sciendo
Agriculture (Poľnohospodárstvo), 70, 2024 (4): 182 − 193

Review

DOI: 10.2478/agri-2024-0013

Utilisation of Empty Fruit Bunch and Oil Palm Frond for *Volvariella volvacea* Cultivation and Application of Spent Mushroom Substrates in Maize Production − a Review

MUHAMMAD WASIL BIN ABU BAKAR[1], MD. KAMAL UDDIN[1]*, SYAHARUDIN ZAIBON[1], MUHAMMAD HUZAIFAH ROSLIM[2], NOOR AZRIMI UMOR[3], MD. ZAKARIA M. SOLAIMAN[4], AHMAD NUMERY ASHFAQUL HAQUE[5], MD. ARIFUL ISLAM KHALID[1], MD. JAHANGIR ALAM[1]

[1]Universiti Putra Malaysia, Serdang, Selangor, Malaysia
[2]Universiti Putra Malaysia Sarawak, Bintulu, Malaysia
[3]Biology Educational Department, UITM Kuala Pilah, Malaysia
[4]UWA School of Agriculture and Environment and UWA Institute of Agriculture, The University of Western Australia, Perth, Australia
[5]Bangladesh Agricultural Research Council, BARC, Dhaka, Bangladesh

Bakar, M.W.B., Uddin, M.K., Zaibon, S., Roslim, M.H., Umor, N.A., Solaiman, M.Z., Haque, A.N.A, Khalid, M.A., and Alam, M.J. (2024). Utilisation of empty fruit bunch and oil palm frond for *Volvariella volvacea* cultivation and application of spent mushroom substrates in maize production: a Review. *Agriculture (Poľnohospodárstvo), 70*(4), 182–193.

Asian countries such as Malaysia and Indonesia are beginning to commercialise the cultivation of *Volvariella volvacea* as the demand rises. However, production is still low due to a lack of knowledge about formulation and poor handling of the spent mushroom substrates. In Malaysia, this shortage can be addressed by selecting high-yielding biomass such as oil palm biomass that can promote the development of *Volvariella.* In addition, the substrates from mushroom cultivation can be used as a soil conditioner for crop cultivation. The growth of mushrooms requires enough nutrients and moisture content. Empty fruit bunches (EFB) and oil palm fronds (OPF) are suitable for this purpose as they possess these properties. The use of oil palm biomass as a substrate would increase the mycelium rate, number of needles and weight in a shorter time. On the other hand, the spent mushroom substrates should be a useful material for the cultivation of maize (*Zea mays* L.) and would improve plant development by increasing soil pH. The importance of EFB and OPF for increasing mushroom yield, and the application of spent substrates in maize cultivation has not yet been established in various studies. This review summarises the properties of oil palm biomass on mushroom development and the application of spent substrates to achieve high maize yields and improve soil physicochemical properties. Future studies should support the utilisation of oil palm biomass for *Volvariella* cultivation and the use of spent substrates for sustainable maize production.

Key words: paddy straw mushroom, corn, biomass, used substrates, time, soil pH, yield

Muhammad Wasil Bin Abu Bakar, Assoc. Prof Dr. Md. Kamal Uddin (*Corresponding author), Dr. Syaharudin Bin Zaibon, Md. Ariful Islam Khalid, Md. Jahangir Alam, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia. E-mail: wasilabubakar9@gmail.com; mkuddin@upm.edu.my; syaharudin@upm.edu.my; khalidbau95@gmail.com
Ts. Dr. Muhammad Huzaifah Bin Mohd Roslim, Crop Science Department, UPM Bintulu, Malaysia. E-mail: muhammadhuzaifah@upm.edu.my
Dr. Noor Azrimi Bin Umor, Biology Educational Department, UITM Kuala Pilah, Malaysia. E-mail: noorazrimi@uitm.edu.com
Assoc. Prof Dr. Md. Zakaria Solaiman, UWA School of Agriculture and Environment the University of Western Australia, Perth, Australia. E-mail: zakaria.solaiman@uwa.edu.au
Ahmad Numery Ashfaqul Haque, Bangladesh Agricultural Research Council, BARC, Dhaka, Bangladesh. E-mail: numerybau@gmail.com

Volvariella volvacea is one of the edible mushrooms in the world among the 7,000 species recognised in the last 10 years, and its production for commercial purposes is still low (El-Sebaaly *et al.* 2021). In some countries, it is also known as rice straw mushroom (Ahlawat & Arora 2016), and in some areas it is also called Chinese mushroom (Sudha *et al.* 2019). In 2022, global mushroom production reached approximately 48.34 million metric tonnes, with *Volvariella volvacea* accounting for about 1% of the total output (Singh *et al.* 2020; Statista 2024). It has the same properties as most mushrooms, namely a high nutritional content of vitamin B3, organic acid, abundant minerals, and a source of polysaccharides, biologically active proteins and antioxidants that can exhibit anticoagulant, anti-inflammatory, antihypertensive, antimicrobial, anticancer, and anti-tumour effects (Eguchi *et al.* 2015). It also rots easily and must be properly treated after harvesting (Sakinah *et al.* 2019). Interestingly, the cultivation of this crop requires lignin-cellulose substrate and sufficient nutrients for good production, and the spent straw can be utilised for the cultivation of other crops and used as a soil conditioner.

Commonly, rice straw is used for paddy straw mushroom cultivation previously with a wide range of cellulosic materials, good carbon-to-nitrogen ratio, and classified as speedily and easily decomposable (Ahlawat & Arora 2016). Before 1970, this mushroom was only cultivated with rice straw as it would have a good impact that is favorable to this type of mushroom developing, and later farmers started to mix the formulation of substrates to improve production (Yella *et al.* 2021). Trials for this mushroom were done on cotton wastes, paddy straws and banana leaves, and the outcomes were not significantly different among the treatments (Zikriya *et al.* 2018). Theoretically, rice straw is classified as a lignocellulosic biomass and approximately consists of around 12% lignin, 25% hemicellulose and 43% cellulose (Harun *et al.* 2022).

On the other hand, waste from oil palms, such as trunk, fronds and empty fruit stalks, are also categorised as lignin-containing cellulosic material, which is widely cultivated and produced in Asia, especially in Malaysia and Indonesia (Dungani *et al.* 2018). About 21% of the freshly cut bunches each day become empty fruit clusters, while the boot and fronds can be recovered in the replanting phase (Triyono *et al.* 2019). From 4.49 million palm trees, 17.73 mil. t of palm oil is extracted, which will produce around 3.72 mil. t of EFB as waste (Alam *et al.* 2015). Estimately, around 25.49 metric tonnes of EFB are produced from 19.5 million metric tonnes of crude palm oil production in 2025 (MPOB 2024). This waste had a composition of 3.3%, 21.3% and 17.6% for cellulose, hemicellulose and lignin, respectively (Mamimin *et al.* 2021).

