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Effects of Different Substrates on the Growth and Nutritional Composition of *Pleurotus ostreatus*: A Review

M. Karmani, G. Subramaniam, L.A. Sivasamugham, W.H. Cheng, L.S. Wong

Faculty of Health and Life Sciences, INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia

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ABSTRACT

Mushrooms are a popular food source as they are highly nutritious and flavorful with a high content of proteins, vitamins, and minerals. Mushrooms could be an alternative solution to the world's food crisis as they are inexpensive to grow on different types of substrates including waste materials. *Pleurotus ostreatus,* frequently known as oyster mushrooms, are the second most cultivated mushroom in the world. This species is known for its high protein content and easy cultivation. Oyster mushrooms have the potential to produce protein-rich biomass when grown on various substrates. There is a need to identify substrates that are cost-effective for the commercial production of nutritious oyster mushrooms as the substrates used currently are either costly or inadequate to produce oyster mushrooms in the required quantity or quality. Thus, the effects of 6 different lignocellulosic substrates on the growth and nutritional composition of *P. ostreatus* were reviewed and analyzed in this article. The substrates included in this review were wheat straw, sugarcane bagasse, corncob, softwood sawdust, hardwood sawdust, and general sawdust. Based on the analyzed data, sugarcane bagasse was concluded as the most suitable substrate to grow *P. ostreatus.* These substrates contain a high amount of nutrients and are also likely to produce a significantly high yield of oyster mushrooms in addition to enhancing the nutritional quality of the mushroom. However, these findings must be evaluated and confirmed through further research in this field.

* Corresponding author

E-mail: geetha.subramaniam@newinti.edu.my (Geetha Subramaniam)

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1 Introduction

The process of photosynthesis generates approximately 200 billion tons of organic compounds every year (Philippoussis 2009). This organic bulk can pollute the environment in many cases especially the lignocellulosic components as they are not readily degraded by organisms (Hatakka 1994; Philippoussis 2009). Waste materials from agriculture and industry can be used to grow mushrooms (Abid et al. 2020; Iwuagwu et al. 2020). Mushrooms are macro-fungal fruiting bodies that are extremely rich in flavor and do not have high calories but are rich in vitamins, minerals, and proteins (Mubasshira et al. 2020). Mushrooms are considered to be the world's most untapped resources for nutritious and healthy food (Kakon et al. 2012).

Oyster mushrooms (*P. ostreatus*) are an edible, lignocellulolytic type of mushrooms (Kumla et al. 2020) with therapeutic elements such as phenolic compounds, dietary fibers, minerals, and numerous bioactive compounds. The fruiting body of mushrooms in the *Pleurotus* genus contains minerals like zinc, iron, phosphorus, potassium, copper, etc. (Garuba et al. 2017). Previous research suggests that the consumption of oyster mushrooms can lower the risk of many diseases such as heart disease, impaired immune response, hepatitis B, liver disease, high blood cholesterol levels, gastric cancer, microbial infection, chronic fatigue syndrome, kidney problems, hypertension, and diabetes (Mubasshira et al. 2020; Ba et al. 2021; Krittanawong et al. 2021). Therefore, oyster mushrooms are an alternative rich source of nutrition and an alternative food source that can promote human health (Valverde et al. 2015).

P. ostreatus contain lignocellulosic enzymes that can convert lignocellulose residues into protein-rich biomass (Adebayo and Martinez-Carrera 2014; Mubasshira et al. 2020; Grimm et al. 2021). These mushrooms require a short growth time relative to other mushrooms and are economical to produce commercially (Abid et al. 2020). Multiple lignocellulosic substrates including agricultural waste products such as sugar cane bagasse, corn cobs, and wheat straw, can be used to cultivate *P. ostreatus* (Owaid et al. 2015; Sözbir et al. 2015; Kumla et al. 2020).

Therefore, this paper is aimed at reviewing the effects of different lignocellulose-rich substrates on the growth and nutritional composition of *P. ostreatus* and to identify the most appropriate substrate that might produce the highest yield of nutritious oyster mushrooms.

