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UTILIZATION OF AGRICULTURAL WASTES FOR OYSTER MUSHROOM CULTIVATION: AN ANALYSIS OF SUBSTRATE PROPERTIES AND COST-EFFECTIVENESS

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Abstract:

Malaysia's agricultural sector significantly contributes to waste production, particularly from major commodity crops such as oil palm, pineapple, and paddy, which contain nutritive value that can be recycled for economic and social benefits. However, improper management of these wastes may lead to environmental pollution. Rubber sawdust is a prevalent substrate for oyster mushroom production; nevertheless, its escalating cost and restricted availability render it more unfeasible. This study explored the potential of using agricultural wastes such as paddy straw (T1), pineapple leaf (T2), and empty fruit bunch (T3) as substrates for cultivating oyster mushrooms (Pleurotus ostreatus), with rubber sawdust (T0) as the control. The treatments were arranged in a Randomized Complete Block Design (RCBD) with four replications. The substrates were analysed for pH and nutrient content (total P, exchangeable K, and Ca), while outputs such as mycelial growth, mushroom yield, and cost-benefit metrics were evaluated. The results showed no significant differences in nutrient content among the substrates, except that pineapple leaves had significantly higher potassium levels. All substrates supported mushroom production except for pineapple leaves. Paddy straw exhibited the fastest sprouting time, requiring only one day after a 45-day incubation period. Rubber sawdust yielded the highest total mushroom output, which was approximately 609.2 grams over three harvesting cycles. These findings

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emphasize the possible use of agricultural residues, particularly paddy straw and empty fruit bunches, as viable and cost-effective alternatives to rubber sawdust for sustainable oyster mushroom production.

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Keyword:

Mushroom Cultivation, Paddy Straw, Pineapple Leaf, Rubber Sawdust

Introduction

Mushroom production has increased to 42.8 million tonnes over the past 30 years, growing more than 13 times since 1990 (Okuda, 2022). More than 73% of the world's mushroom production comes from China, making it the largest producer in the world (Dimopoulou et al., 2022). Mushrooms are now grown in around 100 nations and are gaining popularity all over the world (Thakur, 2020). In Malaysia, the mushroom business is expanding and has great potential to help future food security and provide an alternative food source. Edible mushrooms have been cultivated and used as a source of food for centuries because they can be grown on a wide range of substrates and are highly nutritious. Pleurotus, the members of which are commonly known as oyster mushrooms, is a genus of the most common and often cultivated edible mushrooms Pleurotus mushrooms are white rot fungi so they can produce various lignocellulolytic enzymes (Ishak et al., 2021). Therefore, by-products from agricultural crops containing cellulose, hemicellulose, and lignin can be commonly used as substrates (Kumla et al., 2020).

Meanwhile, agricultural waste management remains a critical global issue, posing significant environmental and economic challenges. About 168 million tons of biomass are produced in Malaysia alone, and the agricultural waste includes sugarcane waste, empty fruit bunches, rice husks, and coconut trunk fiber (Marlina et al., 2015). Improper disposal methods such as open burning contribute to air pollution, greenhouse gas emissions, and soil degradation, thus compromising public health and agricultural sustainability. Amid these concerns, there is growing interest in the valorization of agricultural biomass through circular economy approaches. One promising avenue is the use of lignocellulosic agricultural residues as substrates for edible mushroom cultivation. This not only reduces environmental burdens but also promotes resource-efficient, low-cost production systems.

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The high cost of conventional substrates presents a significant challenge in mushroom cultivation. Commonly used materials are often expensive and limited supply that required the need for more economical alternatives. In other hand, the agricultural residues with high biomass potential often viewed as environmental burdens. It has been seen as an opportunity for mushroom production since offer low cost for mushroom production due to their multiple benefits. However, the reliance on conventional substrates like rubber sawdust is becoming increasingly unsustainable due to supply constraints and rising costs. Therefore, identifying alternative substrates that are locally available, nutrient-rich, and economically viable is essential to scale up sustainable mushroom cultivation practices. This study aims to evaluate the physicochemical properties and economic feasibility of using pineapple leaf waste, paddy straw, and oil palm empty fruit bunch (EFB) as alternative substrates for oyster mushroom cultivation.