Other than that, the substrate selection should also focus on the moisture and nitrogen content of the material used. Optimum moisture is needed to ensure good production, and at the same time, the result declines as the moisture exceeds from optimum limit (Pani *et al.* 2017). The good waste applied can hold around 60−70% water through the cultivation of the mushroom process and needs to be applied with extra water if needed (Luu *et al.* 2022). This moisture will be very related to the production during the post-harvest of mushrooms (Kumar 2015). Besides, the Carbon-to-Nitrogen ratio in substrates is also important in cultivation, a high value would rise mushroom development with the increase of glucose (Diamantopoulou *et al.* 2016). Han *et al.* (2024) reported 27:1 as an optimal ratio for mushroom good development. While another research found that a 40:1 ratio is needed for good *volvariella* development (Amir *et al.* 2025)

The use of different substrates for cultivating *Volvariella volvacea* significantly influences the duration required for complete mycelial colonization. Practically, around 10 days are needed for the mushroom mycelium to fully colonize on the oil palm waste and another 6 days for the pinning (Obodai & Odamtten 2012) and one research study showed that the *Volvariella* can start harvest on day 12 or 14 after the seedling (Triyono *et al.* 2019). On the other hand, one researcher recorded that using rice straw waste can get fully colonized in less than 10 days (Zikriya *et al.* 2018). Moreover, the spent mushroom compost from mushroom cultivation basically would raise the number of waste products after harvest (Zied *et al.* 2020). Many researchers have started to focus on this method. One researcher focused on the benefits of *Volvariella* waste for energy generation that is eco-friendlier (Umor *et al.* 2021), and another researcher highlighted the benefit of mushroom waste as a soil improvement (Yu *et al.* 2019). It can also be used as a biofertiliser for crop cultivation in the agriculture sector (Othman *et al.* 2020).

Finally, promoting sustainable cultivation practices requires emphasizing both yield and organic methods as key strategies to support environmentally friendly agriculture (Tuhy *et al.* 2015). The goal can be realistic by applying agricultural waste on crop cultivation that focuses on quality, higher yield and nutrient uptake (Ashrafi *et al.* 2015). It can also be observed from a nutrient availability point of view and the reduction of the use of fertiliser as it can play crucial role as a biofertiliser (Rajavat *et al.* 2022). By applying amendments in soil, researchers would also need to ensure a good result in moisture content, dry matter, EC, pH, ash, carbon, nitrogen, protein contents, and C: N ratio (Owaid *et al.* 2017). This review focuses on the improvement of *Volvariella* yield using oil palm biomass and the benefits of spent mushroom substrates on soil physical properties and maize production.

1. *Volvariella Mushroom Background*

Volvariella volvacea was cultivated around 30 decades ago, being introduced and starting to be cultivated in Malaysia and other Asian countries, from China after 1900 (Yella *et al.* 2021). It can be cultivated in most areas of the world that offer warm temperatures most of the time, either in subtropical or tropical regions (Sudha *et al.* 2019; Amir *et al.* 2023). Over this decade, its demand was about 5% of the total production of all kinds of mushroom production (Sakinah *et al.* 2019). Commonly, it has been cultivated using rice straw and cotton waste as substrates. However, numerous other materials have also been explored for the cultivation of mushroom, such as oil palm biomass or banana leaf (Yella *et al.* 2021). The substrate is a crucial technology that needs to be developed to make sure this yield, and resources are fully utilised (Amir *et al.* 2023). Figure 1 summarized on the *Volvariella* development that can be divided into 6 stages.

2. *Oil Palm Biomass Production*

Malaysia remains the world's second-largest producer and exporter of palm oil, contributing approximately 26% to global production and accounting for about 35% of global exports in 2024 (Rajakal *et al.* 2024). Approximately 400 palm oil mills are in operation, leading to an increase in oil palm waste from mill production (Umar *et al.* 2021). The waste is generated as biomass waste, some of which is recycled, while most remains unused (Onoja *et al.* 2019). Oil palm biomass generates a large amount of palm kernel shells (PKS), oil palm trunks (OPT), empty fruit bunches (EFB), mesocarp fibres (MF) and oil palm fronds (OPF) and can lead to pollution problems without proper management (Nabilah *et al.* 2023). Major biomass was empty fruit bunches that accumulate after the oil extraction process (Umor *et al.* 2024). This industry is growing rapidly over time and produces a large amount of biomass that must be fully utilised in order to benefit from it (Vakili *et al.* 2015), e.g., as a substrate for mushroom cultivation (Mahari *et al.* 2020)

2.1 *Potential of Oil Palm Biomass for Recycling*

Oil palm biomass is also a valuable agricultural waste, such as empty fruit bunch, which contains a high proportion of organic matter, namely about 95.64% (Nurliyana *et al.* 2015). The nitrogen content is between 0.7% and 1.65%, and the carbon content is between 41.9% and 44% (Chiejina & Osibe 2015; Idris *et al.* 2015; Santi & Goenadi 2019). A study on palm frond waste has shown that it can be a good water reservoir, with more than 60% moisture when wet (Wahab *et al.* 2021) and is also a good source of lignocellulose (Sudheer *et al.* 2016).

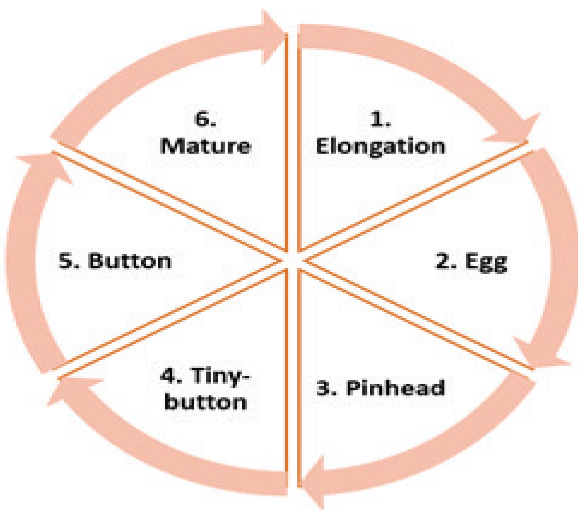

Figure 1. The cycle of *Volvariella sp* (edited by Ahlawat & Arora 2016).

