison methods of fuzzy logic control and feed forward neural network in automatic operating temperature and humidity control system (oyster mushroom farm house) using microcontroller. International Symposium on Electronics and Smart Devices (ISESD), Bandung, Indonesia, IEEE, Bandung, Indonesia, pp 168–173, doi: 10.1109/ISESD.2016.7886713

Aguiar LVB de, Sales-Campos C, Gouvêa PR dos S, Vianez BF, Dias ES, Chevreuil LR (2021) Substrate disinfection methods on the production and nutritional composition of a wild oyster mushroom from the Amazon. *Ciência e Agrotecnologia* 45(1): 1–9, doi: 10.1590/1413-7054202145010321

Agun L, Ahmad N, Redzuan N, Idirs NAS, Taib SM, Zakaria Z, Raja Ibrahim RK (2021) Sterilization of oyster mushroom crop residue substrate by using cold plasma technology. *Materials Today: Proceedings* 39: 903–906, doi: 10.1016/j.matpr.2020.03.584

Agustianto K, Wardana R, Destarianto P, Mulyadi E, Wiryawan IG (2021) Development of automatic temperature and humidity control system in kumbung (oyster mushroom) using fuzzy logic controller. 012090. The 3rd International Conference On Food and Agriculture, IOP Publishing, , doi: 10.1088/1755-1315/672/1/012090

Akbar T, Gunawan I, Utama S (2020) Prototype system of temperature and humidity automatic in oyster mushroom cultivation using Arduino Uno. 012036. The 5th Hamzanwadi International Conference of Technology and Education 2019, IOP Publishing, , doi: 10.1088/1742-6596/1539/1/012036

Akter M, Halawani RF, Aloufi FA, Taleb MdA, Akter S, Mahmood S (2022) Utilization of agro-industrial wastes for the production of quality oyster mushrooms. *Sustainability* 14(2): 1–10, doi: 10.3390/su14020994

Anta DK, Sandra, Hendrawan Y (2021) Neuro-fuzzy humidity control for white oyster mushroom in a closed plant production system. 012066. The 8th International Conference on Sustainable Agriculture and Environment, IOP Publishing, , doi: 10.1088/1755-1315/905/1/012066

Ariffin MAM, Ramli MI, Amin MNM, Ismail M, Zainol Z, Ahmad ND, Jamil N (2020) Automatic climate control for mushroom cultivation using IoT approach. 10th International Conference on System Engineering and Technology (ICSET), Shah Alam, Malaysia, IEEE, Shah Alam, Malaysia, pp 123–128, doi: 10.1109/ICSET51301.2020.9265383

Balasubramanya RH, Kathe AA (1996) An inexpensive pretreatment of cellulosic materials for growing edible oyster mushrooms. *Bioresource Technology* 57(3): 303–305, doi: 10.1016/S0960-8524(96)00086-7

Bandura I, Isikhuemhen OS, Kulik A, Serduk M, Sucharenko O, Jukova V, Koliadenko V, Gaprindashvili N (2021) Effect of perforation size and substrate bag fruiting position on the morphology of fruiting bodies and clusters in Pleurotus ostreatus (Jacq.) P. Kumm. *Journal of Applied Biology & Biotechnology* 9(3): 35–40, doi: 10.7324/JABB.2021.9305

Bellettini MB, Fiorda FA, Maieves HA, Teixeira GL, Ávila S, Hornung PS, Júnior AM, Ribani RH (2019) Factors affecting mushroom Pleurotus spp. *Saudi Journal of Biological Sciences* 26(4): 633–646, doi: 10.1016/j.sjbs.2016.12.005

Bisaria R, Madan M, Vasudevan P, Bisaria VS (1989) Effect of variation in size of containers on yield of Pleurotus sajor-caju. *Biological Wastes* 30(2): 149–152, doi: 10.1016/0269-7483(89)90068-2

Cikarge GP, Arifin F (2018) Oyster mushrooms humidity control based on fuzzy logic by using Arduino ATMega238 microcontroller. Journal of Physics: Conference Series, 012002. IOP Publishing, , doi: 10.1088/1742-6596/1140/1/012002