2 Selection of Literature

This paper involved systematically reviewing and analyzing the currently available research on the effects of different substrates on the growth and nutritional composition of *P. ostreatus*. The search for relevant studies was done using electronic databases like NCBI, Google Scholar, Research Gate, and others. The inclusion and exclusion criteria used to select the papers for this review are stated in Table 1.

3 Cultivation and Analysis of *P. ostreatus* Nutritional Content

Significant differences in the nutritional content, particularly the protein content, have been observed in the cultivation of edible mushrooms. This could be influenced by several factors such as the types of mushroom species, the used substrate, and the level of nitrogen available in the growth substrate (Belletini et al. 2019). Currently, the number of studies that focus on the utilization of lignocellulosic substrates are increasing (Iwuagwu et al. 2020; Nongthomban et al. 2021). Ganash et al. (2021) demonstrated that *Pleurotus* species are very effective in breaking down lignocellulosic residues making it a suitable mushroom to be cultivated on lignocellulosic substrates (Figure 1). This could be due to the type and quantity of enzymes including lignolytic,

Table 1 The inclusion and exclusion criteria that have been conducted for this review paper.

Inclusion Criteria	• Papers for fresh mushrooms belonging to the *Pleurotus* genus • Papers that included information about nutritional content, substrate quality, growth conditions, regional conditions, substrate availability, etc.
Exclusion Criteria	• Papers for fresh mushrooms belonging to other genera of mushrooms except *Pleurotus*. • Papers for dry mushrooms belonging to other genera of mushrooms including *Pleurotus*. • Papers for canned mushrooms or other extracts belonging to other genera of mushrooms including *Pleurotus*.

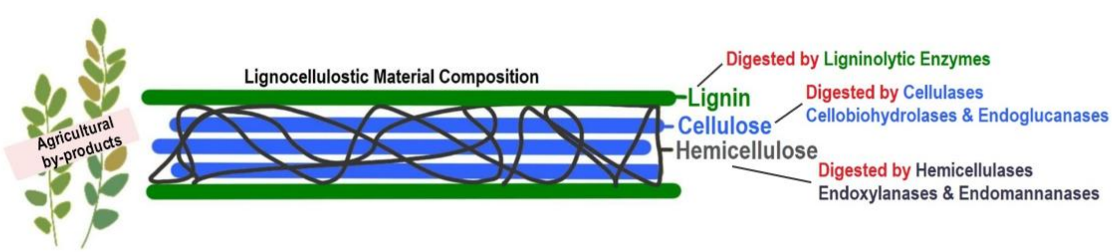

Figure 1 Systemic representation of enzymatic degradation of lignocellulosic agricultural wastes by *P. ostreatus* enzymes

cellulase, and hemicellulase enzymes, that are generated by fungi throughout the vegetative development (Ogundele et al. 2017). The majority of agro-industrial waste consists of lignocellulosic materials; the cultivation of edible mushrooms using these substrates would greatly reduce the environmental waste while providing suitable and economical substrates for mushroom cultivation (Kumla et al. 2020).

Table 2 consists of the proximate size and number of fruiting bodies of *P. ostreatus* that were generated on different lignocellulosic substrates. From the data given in table 2, it can be concluded that the cultivation of wheat straw, corn cob, and sugarcane bagasse produced *P. ostreatus* with the largest cap diameter (84 – 89.3 mm), followed by general sawdust, hardwood sawdust, and softwood sawdust (Upadhyay et al. 2002; Phillipoussis 2009; Fanadzo et al. 2010; Hoa et al. 2015; Girmay et al. 2016; Masevhe et al. 2016; Salama et al. 2016; Ogundele et al. 2017). The cap diameter is an essential growth parameter. The cap or pilieus which contains the spore-bearing surface of the mushroom is supported by the stalk and constitutes the fruiting body. According to Onyango et al., (2011), big fruit bodies, in general, are the desired feature highly valued in mushroom cultivation. It was observed that the cultivation of wheat straw also produced an average of 18 fruiting bodies, the second-highest number compared to sugarcane bagasse and corn cob which produced the lowest number of fruiting bodies (< 10 mm). Among all the substrates, hardwood sawdust seemed to be the least suitable substrate for the cultivation of *P. ostreatus* based on the low number of fruiting bodies (<15 mm) and a comparatively small cap diameter (24 mm). However, it was interesting that cultivation on softwood sawdust had the highest number of fruiting bodies with the smallest cap diameter. Although the size of the fruiting bodies is a definite factor for considering when selecting a suitable substrate for the cultivation of *P. ostreatus*, an equally important factor would be the nutritional content of the mushroom.