2.2 *Main Properties of Oil Palm biomass that Fit the Volvariella Cultivation*

In Malaysia, sawdust is commercially used for mushroom cultivation, while in other countries mainly wheat or rice straw is used and overall production is strongly supported by the lignocellulosic material from agricultural wastes (Zikriyani *et al.* 2018; Yella *et al.* 2021). Fungi such as *Volvariella* require cellulosic material for their development (Ahlawat & Arora 2016). The cellulase content decreases in the course of composting and decomposition (Sun *et al.* 2021). Table 1 shows the content of hemicellulose, cellulose and lignin in the biomass of oil palms from different regions and countries:

2.3 *Effect of Oil Palm Biomass to the Yield of Volvariella Mushroom*

Oil palm waste fibres such as mesocarp fibres and empty fruit bunch fibres are effective substrates for the growth of mushroom (Sudherr *et al.* 2016). One study observed that empty fruit bunch or shredded palm pressed fibre (PPF) of oil palm cooperated with rubber tree sawdust is potential to give high yield of mushroom (Ali *et al.* 2013). The optimum amount of oil palm empty fruit bunch mixed with nutrients will give high yield of mushroom production (Marlina *et al.* 2015). The research has revealed that whole stalk empty fruit bunch applications give yield of 2.4 kg/m^2 and 3.61% average biological conversion efficiency (BCE) of *Volvariella* (Triyono *et al.* 2019). Oil palm empty fruit bunch show a good reduction for the percentage of the lignocellulose that will also rise the yield of *Volvariella* (Mariadass *et al.* 2024). The yield of *Volvariella* with the pallet oil palm empty fruit bunch is also higher than the use of fibre (Umor *et al.* 2021). Azman *et al.* 2023 presented that oil palm empty fruit bunch shows highest yield compared to rice straw, sawdust and oil palm trunk. Mushroom cultivated with 100% oil palm empty fruit bunch showed 1.9 times faster compared to the control for mushroom growth and agronomic performance (Aubrey *et al.* 2022). One paper showed that the biological efficiency of *Volvariella* cultivation with the application of empty fruit bunches still low at 3.6−6.5% while using paddy straw or banana leaves can give up to 10.2−15.2% (Suwannarach *et al.* 2022).

3. *Composting of Volvariella Substrate*

Composting is to get stable organic matter through biological aerobic, and it can be done by natural or added material to boost the microbial ac-

T a b l e 1

Hemicellulose, cellulose and lignin content of oil palm biomass from differents country observation

Material	Origin	Hemicellulose [%]	Cellulose [%]	Lignin [%]	Reference
OEFB	Malaysia	18.03	45.22	35.90	(Umor *et al.* 2021)
		35.80	36.70	18.60	(Ching & NG 2014)
	Thailand	6.30	41.90	0.70	(Palamae *et al.* 2017)
		37.83	24.21	37.96	(Wadchasit *et al.* 2020)
	Nigeria	33.50	43.51	19.80	(Onuorah *et al.* 2015)
		NA	54.12	18.29	(Kolajo *et al.* 2024)
	Indonesia	13.50	36.67	31.16	(Cifriadi *et al.* 2017)
		20.70	30.41	35.94	(Kristiani *et al.* 2016)
OPF	Malaysia	19.20	31.50	14.00	(Hong *et al.* 2012)
		24.00	58.00	5.00	(Sabrina *et al.* 2013)
	Indonesia	12.41	45.44	15.34	(Astuti *et al.* 2019)
		34.00	42.67	22.90	(Kumneadklang *et al.* 2019)

Note: OEFB − oil palm empty fruit bunches; OPF − oil palm fronds.

tivity (Pergola *et al.* 2018). It was the first step in mushroom cultivation (Li *et al.* 2017) and related to various aerobic microorganisms in the organic matter pure from agricultural waste (Leiva *et al.* 2016). The process can be done either in short or long term, novel procedure is short composting substrate, which reduces the chance of infection by competitive species, possesses energy conservation, achieves high production efficiency, and has a shorter production duration (Liu *et al.* 2022). Composting would produce a superior nutritional source, especially protein for mushrooms from the components of raw lignocellulosic materials (Mohamed *et al.* 2016).

3.1 *Volvariella Development Effect by Different Period of Composting*

Basically, for mushroom composting of substrate, the period suggested before spawning ranged from 5 − 10 days (Umor *et al.* 2023; Mariadass *et al.* 2024). Besides, it also suggested not to be more than 8 days as the activity will start to drop off (Triyono *et al.* 2019). On the other hand, Vieira *et al.* (2016) suggested 7 days of composting to get as high as an effective period for the good composting process. It is similar to one study that observed 7 days is good for the activity and pH of compost compared to 5 days, 3 days, or un-composted substrates (Saskiawan *et al.* 2023). The 8 days of composting together with fertiliser will increase the decomposition rate that will lead to high productivity in the harvest stage (Triyono *et al.* 2019). To get good development of fruiting bodies by substrate 4 days is suggested rather than 3 or 5 days of composting (Guo *et al*. 2023). Furthermore, the composting of substrate for 7 days is showing good results of yield (Vieira *et al.* 2016) and lessen to 5 days also has the potential to get high yield (Yang *et al.* 2022). Another researcher proved that without composting, the substrate can also give a higher yield of *Volvariella* (Umor *et al.* 2024). For better results on mushroom development, 1 day of composting is acceptable with the help of a steamer being cooled down and proceeding to spawn (Ahlawat & Arora 2016). Composting substrate for 4 or 5 days is significant for the mushroom development together with high polysaccharide content compared to 3 days of composting (Guo *et al.* 2023). Biological efficiency observed in one trial using paddy straw as substrate for 3 different days of composting 3, 6 & 9 days were 10.25, 7.2 and 6.82% (Elangovan *et al.* 2023)

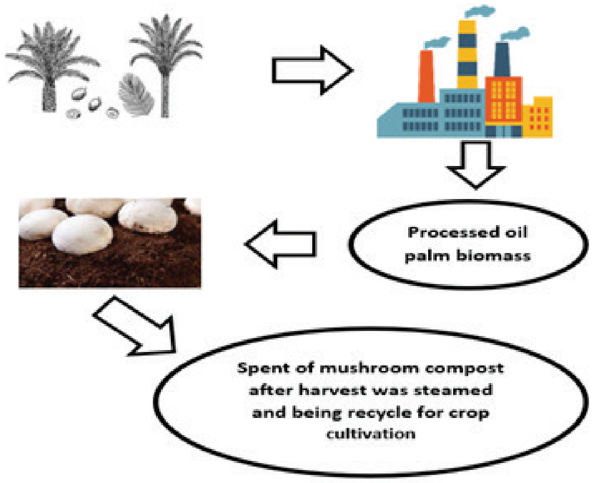

Figure 2. Flow for the management of oil palm biomass.

4. *Maize Cultivation Prospect*

Maize cultivation is one of the most important agricultural activities globally and has been increasing significantly in Malaysia. This increase may be caused by the use for various industries to fulfill the market demand (Sirisuntornlak *et al.* 2021) and being used for human diet and some animal meal that can be declared as a major supply of energy to the poultry (Urassa 2015; Dei & Herbert 2017). Maize is also being largely involved in import or export process within the country (Wang & Hu 2021). Cultivation of maize in terms of yield is the same as most of the crops in the world that will be affected by the harvest stage, climatic conditions and varieties used (Nazli *et al.* 2019). The cultivation of maize will benefit from the application of organic material rather than chemical material to increase the chemical and physical properties of soil that will lead to good crop production (Omovbude *et al.* 2019). With soil nutrient deficiency, weakly structured, low retention, and water holding and retention capacity will be a limitation to support the growth of maize (Adzemi *et al.* 2017).