Cruz-del Amen J dela, Flores Villaverde J (2019) Fuzzy logic-based controlled environment for the production of oyster mushroom. 11th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), Laoag, Philippines, IEEE, Laoag, Philippines, pp 1–5, doi: 10.1109/HNICEM48295.2019.9072902

Fauzi RM, Waranti FS, Rais IK, Somantri Y (2020) Oyster mushroom cultivation solution based IoT for nova farmers. 012044. International Symposium on Materials and Electrical Engineering 2019, IOP Publishing, , doi: 10.1088/1757-899X/850/1/012044

Fuady GM, Turoobi AH, Majdi MN, Syaiin M, Adhitya RY, Rachman I, Rachman F, Negara MAP, Soeprijanto A, Soelistijono RT (2017) Extreme learning machine and back propagation neural network comparison for temperature and humidity control of oyster mushroom based on microcontroller. International Symposium on Electronics and Smart Devices (ISESD), Yogyakarta, IEEE, Yogyakarta, pp 46–50, doi: 10.1109/ISESD.2017.8253303

Gajbhiye D, Joshi K, Mekala M (2018) Temperature & humidity control by using neural network for oyster mushroom cultivation. Second International Conference on Computing Methodologies and Communication (ICCMC), Erode, IEEE, Erode, pp 135–139, doi: 10.1109/ICCMC.2018.8487839

Goh ZM, Alhady SSN, Wahab AAA, Othman WAFW (2021) Notifier of mushroom cultivation room using EdSim51 simulator. 012027. Intelligent Robotics, Mechatronics and Automation Systems 2021, IOP Publishing, , doi: 10.1088/1742-6596/1969/1/012027

Gowda NAN, Kumaran GS, Pandey M (2014) Performance Evaluation of Paddy Straw Pasteurizer for Mushroom Cultivation. *Agricultural Mechanization in Asia, Africa, And Latin America* 45(3): 28–36

Gowda N. A. N, Kumaran GS (2014) Design and Development of a Hot Water Paddy Straw Pasteurizer for Mushroom Cultivation. *Agricultural Mechanization in Asia, Africa, And Latin America* 45(2): 11–18

Gregori A, Svagelj M, Pohleven J (2007) Cultivation techniques and medicinal properties of pleurotus spp. *Food Technol Biotechnol* 45(3): 238–249

Hadi MokhS, Kusuma AUPY, Mizar MA, Lestari D, Witjoro A, Irvan M (2021) IoT and fuzzy logic based smart mushroom cultivation technology. 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE), Malang, Indonesia, IEEE, Malang, Indonesia, pp 346–350, doi: 10.1109/ICEEIE52663.2021.9616842

Hendrawan Y, Anta DK, Ahmad AM, Sutan SM (2019) Development of fuzzy control systems in portable cultivation chambers to improve the quality of oyster mushrooms. 032013. 9th Annual Basic Science International Conference 2019 (BaSIC 2019), IOP Publishing, , doi: 10.1088/1757-899X/546/3/032013

Ibrahim R, Mohd Jamil AAI, Hasan SMZ, Mat Arshad A, Zakaria Z (2017) Enhancing growth and yield of grey oyster mushroom (*Plearotussajorcaju*) using different acoustic sound treatments. *MATEC Web of Conferences* 97: 01054, doi: 10.1051/matecconf/20179701054

Iossi MR, Cobos JDV, Alegria FJG, Zied DC (2018) Pleurotus spp. cultivation on Brachiaria sp. straw treatment with alkaline water. *Brazilian Journal of Microbiology* 49(1): 64–67, doi: 10.1016/j.bjm.2018.06.003

Jaramillo Mejía S, Albertó E (2013) Heat treatment of wheat straw by immersion in hot water decreases mushroom yield in Pleurotus ostreatus. *Revista Iberoamericana de Micología* 30(2): 125–129, doi: 10.1016/j.riam.2012.11.004

Menon S, Ayesha S, Pavithra K P, Malsawmtluangi M M (2021) Growth and nutritional indices of oyster mushroom (pleurotus ostreatus) on different substrates. *Current Trends in Biotechnology and Pharmacy* 15(5): 365–372, doi: 10.5530/ctbp.2021.3s.27