Material and Methods

Study Location and Experimental

This study was conducted from March to August 2024 at the Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA (UiTM), Malaysia. Four substrate treatments were evaluated: paddy straw, pineapple leaf waste, oil palm empty fruit bunch (EFB), and rubber sawdust (control). Substrates were selected based on their local availability and lignocellulosic composition. Paddy straw was collected from Sekinchan, Selangor; pineapple leaves from Kuala Sungai Baru, Melaka; and EFB from SD Guthrie Kempas Estate, Melaka. Rubber sawdust was obtained from a commercial mushroom supplier in Melaka. A Randomized Complete Block Design (RCBD) was employed with four replications per treatment. Each treatment was repeated to ensure statistical reliability.

Substrate Preparation and Inoculation

All substrate materials were air-dried, chopped, and homogenized. The base formulation included each substrate type mixed with fine rice bran and calcium carbonate ($CaCO_3$) in a ratio of 10:1:0.1 (w/w). The mixture was packed into polypropylene bags (8.5 cm × 35 cm), fitted with PVC collars and cotton plugs. The substrate bags underwent sterilization in an autoclave at 120°C for a duration of six hours. Following a 12-hour chilling interval, bags were injected under sterile states with Pleurotus ostreatus spawn. Inoculated bags were incubated at ambient room temperature (25–28°C) in a dark, humid environment for 45 days to facilitate mycelial colonization.

Growth Monitoring and Yield Assessment

Mycelial growth was observed daily until full colonization. Upon completion, fruiting was induced by removing the bag caps and misting the blocks regularly to maintain high humidity. Harvesting was performed over three flushes for each treatment. Data collected included volume of mycelium growth (cm^3), days of sprouting, and total mushroom yield per bag (g).

Chemical Analysis of Substrates

The Chemical properties of each substrate were analysed prior to inoculation. Substrate pH was determined using a 1:10 (w/v) substrate-to-water ratio with a calibrated pH meter.

Macronutrients like phosphorus (P), potassium (K), and calcium (Ca) were quantified using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) following acid digestion. Utilizing the Loss on Ignition (LOI) technique at 550°C, the organic matter content was quantified.

Economic Evaluation

A cost-benefit analysis was conducted to assess the economic viability of each substrate treatment. Input costs included raw materials and substrate preparation. Cost and net profit were calculated based on total mushroom yield and prevailing market prices.

Statistical Analysis

All data were examined utilizing SPSS statistical software. A one-way analysis of variance (ANOVA) was performed, accompanied by Tukey's tests, to assess the significant mean differences ($p<0.05$) across treatments.

Results and Discussions

Chemical Composition of Substrates

Table 1 presents the mean values of pH, phosphorus (P), potassium (K), calcium (Ca), and organic matter content across four different agricultural waste substrates. The data reveal significant differences in chemical composition, which may influence the suitability of these substrates for oyster mushroom cultivation. The pH levels varied significantly ($p = 0.001$), ranging from 5.00 in rubber sawdust to 8.59 in pineapple leaves. The substrate derived from pineapple leaves (T2) exhibited the highest pH value, likely due to the presence of certain organic compounds and minerals that contribute to a more alkaline environment. This alkalinity can significantly affect nutrient availability and the composition of microbial flora within the substrate (Vidya, 2017). According to Sultana (2018), the ideal pH range for oyster mushroom cultivation is between 5.5 and 6.5. Hence, while rubber sawdust is on the lower end and pineapple leaves exceed this range, paddy straw (6.69) and EFB (7.28) fall closer to the optimal threshold.

No significant difference was observed in phosphorus content among the substrates ($p = 0.244$). However, rubber sawdust exhibited the highest phosphorus concentration (3794.62 mg/L), while paddy straw had the lowest (1796.25 mg/L). This finding is consistent with the study by Afief (2015), which reported that rubber sawdust supports enhanced growth and yield of oyster mushrooms due to its sufficient phosphorus content, which is crucial for healthy mycelial development. Furthermore, Zhuo (2017) emphasized that phosphorus plays an essential role in various physiological functions in oyster mushrooms, including membrane and nucleic acid synthesis, energy transfer (ATP production), and intracellular signal transduction processes. These functions are vital for robust mycelial colonization and fruiting body formation.