5. *Post Management of Spent Mushroom Substrates*

Generally, spent mushroom substrate or spent mushroom compost is generated by the cultivation of mushrooms (Li *et al.* 2017). Its management has become challenging for the mushroom producer in terms of economically sustainable and environmentally solutions for this organic residue (Paula *et al.* 2017) and has become an abundant agricultural waste (Othman *et al.* 2020) that will bring to serious environmental problems at the end of mushroom cultivation (Martin *et al.* 2023). This waste would mostly be made of cellulose material that can continue to be decomposed after being used for the mushroom cultivation (Sun *et al.* 2021). Interestingly, many researchers start to highlight the potential of spent mushroom substrates compost such as reusing for mushroom cultivation (Cunha Zied *et al.* 2020), applying it on soil as plant development supporting material (Mwangi *et al.* 2024) and converting it into animal feed or fertiliser (Umor *et al.* 2021). The diagram concludes on the flow from the process of oil palm biomass converting into mushroom substrate by composting and lastly being reused for soil amendment of crop cultivation (Omovbude *et al.* 2019; Triyono *et al.* 2019; Cunha *et al.* 2020).

5.1 *Effect of Spent Mushroom Substrates on Physiochemical Properties of Soil*

Spent mushroom substrates can be fantastically used in horticulture or agriculture, helping to reduce the use of non-renewable resources such as peat soils (Paula *et al.* 2017), to be used as a soil fertiliser (Umor *et al.* 2021) and positively influence soil properties for plant cultivation (Cunha Zied *et al.* 2020). It also contains nutrients that are important for the health of the field, such as nitrogen, phosphorus, and potassium (Madrim 2018; Othman *et al.* 2020). It can also be a good mobilizer of phosphate, allowing the highest uptake of phosphate by the root and transfer to the leaves (Roy *et al.* 2015). The optimal application of spent mushroom substrate has a positive effect on the utilisation of carbon sources in the soil (Li *et al.* 2020). Nutrients P and K increase over time, while C and N decrease over time (Ashrafi *et al.* 2014). The results showed that the available and total nitrogen, potassium and phosphorus content increased significantly when the soil was mixed with 39%, 24%, 17%, 28%, 18% and 70% of the residual substrate of *V. volvacea* after one to three weeks, and slowly decreased thereafter (Yang *et al.* 2017). The result of using mushroom substrates was improved by adding chicken manure to promote the composting of these wastes (Tao *et al.* 2022). On the other hand, the used mushroom substrates increase soil pH by 1.0 − 1.2 units compared to untreated soil (Lipiec *et al.* 2021). A study has shown that fresh mushroom substrate has a pH of 6.2 and increases to 7.2 after conversion to biochar (Lou *et al.* 2017). On the other hand, the pH of oyster mushroom substrate was slightly acidic at 5.06 (Owaid *et al.* 2017) and that of button mushroom substrate was quite alkaline at 7.6 (Carpio *et al.* 2023). Wei *et al.* (2020) found that the spent mushroom substrate has a positive effect on soil pH. Another study showed that the pH decreases when using spent mushroom substrates, but the electrical conductivity of the soil increases (Van & Wang 2015). The higher pH of spent mushroom substrates was 7.8 − 8.1, which favours acidic soils (Velusami *et al.* 2022) and this value increases with a higher number of spent mushroom substrates (Ashrafi *et al.* 2014).

5.2 *Effect of Spent Mushroom Substrates on Phosphorus Availability in Soil*

The waste from mushroom cultivation contains abundant nutrients, including organic matter, phosphorus (P) and nitrogen (N), which can provide nutrients to the soil (Lou *et al.* 2015). They can also be converted into fertilisers by using methods such as composting and vermicomposting, which can avoid or reduce the use of chemical fertilisers (Rajavat *et al.* 2022). Theoretically, the mushroom substrate, which is already mixed with nutrients, can serve as a nutrient cycle and increase the bioavailability of nutrients to the soil (Hu *et al.* 2021). A study has proven that it is a good substitute for fertiliser without any negative impact on the crop (Hacket 2015). The nutrient content of spent mushroom substrates was higher compared to standard media or peat soil (Catal & Peksen 2018). Application of spent mushroom substrates at 40 or 20 t/ha increases phosphorus availability in the soil (Gerdelidani & Hosseini 2017). The application of 12 t/ha of spent enoki substrate and 10 t/ha of spent button substrate was effective in supplying phosphorus after deducting chemical fertilisers (Chen *et al.* 2022). The application of spent mushroom substrates to the soil with or without the addition of fertiliser resulted in the same total phosphorus content of 0.21 g/kg (Kwiatkowska & Joniec 2022). Phosphorus analysis of spent button mushroom and oyster mushroom showed a content of 6.80 g/kg and 3.74 kg, respectively (Paredes *et al.* 2016). Carpio *et al.* (2023) found a low available phosphorus content of 1.14 g/kg in compost from button mushrooms and another researcher found a lower phosphorus content in compost from oyster mushrooms, which was 0.8 mg/kg (Wiafe-Kwagyan & Odamtten 2018). The percentage of phosphorus in the spent mushrooms increases with the time of composting after mushroom cultivation as found in this study, which was 0.35% phosphorus in 1 month and up to 0.65% in 3 months (Ashrafi *et al.* 2014).

5.3 *Effect of Spent Mushroom Substrates on Various Crop Cultivation*

Mixing the mushroom substrates for growing other crops would be helpful to achieve healthier plants and higher yields (Jasińska 2018). Some spent mushrooms also have a high nitrogen content (Owaid *et al.* 2017) and are also a good material for nutrient conservation in the soil (Lou *et al.* 2015) that will promote plant development and lead to successful crop production. A study has shown that the application of 15 tonnes of compost from spent mushrooms per hectare has a good effect on the yield of barley and as a nitrogen supplier (Hacket 2015). The application of spent mushrooms as a top dressing in vegetable cultivation shows good results for productivity (Zied *et al.* 2021). A study on lettuce shows that the application of substrates from mushroom waste gives the same results as the application of mineral fertilisers (Paredes *et al.* 2016) and a study also shows a good development of the lettuce crop when applying 45% or 75% of substrates from mushroom waste (Marques *et al.* 2014). On the other hand, the use of spent mushroom substrate from button and oyster mushrooms was found to increase the development of *Capsicum annuum* L. (Roy *et al.* 2015). One study concluded that aged mushroom substrates is more suitable for plant production than fresh mushroom substrates (Demir 2017). The use of mushroom substrates is suitable as a substitute for synthetic fertilisers in maize cultivation (Alves *et al.* 2022). Table 2 focuses on the effect of spent mushroom on different setups using spent mushroom substrates.