Edible mushrooms are rich in proteins, carbohydrates, and minerals while being low in lipid content (Valverde et al. 2015). The substrates on which the mushrooms are cultivated also have an impact on the overall energy of mushrooms and nutritional content (Hoa et al. 2015). Mushrooms, including *P. ostreatus*, are saprophytes; they extract the required nutrients from the substrate they are cultivated on. Based on the data in table 3, *P. ostreatus* grown on corn cob substrate had the highest protein content

Table 2 Proximate size and number of fruiting bodies of *Pleurotus ostreatus* based on cultivation with common lignocellulosic substrates.

Substrate	Cap Diameter (mm)	Stripe Length (mm)	Stripe Thickness (mm)	No. of Effective Fruiting Bodies	References
Corn Cob	86.7	35.3	11.1	7.9	Hoa et al. 2015; Philippoussis 2009
Sawdust (Soft Wood)	17.6	-	-	29.6	Ogundele et al. 2017; Philippoussis 2009
Sawdust (Hardwood)	24.0	-	-	14.6	Hoa et al. 2015; Ogundele et al. 2017; Philippoussis 2009
Sawdust (General)	70.6	38.2	8.5	11.5	Girmay et al. 2016; Hoa et al. 2015
Sugarcane Bagasse	84.8	35.7	10.2	8.1	Hoa et al. 2015; Philippoussis 2009
Wheat Straw	86-89.3	28.1	10.3	18.3	Fanadzo et al. 2010; Girmay et al. 2016; Masevhe et al. 2016; Salama et al. 2016; Upadhyay et al. 2002

Table 3 Proximate nutritional composition and energy of *P. ostreatus* based on cultivation with common lignocellulosic substrates.

Substrate	Moisture	Ash	Fat	Protein	Carbohydrate	Fiber	Energy (Kcal/100g)	References
Corn Cob	90.57%	7.10%	2.67%	29.70%	30.78%	29.75%	265.95	Hoa et al. 2015; Philippoussis 2009
Sawdust (Soft Wood)	7.88%	9.59%	1.81%	17.68%	52.04%	10.66%	-	Ogundele et al. 2017; Philippoussis 2009
Sawdust (Hardwood)	8.93%	9.83%	1.72%	11.05%	41.57%	11.05%	-	Hoa et al. 2015; Ogundele et al. 2017; Philippoussis 2009
Sawdust (General)	91.06%	5.90%	1.32%	19.52%	51.26%	22.00%	295.00	Girmay et al. 2016; Hoa et al. 2015
Sugarcane Bagasse	91.56%	6.68%	2.00%	27.13%	34.94%	29.25%	266.28	Hoa et al. 2015; Philippoussis 2009
Wheat Straw	90.16%	0.82%	0.15%	1.66%	7.22%	-	110.23	Fanadzo et al. 2010; Girmay et al. 2016; Masevhe et al. 2016; Salama et al. 2016; Upadhyay et al. 2002.

Table 4 Proximate mineral composition of *P. ostreatus* based on cultivation with common lignocellulosic substrates.