Mohammed MF, Azmi A, Zakaria Z, Tajuddin MFN, Isa ZM, Azmi SA (2018) IoT based monitoring and environment control system for indoor cultivation of oyster mushroom. 012053. 1st International Conference on Green and Sustainable Computing (ICoGeS) 2017, IOP Publishing, , doi: 10.1088/1742-6596/1019/1/012053

Mohd Ariffin MA, Ramli MI, Zainol Z, Mohd Amin MN, Ismail M, Adnan R, Ahmad ND, Husain N, Jamil N (2021) Enhanced IoT-based climate control for oyster mushroom cultivation using fuzzy logic approach and node MCU microcontroller. *Pertanika Journal of Science and Technology* 29(4): 2863–2885, doi: 10.47836/pjst.29.4.34

Mukherjee A, Sarkar T, Chatterjee K, Lahiri D, Nag M, Rebezov M, Shariati MA, Miftakhutdinov A, Lorenzo JM (2022) Development of artificial vision system for quality assessment of oyster mushrooms. *Food Analytical Methods* 1(1): 1–14, doi: 10.1007/s12161-022-02241-2

Najmurrokhman A, Kusnandar, Daelami A, Nurlina E, Komarudin U, Ridhatama H (2020) Development of temperature and humidity control system in internet-of-things based oyster mushroom cultivation. 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI). Yogyakarta, Indonesia, IEEE, Yogyakarta, Indonesia, pp 551–555, doi: 10.1109/ISRITI51436.2020.9315426

Najmurrokhman A, Kusnandar, Komarudin U, Daelami A, Adiputra F (2019) Design and implementation of temperature and humidity control system in oyster mushroom cultivation using fuzzy logic controller. International Conference on Computer, Control, Informatics and its Applications (IC3INA), Tangerang, Indonesia, IEEE, Tangerang, Indonesia, pp 146–150, doi: 10.1109/IC3INA48034.2019.8949573

Nakano Y, Fujii H, Kojima M (2011) Effects of light wavelength and intensity on the expression of photoresponse genes in oyster mushroom mycelia. *Journal of Light & Visual Environment* 35(1): 90–94, doi: 10.2150/jlve.35.90

Nasution TH, Yasir M, Fahmi, Soeharwinto S (2019) Designing an IoT system for monitoring and controlling temperature and humidity in mushroom cultivation fields. International Conference on Electrical Engineering and Computer Science (ICECOS), Batam Island, Indonesia, IEEE, Batam Island, Indonesia, pp 326–331, doi: 10.1109/ICECOS47637.2019.8984446

Nongthombam J, Kumar A, Manikanta B, Madhushekhar M, Patidar S (2021) A review on study of growth and cultivation of oyster mushroom. *Plant Cell Biotechnology and Molecular Biology* 22(5 & 6): 55–65

Oseni TO, Dlamini SO, Earnshaw DM, Masarirambi MT (2012) Effect of substrate pre-treatment methods on oyster mushroom (Pleurotus ostreatus) production. *International Journal of Agriculture & Biology* 14(2): 251–255

Panjikkaran ST, Mathew D (2013) An environmentally friendly and cost effective technique for the commercial cultivation of oyster mushroom [*Pleurotus florida* (Mont.) Singer]: Environmentally friendly mushroom cultivation technique. *Journal of the Science of Food and Agriculture* 93(4): 973–976, doi: 10.1002/jsfa.5827

Phuong TT (2016) Development of a new cotton waste composting technology for cultivation of oyster. *ARPN Journal of Engineering and Applied Sciences* 11(21): 12607–12613

Popovych V, Les M, Shuplat T, Bosak P, Fitak M, Popovych N (2019) The effects of temperature and moisture stress content on the extensive cultivation of the oyster mushroom. *Bulletin of the Iraq Natural History Museum* 15(4): 473–489, doi: 10.26842/binhm.7.2019.15.4.0473

Rizaldi T, Raju, Piliang MR (2019) Design of filler and compactor for oyster mushroom growing medium (baglog). 012031. International Conference on Agricultural, Environmental, and Food Security (AEFS), IOP Publishing, , doi: 10.1088/1755-1315/260/1/012031

Roshita I, Goh SY (2018) Effect of exposure to different colors light emitting diode on the yield and physical properties of grey and white oyster mushrooms. 020110. the 4th International Conference on Green Design and Manufacture 2018, Ho Chi Minh, Vietnam, AIP Publishing, Ho Chi Minh, Vietnam, pp 1–7, doi: 10.1063/1.5066751