5.3.1 *Effect of Mushroom Substrates on Growth and Photosynthesis Rate of Maize*

Spent mushroom substrates (SMS) have gained attention for their multifunctional role in agriculture, particularly as a carrier for plant growth-promoting microbes (Othman *et al.* 2020), which can enhance plant growth and yield (Yu *et al.* 2019). It can also act as a slow-release fertiliser that causes efficient nutrient uptake, which promotes good plant

Table 2

Effect of various types of spent mushroom substrates to maize crop at different area

Area	Recommended doses	Spent mushroom application	Respond	Reference
Mushroom Research Centre, Solan, India	15 t/ha of spent mushroom compost	Button mushroom	6.6 t/ha	(Yadav *et al.* 2015)
Faculty of Chemistry, University of Technology Smoluchowskiego, Poland	0.3 t/ha spent mushroom compost	–	6.4 t/ha grain	(Tuhy *et al.* 2015)
Agricultural Sciences and a Sustainable Environment, Pennsylvania State University, Berks Campus, Pennsylvania, U.S.	50 t/ha of spent mushroom compost	Fresh mushroom substrate	Increase the yield compared to the control	(Coles *et al.* 2020)
Gorowong Village, Parungpanjang District, Bogor Regency, West Java	45 t/ha	Vermicompost mushroom substrate	31.7 g of 100 seed grains	(Purnawanto *et al.* 2022)
College of Agriculture, MSU, Marawi City	20 t/ha	Half-dry spent mushroom	4.28 t	(Ambos & Calipusan 2017)
Department of Pathology, Federal Research Institute of Nigeria	27 kg/ha	Hydroponic geminate stage	1.8 cm higher than chemical fertiliser treatment	(Oluwabamiro *et al.* 2023)

development with sufficient nutrients (Muchena *et al.* 2021) and neutralises the pH of the soil, which has a positive effect on plant growth (Coles *et al.* 2020; Oluwabamiro *et al.* 2023). One researcher found that the mushroom compost consumed increased the potassium content in the soil and was also high in the analysis of leaf uptake (Alves *et al.* 2022). A study conducted at the early stage of maize in 8 days using spent mushroom substrates in a hydroponics plant gave 750 g fresh weight, 400 g dry weight, 11.6 cm plant height, and the highest results in maize, fibre and ash compared to NPK and control (Oluwabamiro *et al.* 2023). Another study conducted up to the maturity stage, applying 2.5 t/ha of spent mushrooms with 2.5 t/ha of chicken manure, showed a 20% increase in leaf index compared to the control and a plant height of 246.9 cm compared to the control (159 cm) (Omovbude *et al.* 2019). The application of compost from spent mushrooms to the plant appeared to increase chlorophyll content, which is a sign of a high photosynthetic rate of the leaf (Roy *et al.* 2015; Salachna *et al.* 2021), and the use of vermicompost from spent mushroom substrate had the same effect on the increase in chlorophyll content (Duggan 2015).

CONCLUSIONS

The growing demand for agricultural products has significantly increased biomass waste generation, posing environmental challenges if not effectively managed. This study highlights the potential of repurposing oil palm biomass, specifically empty fruit bunches (EFB) and oil palm fronds (OPF) as substrates for *Volvariella* mushroom cultivation, offering a sustainable approach that not only improves mushroom yield and biological efficiency but also contributes to circular agricultural practices. Furthermore, the reuse of spent mushroom substrates (SMS) as a soil conditioner for maize demonstrates promising benefits for soil health and crop growth. However, existing research remains limited and sometimes yields inconsistent results. To fully realize the potential of these practices, further studies are needed to optimize substrate formulations, assess the long-term agronomic and environmental impacts, and evaluate their scalability. Advancing this line of research will contribute to more sustainable and resource-efficient agricultural systems by reducing biomass waste and enhancing overall productivity.

Acknowledgements: Conceptualization, M.K.U. and S.Z., literature collection, A.N.A.H. and M.H.R., writing-original draft preparation, N.A.U., writing-review and editing, M.K.U., S.Z., M.H.R. and N.A.U. All authors have read and agreed to the published version of the manuscript. The authors thank the grant FRGS5540389, Universiti Putra Malaysia. and PARTNER Project founder by Bangladesh Agriculture Research Council (BARC), vote 6380231.

REFERENCES

Adzemi, M., Usman, M., Rawayau, Y., & Dalorima, T. (2017). Soil suitability evaluation for maize crop production in Terengganu Region of Malaysia. *International Journal of Scientific Research in Science and Technology*, *3*(8), 151 − 158. Available at: https://ijsrset.com/IJSRSET173821.

Ahlawat, O. P. & Arora, B. (2016). Paddy straw mushroom (Volvariella volvacea) cultivation. In Upadhyay, R. C. (Ed.) *Mushrooms in India: Diversity, Improvement, Cultivation, Medicinal Uses and Value Addition for Rural Development.* CRDT, IIT New Delhi, pp. 165 – 182. Avaiable at: https://www.researchgate.net/publication/343499927.

Alam, A. F., Er, A. C. & Begum, H. (2015). Malaysian oil palm industry: Prospect and problem. *Journal of Food, Agriculture & Environment*, *13*(2), 143 − 148. Avaiable at: https://www.wflpublisher.com/Abstract/3952.

Ali, N., Tabi, A. N. M., Zakil, F. A., Fauzai, W. N. F. M., & Hassan, O. (2013). Yield performance and biological efficiency of empty fruit bunch (EFB) and palm pressed fibre (PPF) as substrates for the cultivation of Pleurotus ostreatus. *Jurnal Teknologi*, *64*(1). DOI:10.11113/jt.v64.1243.

Alves, L. D. S., Caitano, C. E. C., Ferrari, S., Vieira Júnior, W. G., Heinrichs, R., de Almeida Moreira, B. R.,... & Zied, D. C. (2022). Application of spent sun mushroom substrate in substitution of synthetic fertilizers at maize topdressing. *Agronomy*, *12*(11), 2884. DOI:10.3390/agronomy12112884.

Ambos, A. L. & Calipusan, B. C. (2017). Growth and yield performance of sweet corn (Zea Mays L.) intercropped with sweet potato (Ipomoea batatas L.) applied with mushroom spent and rice ash. *Science International*, *29*(2), 87 − 87. Avaiable at: https://www.sci-int.com/pdf/636296604167668740.pdf.

Amir, N. F., Aris, A. M., Mohamad, A., Umor, N. A., Abdullah, S., & Yusof, F. M. (2023). Mycelium running of *Volvariella volvacea* on palm oil empty fruit bunch fibre following different substrate and mycelium treatment. In *IOP Conference Series: Earth and Environmental Science*, *1151*(1), 012054. DOI:10.1088/1755-1315/1151/1/012054.