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Table 1: Mean Comparison of Chemical Composition of Substrates

Substrate	pH	P (mg/L)	K (mg/L)	Ca (mg/L)	Organic Matter (%)
Rubber Sawdust	5.00[d]	3794.62[a]	4222.50[c]	16792.75[a]	10.7604[a]
Paddy Straw	6.69[c]	1796.25[a]	7816.75[b]	7924.25[a]	11.1550[a]
Pineapple Leaves	8.59[a]	2841.00[a]	14742.50[a]	12292.75[a]	11.7675[a]
EFB	7.28[b]	2449.00[a]	9350.75[b]	9470.00[a]	18.6425[a]
P value	0.001	0.244	0.001	0.122	0.349

Means with the same column followed by the same letters are not significantly different at $p \leq 0.05$ according to Tukey's test.

A statistically significant difference was observed in potassium content among the substrates ($p = 0.001$). Pineapple leaves recorded the highest potassium concentration (14,742.50 mg/L), substantially higher than the other substrates. Potassium plays a vital role in enzyme activation, osmotic regulation, and overall metabolic processes, which are essential for enhanced mycelial development and fruit body formation in oyster mushrooms. According to Hoa et al. (2015), a high potassium content in the substrate was associated with rapid mycelial colonization which often within five days and improved yield performance. Similarly, Oinam (2020) reported that mixed substrates with elevated potassium levels outperformed standalone substrates in supporting the growth and yield of oyster mushrooms, highlighting potassium's positive influence on productivity.

Although the calcium content among the substrates was not statistically different ($p = 0.122$), notable variation was observed. Rubber sawdust exhibited the highest calcium concentration (16,792.75 mg/L), which may enhance the structural development of oyster mushrooms. Calcium plays a vital role in maintaining cell wall stability, regulating cellular signaling, and supporting fruiting body formation, particularly by increasing resistance to mechanical stress during growth (Koutrotsios et al., 2014). Similarly, the organic matter content did not show a statistically significant difference ($p = 0.349$). However, empty fruit bunches (EFB) had the highest organic matter percentage (18.64%), while rubber sawdust had the lowest (10.76%). High levels of organic matter are generally associated with improved microbial activity and increased nutrient availability that promote conducive to robust mushroom growth and substrate decomposition. According to Ali et al (2013), EFB is rich in lignocellulosic materials such as cellulose and hemicellulose, which not only enhance substrate structure and aeration but also serve as a steady nutrient source for mycelial colonization.

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Mycelium Growth Volume

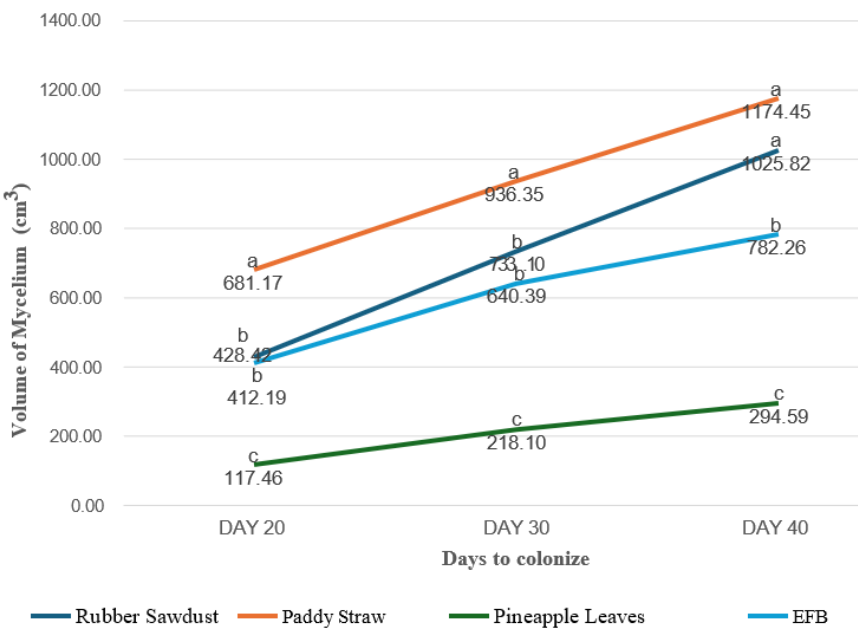

Figure 1: Mycelial Growth Volume During the Incubation Period

Figure 1 illustrates the progression of mycelial growth volume (cm^3) over a 40-day incubation period across four different substrates. Analysis of variance (ANOVA) shows there were significant difference on the volume of mycelial growth between four different types of substrates for each of interval ($p<0.05$). Paddy straw consistently supported the most vigorous mycelial development, with a steady increase from 681.17 cm^3 on Day 20 to 936.35 cm^3 on Day 30, reaching 1174.45 cm^3 by Day 40. This was significantly higher than the other substrates throughout the incubation period. This consistent growth may be attributed to paddy straw's optimal pH (6.69), aligning with the ideal range for oyster mushroom growth (5.5–6.5), as well as its relatively balanced nutrient profile and high organic matter content. Furthermore, paddy straw contains moderate phosphorus content that can supports efficient mycelial metabolism. Phosphorus plays a role in energy transfer and cellular development. According to Ghaffar et al (2024), paddy straw contains higher quantities of minerals and iron compared to other substrates, which are necessary for the growth of mushrooms and leading to a good yield.