	Mineral (mg/100g dry weight)								
Substrate	Ca	Cu	Fe	K	Mg	Mn	P	Zn	References
Corn Cob	340.08	2.55	14.64	2,624	225.17	3.68	717.49	11.45	Hoa et al. 2015
Soft Wood Sawdust	3.42	-	-	21.36	1.04	-	10.09	0.95	Ogundele et al. 2017
Hardwood Sawdust	3.51	-	-	21.81	1.25	-	10.36	0.96	Ogundele et al. 2017
General Sawdust	336.02	2.08	14.83	1424.37	217.76	2.06	620.35	8.69	Hoa et al. 2015
Sugarcane Bagasse	345.06	2.22	14.85	2573.79	237.07	3.06	732.27	8.56	Hoa et al. 2015
Wheat Straw	-	-	-	1.12-1.13	-	-	1.82-1.84	-	Masevhe et al. 2016; Salama et al. 2016

followed by sugarcane bagasse and other substrates such as general sawdust, softwood sawdust, hardwood sawdust, and wheat straw. Furthermore, cultivation of *P. ostreatus* on both corn cob and sugarcane bagasse produced mushrooms with high carbohydrate content resulting in more than 265 Kcal/100 g of calories, indicating a higher nutritional content with a comparatively lower calorie value. This could be because a significant amount of the carbohydrate content in mushrooms consists of dietary fiber (Nakalembe et al. 2015; Kumari 2020). Although the individual substrates such as corn cob and sugarcane bagasse seem to produce *P. ostreatus* with high protein and carbohydrate content, it would be interesting to study the effects of mixing substrates on the growth and nutritional content of this mushroom. Owaid et al. (2015) reported an increase in the productivity and biological efficiency of *P. ostreatus* in mixed substrates compared to using wheat straw alone. This indicates that more studies on the utilization of mixed substrates from agro-industrial waste and their effects on the growth output and nutritional content of *P. ostreatus* should be carried out.

Mushroom fruiting bodies have a high concentration of easily absorbed mineral components which could be due to their capability of bio-accumulation of metals (Gebrelibanos et al. 2016). Since the fungal hyphae come in contact with the compound and absorb its important components, the substrate has a direct impact on the mineral composition of the mushroom (Bellettini et al. 2019). *P. ostreatus* has been known to contain generally high levels of nutritionally essential minerals, including potassium and phosphorus, and sufficient quantities of ferum with high bioavailability (Raman et al. 2021). Table 4 shows the approximate mineral composition of *P. ostreatus* based on cultivation with common lignocellulosic substrates. These data show that growing *P. ostreatus* on sugarcane bagasse leads to mushrooms with significantly high mineral content, particularly in comparison with sawdust which is the common substrate utilized to cultivate edible mushrooms. It has to be noted that the mineral content in mushrooms is important as they are considered a "dietary supplement" with low calorific value and high protein content (Kakon et al. 2012). The high mineral content in combination with the large-cap diameter of *P. ostreatus* makes sugarcane bagasse a more suitable substrate for the cultivation of this species of edible mushroom.

4 Conclusion and Recommendations for Future Research

Substrates directly impact mushroom composition, so the choice of appropriate substrate is of utmost importance. Based on the reviewed data, sugarcane bagasse has been concluded as the best substrate for *P. ostreatus* cultivation. The nutritional content of *P. ostreatus* grown on sugarcane bagasse is comparable to cultivation on other substrates. Furthermore, sugarcane bagasse is also well-researched for *Pleurotus* growth. As long as parameters such as pH, moisture content of the substrate, etc. are critically analyzed beforehand, sugarcane bagasse is an appropriate choice of substrate for *P. ostreatus* cultivation.

As with the majority of studies, the design of the current study is subject to limitations. The data that have been quoted in this review are from multiple studies which are different from each other in methodology (such as pre-treatment sterilization) or environmental conditions and differences in microclimates. Although this paper theoretically concludes based on data from several papers that sugarcane bagasse is the most suitable substrate for *P. ostreatus* cultivation, there is a need to confirm this based on actual results from the field compared with other substrates simultaneously while maintaining similar culture conditions, and other factors such as temperature and nitrogen levels.

Conflict of Interest

The authors declare no conflict of interest. This paper has not been submitted for publication in any other journal.

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