Amir, N. F., Mohd-Aris, A., Mohamad, A., Abdullah, S., Yusof, F. Z., & Umor, N. A. (2023). Spawn production and cultivation technology for *Volvariella volvacea*: a perspective. *Food Research*, *7*(4), 93−101. DOI:10.26656/fr.2017.7(S4).12.

Amir, N.F., Mohd-Aris, A., Tuan-Zakaria, T.N., Umor, N.A., Mohamad, A., Razali, N.M., ... & Abdullah, S. (2025). Effect of physiochemical parameters on yield and biological efficiency of *Volvariella volvacea* cultivated on empty fruit bunch pellets. *Heliyon*, *11*(4). Avaiable at: https://ir.uitm.edu.my/id/eprint/106270.

Ashrafi, R., Rahman, M.M., Jahiruddin, M., & Mian, M.H. (2014). Quality assessment of compost prepared from spent mushroom substrate. *Progressive Agriculture*, *25*, 1−8. DOI:10.3329/pa.v25i0.24063.

Astuti, T., Rofiq, M.N. & Santoso, U. (2019). Analysis of fibre fraction of palm oil frond fermented with different microbes and soluble carbohydrates addition as ruminant feeding. *IOP Conference Series: Earth and Environmental Science*, *347*(1), 012059. DOI:10.1088/1755-1315/347/1/012059.

Aubrey, M.L.L., Chin, C.F.S., Seelan, J.S.S., Chye, F.Y., Lee, H.H., & Rakib, M.R.M. (2022). Conversion of oil palm by-products into value-added products through oyster mushroom (Pleurotus ostreatus) cultivation. *Horticulturae*, *8*(11), 1040. DOI:10.3390/horticulturae8111040.

Azman, N.F., Katahira, T., Nakanishi, Y., Chisyaki, N., Uemura, S., Yamada, M., ... & Yamauchi, M. (2023). Sustainable oil palm biomass waste utilization in Southeast Asia: Cascade recycling for mushroom growing, animal feedstock production, and composting animal excrement as fertilizer. *Cleaner and Circular Bioeconomy*, *6*, 100058. DOI:10.1016/j.clcb.2023.100058.

Carpio, M.J., Andrades, M.S., Herrero-Hernández, E., Marín-Benito, J.M., Sánchez-Martín, M.J., & Rodríguez-Cruz, M.S. (2023). Changes in vineyard soil parameters after repeated application of organic-inorganic amendments based on spent mushroom substrate. *Environmental Research*, *221*, 115339. DOI:10.1016/j.envres.2023.115339.

Catal, S. & Peksen, A. (2018). Physical, chemical and biological properties of spent mushroom substrates of different mushroom species. *ISHS Acta Horticulturae 1287*, 353−360. DOI:10.17660/ActaHortic.2020.1287.45.

Chen, L., Zhou, W., Luo, L., Li, Y., Chen, Z., Gu, Y., ... & Deng, L. (2022). Short-term responses of soil nutrients, heavy metals and microbial community to partial substitution of chemical fertilizer with spent mushroom substrates (SMS). *Science of the Total Environment*, *844*, 157064. DOI:10.1016/j.scitotenv.2022.157064.

Chiejina, N.V. & Osibe, D.A. (2015). Oil palm fruit fibre promotes the yield and quality of Lentinus squarrosulus (Mont.) Singer, an edible Nigerian mushroom. *African Journal of Biotechnology*, *14*(14), 1195−1200. DOI:10.5897/AJB2015.14400.

Ching, Y.C. & Ng, T.S. (2014). Effect of preparation conditions on cellulose from oil palm empty fruit bunch fiber. *BioResources*, *9*(4), 6373−6385. DOI:10.15376/biores.9.4.6373-6385.

Cifriadi, A., Panji, T., Wibowo, N.A., & Syamsu, K. (2017). Bioplastic production from cellulose of oil palm empty fruit bunch. *IOP Conference Series: Earth and Environmental Science*, *65*(1), 012011. DOI:10.1088/1755-1315/65/1/012011.

Coles, P.S., Nogin, G., Fidanza, M., & Roth, G. (2020). Evaluation of fresh mushroom compost in a field corn production system. *Compost Science & Utilization*, *28*(2), 76−86. DOI:10.1080/1065657X.2020.1749184.

Cunha Zied, D., Sánchez, J.E., Noble, R., & Pardo-Giménez, A. (2020). Use of spent mushroom substrate in new mushroom crops to promote the transition towards a circular economy. *Agronomy*, *10*(9), 1239. DOI:10.3390/agronomy10091239.

Demir, H. (2017). The effects of spent mushroom compost on growth and nutrient contents of pepper seedlings. *Mediterranean Agricultural Sciences*, *30*(2), 91−96. Avaiable at: https://dergipark.org.tr/en/pub/mediterranean/issue/30609/333547.

Diamantopoulou, P., Papanikolaou, S., Aggelis, G., & Philippoussis, A. (2016). Adaptation of *Volvariella volvacea* metabolism in high carbon to nitrogen ratio media. *Food Chemistry*, *196*, 272−280. DOI:10.1016/j.foodchem.2015.09.027.

Duggan, T. (2015). *Effects of Vermicomposted Spent Mushroom Compost on Growing Medium Characteristics, Plant Growth, Yield and Abiotic Stress Tolerance.* PhD Thesis, University College Cork, 191p. Avaiable at: https://dergipark.org.tr/en/pub/mediterranean/issue/30609/333547.

Dungani, R., Aditiawati, P., Aprilia, S., Yuniarti, K., Karliati, T., Suwandhi, I., & Sumardi, I. (2018). Biomaterial from oil palm waste: properties, characterization and applications. *Palm Oil*, *31*, 1−6. DOI:10.5772/intechopen.76412.

Eguchi, F., Kalaw, S.−P., Dulay, R.M.R., Miyasawa, N., Yoshimoto, H., Seyama, T., & Reyes, R.G. (2015). Nutrient composition and functional activity of different stages in the fruiting body development of Philippine paddy straw mushroom, *Volvariella volvacea* (Bull.: Fr.) Sing. *Advances in Environmental Biology*, *9*(22 S3), 54−66. https://www.researchgate.net/publication/301787377.

Elangovan, M., Thakur, N., & Biswas, M. K. (2023). Enhancing Yield and Biological Efficiency of *Volvariella volvaceae* through Non-Conventional Cultivation Methods. *International Journal of Environment and Climate Change*, *13*(10), 3145−3151. DOI: 10.9734/ijecc/2023/v13i102983.

El-Sebaaly, Z., Hammoud, M., & Sassine, Y.N. (2021). History, health benefits, market, and production status of button mushroom. In Sassine, Y.N. (Ed.) *Mushrooms: Agaricus bisporus,* Wallingford UK: CABI, pp. 1−65. DOI: 10.1079/9781800620414.0001.