Roshita I, Nurfazira KMP, Fern CS, Ain MSN (2017) Electrical stimulation in white oyster mushroom (Pleurotus florida) production. 3rd Electronic and Green Materials International Conference 2017 (EGM 2017), Krabi, Thailand, The American Institute of Physics, Krabi, Thailand, p 020053, doi: 10.1063/1.5002247

Sánchez C (2010) Cultivation of pleurotus ostreatus and other edible mushrooms. *Applied Microbiology and Biotechnology* 85(5): 1321–1337, doi: 10.1007/s00253-009-2343-7

Saritha B, Pandey M (2010) Evaluation of alternate substrate pasteurization techniques for culinary-medicinal white oyster mushroom, pleurotus ostreatus var. Florida (agaricomycetideae) cultivation. *International Journal of Medicinal Mushrooms* 12(3): 309–316, doi: 10.1615/IntJMedMushr.v12.i3.100

Setiawati DA, Utomo SG, Murad, Putra GMD (2021) Design of temperature and humidity control system on oyster mushroom plant house based on Internet of Things (IoT). 012002. 3rd international conference on bioscience and biotechnology, IOP Publishing, , doi: 10.1088/1755-1315/712/1/012002

Sharma VP, Kumar A, Kumar S, Barh A, Kamal S (2020) Substrate sterilization with thiophanate-methyl and its biodegradation to carbendazim in oyster mushroom (Pleurotus ostreatus var. florida). *Environmental Science and Pollution Research* 27(1): 899–906, doi: 10.1007/s11356-019-07050-5

Shrestha S, Bhattarai S, Shrestha R, Shrestha J (2021) Effect of different substrate sterilization methods on performance of Oyster mushroom (Pleurotus ostreatus). *Journal of Agricultural Science* 32(1): 127–132, doi: 10.15159/jas.21.03

Sihombing P, Astuti TP, Herriyance, Sitompul D (2018) Microcontroller based automatic temperature control for oyster mushroom plants. 012031. 2nd International Conference on Computing and Applied Informatics 2017, IOP Publishing, , doi: 10.1088/1742-6596/978/1/012031

Soares F, Herliyana EN, Mansur I (2022) Cultivation of white oyster mushroom (pleuorotus ostreatus) on some ligno-celluloses materials. *IOP Conference Series: Earth and Environmental Science* 959(1): 1–8, doi: 10.1088/1755-1315/959/1/012068

Soldatenko A, Devochkina N, Ivanova M (2019) Efficiency of the newest sterile substrate production technology for oyster cultivation. International Conference on Sustainable Development of Cross-Border Regions, IOP Publishing, pp 1–3, doi: 10.1088/1755-1315/395/1/012086

Sulistyanto MPT, Harianto W, Nugroho DA, Retandi RE, Akbar AK, Tjahjanti PH (2018) The controlling and monitoring system in oyster mushroom cultivation using fuzzy logic through web technology integrated with Internet of Things. *MATEC Web of Conferences* 197: 15002, doi: 10.1051/matecconf/201819715002

Surige YD, M PWS, N GPK, W AKP, Gamage N, Nawinna D (2021) IoT-based monitoring system for oyster mushroom farming. 3rd International Conference on Advancements in Computing (ICAC), Colombo, Sri Lanka, IEEE, Colombo, Sri Lanka, pp 79–84, doi: 10.1109/ICAC54203.2021.9671112

Thong-un N, Wongsaroj W (2022) Productivity enhancement using low-cost smart wireless programmable logic controllers: A case study of an oyster mushroom farm. *Computers and Electronics in Agriculture* 195(1): 1–15, doi: 10.1016/j.compag.2022.106798

Tongcham P, Supa P, Pornwongthong P, Prasitmeeboon P (2020) Mushroom spawn quality classification with machine learning. *Computers and Electronics in Agriculture* 179(1): 1–8, doi: 10.1016/j.compag.2020.105865

Zhang R, Li X, Fadel JG (2002) Oyster mushroom cultivation with rice and wheat straw. *Bioresource Technology* 82(3): 277–284, doi: 10.1016/S0960-8524(01)00188-2