EFB followed a similar growth trend, beginning at 428.42 cm^3 on Day 20 and rising sharply to 753.10 cm^3 on Day 30, culminating in 1025.82 cm^3 by Day 40. Although slightly less effective than paddy straw, EFB still showed considerable promise as a substrate, particularly due to its high organic matter and potassium content as shown in Table 1. The high organic matter (18.64%) provides a rich environment for microbial interactions, sustained nutrient release, and fostering continuous colonization. Besides that, the substantial mycelial development observed in EFB can be attributed to its high potassium content (9350.75 mg/L), which is essential for enzymatic activation and osmotic regulation. Potassium-rich substrates enhance nutrient uptake and mycelial spread.

Although pineapple leaves had the highest potassium content (14,742.50 mg/L), they did not support growth. This is due to the presence of inhibitory phenolics outweighed nutrient advantages. This phenolic contains meliadonoside, feralolide, kukoamine A, that contribute to inhibition of microbial growth (Ya'acob et al., 2022). This highlights the importance of considering both nutrient profiles and chemical inhibitors when assessing substrate viability.

Yield Performance

Table 2: Days of Sprouting and Yield of Mushrooms Over Three Harvesting Cycles

Substrate	Days to sprouting	Yield (gram/block)
Rubber Sawdust	5	609.02
Paddy Straw	1	209.88
Pineapple Leaves	n/a	n/a
EFB	9	208.80

n/a: not available

Table 2 shows the substrate derived from paddy straw exhibited the shortest time to sprouting, which require just one day after exposure to fruiting conditions. This was followed by the rubber sawdust and EFB substrates, which required approximately five and nine days, respectively, to initiate sprouting. In contrast, the substrate composed of pineapple leaves failed to produce any visible fruiting bodies within the observation period, indicating its unsuitability for supporting the reproductive phase of oyster mushroom development. Rubber sawdust produced the highest total yield, recording 606.02 grams per block over three harvesting cycles. In contrast, the yields from paddy straw and EFB substrates were comparatively lower and showed minimal difference, averaging between 208 and 210 grams per block.

Cost-Benefit Analysis

Table 3: Economic Evaluation of Substrate

Substrate	Cost (RM/block)	Gross Return (RM/block)	Net Profit (RM/block)
Rubber Sawdust	2.50	7.20	4.70
Paddy Straw	1.30	2.52	1.22
Pineapple Leaves	1.30	n/a	n/a
EFB	1.30	2.51	1.21

Market price: RM12/kg

Rubber sawdust gave the highest economic return among all of the substrates tested, recorded a gross return of RM 7.20 per block with a profit of RM4.70. Although the production cost relatively higher compared to other substrate but it achieved substantial and made it the most cost-effective substrate. Paddy straw and EFB were relatively similar-sized contributors in terms of economics with gross returns of RM2. 52 and RM2. 51 respectively, and a similar net profit of RM1.22 and RM1.21 per block. Their lower cost (RM1.30/block) resulted in relatively moderate profitability and appeared economical to growers as low-cost alternatives. However, Pineapple leaves, on the other hand, did not generate any measurable yield, and as a result, no gross return or net profit could be calculated.

Conclusion

In conclusion, paddy straw and empty fruit bunch (EFB) are favourable, economical substitutes for rubber sawdust for oyster mushroom cultivation. Despite having the highest yield and profit, rubber sawdust is becoming less viable because of its limited supply and rising costs. Mycelial development and sprouting were quickest in paddy straw and followed by EFB due to its high organic content. Despite having high potassium levels, pineapple leaves did not promote the growth of mushrooms, most likely due to inhibitory chemicals. In general, mushroom growing can become more economical and ecologically beneficial by utilizing agricultural waste such as paddy straw and EFB.

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