Gerdelidani, A.F. & Hosseini, H.M. (2017). Effects of sugar cane bagasse biochar and spent mushroom compost on phosphorus fractionation in calcareous soils. *Soil Research*, *56*(2), 136−144. DOI:10.1071/SR17091.

Guo, Y.X., Yang, Y.R., Qin, Y., Guan, T.K., Yang, Q.Z., Wang, Y.X., ... & Chen, Q.J. (2023). Nutritional qualities and antioxidant activity of Pleurotus floridanus grown on composted peach sawdust substrate with different composting time. *Biotechnology and Applied Biochemistry*, *70*(1), 210−220. DOI:10.1002/bab.2344.

Hackett, R. (2015). Spent mushroom compost as a nitrogen source for spring barley. *Nutrient Cycling in Agroecosystems*, *102*, 253−263. DOI:10.1007/s10705-015-9691-5.

Han, J., Sun, R., Huang, C., Xie, H., Gao, X., Yao, Q., ... & Gong, Z. (2024). Effects of different carbon and nitrogen ratios on yield, nutritional value, and amino acid contents of Flammulina velutipes. *Life*, *14*(5), 598. DOI:10.3390/life14050598.

Harun, S.N., Hanafiah, M.M. & Noor, N.M. (2022). Rice straw utilisation for bioenergy production: A brief overview. *Energies*, *15*(15), 5542. DOI:10.3390/en15155542.

Herbert, K.D. (2017). Assessment of maize (Zea mays) as feed resource for poultry. In Manafi, M. (Ed.) *Poultry Science,* InTech, pp. 1−32. DOI:10.5772/65363.

Hong, L.S., Ibrahim, D. & Omar, I.C. (2012). Oil palm frond for the production of bioethanol. *International Journal of Biochemistry and Biotechnology*, *1*(1), 007-

011. Avaiable at: https://internationalscholarsjournals.org/articles/4069159505052012.

Hosseini, S.E., Wahid, M.A. & Ganjehkaviri, A. (2015). An overview of renewable hydrogen production from thermochemical process of oil palm solid waste in Malaysia. *Energy Conversion and Management*, *94*, 415−429. DOI:10.1016/j.enconman.2015.02.012.

Hu, Y., Mortimer, P.E., Hyde, K.D., Kakumyan, P., & Thongklang, N. (2021). Mushroom cultivation for soil amendment and bioremediation. *Circular Agricultural Systems*, *1*(1), 1−14. DOI:10.48130/CAS-2021-0011.

Idris, J., Shirai, Y., Anduo, Y., Ali, A.A.M., Othman, M.R., Ibrahim, I., ... & Hassan, M.A. (2015). Improved yield and higher heating value of biochar from oil palm biomass at low retention time under self-sustained carbonization. *Journal of Cleaner Production*, *104*, 475−479. DOI:10.1016/j.jclepro.2015.05.023.

Jasińska, A. (2018). Spent mushroom compost (SMC)–retrieved added value product closing loop in agricultural production. *Acta Agraria Debreceniensis*, *150,* 185−202. DOI:10.34101/actaagrar/150/1715.

Kolajo, T.E., Ewemoje, O.E. & Adefowope, G. (2024). Physico-chemical assays of oil palm (Elais guineesis) empty fruit bunch fractions for biosynthesis. *Journal of Materials and Environmental Science, 15*(3), 386−396. Avaiable at: https://www.jmaterenvironsci.com/Document/vol15/vol15_N3/JMES-2024-150324-Kolajo.pdf.

Kristiani, A., Effendi, N., Styarini, D., Aulia, F., & Sudiyani, Y. (2016). The effect of pretreatment by using electron beam irradiation on oil palm empty fruit bunch. *Atom Indonesia*, *42*(1), 9−12. DOI:10.17146/aij.2016.472.

Kumar, K. (2015). Studies on development and shelf life evaluation of soup powder prepared by incorporation of white button mushroom (Agaricus bisporus L.). *South Asian Journal of Food Technology and Environment*, *1*(3&4), 219−224. Avaiable at: https://journals.indexcopernicus.com/api/file/viewByFileId/972543.

Kumneadklang, S., Sompong, O. & Larpkiattaworn, S. (2019). Characterization of cellulose fiber isolated from oil palm frond biomass. *Materials Today: Proceedings*, *17*, 1995−2001. DOI:10.1016/j.matpr.2019.06.247.

Kwiatkowska, E. & Joniec, J. (2022). Effects of agricultural management of spent mushroom waste on phytotoxicity and microbiological transformations of C, P, and S in soil and their consequences for the greenhouse effect. *International Journal of Environmental Research and Public Health*, *19*(19), 12915. DOI:10.3390/ijerph191912915.

Leiva, F., Saenz-Díez, J.C., Martínez, E., Jiménez, E., & Blanco, J. (2016). Environmental impact of mushroom compost production. *Journal of the Science of Food and Agriculture*, *96*(12), 3983−3990. DOI:10.1002/jsfa.7587.

Li, F., Kong, Q., Zhang, Q., Wang, H., Wang, L., & Luo, T. (2020). Spent mushroom substrates affect soil humus composition, microbial biomass and functional diversity in paddy fields. *Applied Soil Ecology*, *149*, 103489. DOI:10.1016/j.apsoil.2019.103489.

Li, Z., Chen, M., Yu, C., Li, Q., Zhou, F., & Li, Y. (2017). Five steps to cultivate *Volvariella volvacea*. *Agricultural Science & Technology*, *18*(9), 1593−1594.

Lipiec, J., Usowicz, B., Kłopotek, J., Turski, M., & Frąc, M. (2021). Effects of application of recycled chicken manure and spent mushroom substrate on organic matter, acidity, and hydraulic properties of sandy soils. *Materials*, *14*(14), 4036. DOI:10.3390/ma14144036.

Liu, Q., Kong, W., Cui, X., Hu, S., Shi, Z., Wu, J., ... & Qiu, L. (2022). Dynamic succession of microbial compost communities and functions during Pleurotus ostreatus mushroom cropping on a short composting substrate. *Frontiers in Microbiology*, *13*, 946777. DOI:10.3389/fmicb.2022.946777.

Lou, Z., Sun, Y., Bian, S., Baig, S.A., Hu, B., & Xu, X. (2017). Nutrient conservation during spent mushroom compost application using spent mushroom substrate derived biochar. *Chemosphere*, *169*, 23−31. DOI:10.1016/j.chemosphere.2016.11.044.

Lou, Z., Zhu, J., Wang, Z., Baig, S.A., Fang, L., Hu, B., & Xu, X. (2015). Release characteristics and control of nitrogen, phosphate, organic matter from spent mushroom compost amended soil in a column experiment. *Process Safety and Environmental Protection*, *98*, 417−423. DOI:10.1016/j.psep.2015.10.003.

Luu, T.T. H., Bui, D.K., Huynh, N., Le, T.L., & Green, I. (2022). Effect of the cultivation technology on the yield of paddy straw mushroom (*Volvariella volvacea*). *The Korean Journal of Mycology*, *50*(3), 161−171. DOI:10.4489/KJM.20220017.

Madrim, N. (2018). *Composting and Vermicomposting of Spent Mushroom Substrate for Organic Fertiliser and Cultivation of Schizophyllum Commune*. Master's thesis, University of Malaya (Malaysia). Avaiable at: https://www.proquest.com/openview/7c45b8844cf6ac9ebc3144dfcfe4028a.

Mahari, W.A.W., Peng, W., Nam, W.L., Yang, H., Lee, X.Y., Lee, Y.K., ... & Lam, S.S. (2020). A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry. *Journal of Hazardous Materials*, *400*, 123156. DOI:10.1016/j.jhazmat.2020.123156.

Mamimin, C., Chanthong, S., Leamdum, C., Sompong, O., & Prasertsan, P. (2021). Improvement of empty palm fruit bunches biodegradability and biogas production by integrating the straw mushroom cultivation as a pretreatment in the solid-state anaerobic digestion. *Bioresource Technology*, *319*, 124227. DOI:10.1016/j.biortech.2020.124227.

Mariadass, M., Md Shaarani, S., Ab Rahman, R., Veeramalai, S., & Wan Azelee, N.I. (2024). Biodegradation of oil palm empty fruit bunch during cultivation of *Volvariella volvacea*. *Environmental Quality Management*, *33*(4), 749−758. DOI:10.1002/tqem.22151.

Marlina, L., Sukotjo, S. & Marsudi, S. (2015). Potential of oil palm empty fruit bunch (EFB) as media for oyster mushroom, Pleurotus ostreatus cultivation. *Procedia Chemistry*, *16*, 427−431. DOI:10.1016/j.proche.2015.12.074.

Marques, E.L.S., Martos, E.T., Souza, R.J., Silva, R., Zied, D.C., & Dias, E.S. (2014). Spent mushroom compost as a substrate for the production of lettuce seedlings. *Journal of Agricultural Science*, *6*(7), 138−143. DOI:10.5539/jas.v6n7p138.

Martin, C., Zervakis, G.I., Xiong, S., Koutrotsios, G., & Strætkvern, K.O. (2023). Spent substrate from mushroom cultivation: exploitation potential toward various applications and value-added products. *Bioengineered*, *14*(1), 2252138. DOI:10.1080/21655979.2023.2252138.

Mohamed, M.F., Refaei, E.F., Abdalla, M.M., & Abdelgalil, S.H. (2016). Fruiting bodies yield of oyster mushroom (Pleurotus columbinus) as affected by different portions of compost in the substrate. *International Journal of Recycling of Organic Waste in Agriculture, 5,* 281−288. DOI:10.1007/s40093-016-0138-2.

Muchena, F.B., Pisa, C., Mutetwa, M., Govera, C., & Ngezimana, W. (2021). Effect of spent button mushroom substrate on yield and quality of baby spinach (Spinacia oleracea). *International Journal of Agronomy*, *2021*(1), 6671647. DOI:10.1155/2021/6671647.

Mwangi, R.W., Mustafa, M., Kappel, N., Csambalik, L., & Szabó, A. (2024). Practical applications of spent mushroom compost in cultivation and disease control of selected vegetables species. *Journal of Material Cycles and Waste Management*, *26,* 1918 − 1933. DOI:10.1007/s10163-024-01969-9.

Nabila, R., Hidayat, W., Haryanto, A., Hasanudin, U., Iryani, D.A., Lee, S., ... & Yoo, J. (2023). Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization. *Renewable and Sustainable Energy Reviews*, *176*, 113193. DOI:10.1016/j.rser.2023.113193.

Nannapaneni, K.K., Subbiah, A.K. & Damodarasamy, A. (2016). Studies on the influence of carbon and nitrogen nutrition on the chlamydospores production of *Volvariella volvaceae* (Bull. Ex Fr.) sing. and *Volvariella bombycina* (Schaeff.) Singer. *International Journal of Current Research*, *8*(07), 34618 − 34623. https://www.researchgate.net/profile/N-Kiran-Kumar-3/publication/315724384

Nazli, M.H., Halim, R.A., Abdullah, A.M., Hussin, G., & Samsudin, A.A. (2019). Potential of four corn varieties at different harvest stages for silage production in Malaysia. *Asian-Australasian Journal of Animal Sciences*, *32*(2), 224 − 232. DOI:10.5713/ajas.18.0175.

Nurliyana, M.Y., H'ng, P.S., Rasmina, H., Kalsom, M.U., Chin, K.L., Lee, S.H., ... & Khoo, G.D. (2015). Effect of C/N ratio in methane productivity and biodegradability during facultative co-digestion of palm oil mill effluent and empty fruit bunch. *Industrial Crops and Products*, *76*, 409 − 415. DOI:10.1016/j.indcrop.2015.04.047.

Obodai, M. & Odamtten, G.T. (2012). Mycobiota and some physical and organic composition of agricultural wastes used in the cultivation of the mushroom *Volvariella volvacea*, *Journal of Basic & Applied Mycology, 3*(2012), 21 − 26.

Oluwabamiro, K.S., Adenipekun, C.O., Ijimbili, S.B., & Oyetunji, O.J.(2022). Comparative effect of spent mushroom compost and NPK fertilizer on the growth of Sorghum bicolor L. Moench and Zea mays L. using fodder hydroponics techniques. *Biotechnology Journal International, 27*(5), 92 − 102. DOI:10.9734/BJI/2023/v27i5700.

Omovbude, S., Udom, B.E., & Udensi, U.E. (2019). Effects of poultry manure and spent mushroom substrate on soil, weed and maize performance in an Ultisol. *Greener Journal of Agricultural Sciences, 9*(2), 146 − 154. DOI:10.15580/GJAS.2019.2.033119060.

Onoja, E., Chandren, S., Abdul Razak, F.I., Mahat, N.A., & Wahab, R.A. (2019). Oil palm (Elaeis guineensis) biomass in Malaysia: the present and future prospects. *Waste and Biomass Valorization*, *10*, 2099 − 2117. DOI:10.1007/s12649-018-0258-1.

Onuorah, E.O., Nwabanne, J.T. & Nnabuife, E.L.C. (2015). Pulp and paper making potentials of Elaeis guineensis (oil palm) grown in south east, Nigeria. *World Journal of Engineering*, *12*(1), 1 − 12. DOI:10.1260/1708-5284.12.1.1.

Othman, N.Z., Sarjuni, M.N.H., Rosli, M.A., Nadri, M.H., Yeng, L.H., Ying, O.P., & Sarmidi, M.R. (2020). Spent mushroom substrate as biofertilizer for agriculture application. In Zakaria, Z., Boopathy, R., Dib., J. (Eds.) *Valorisation of Agro-industrial Residues–Volume I: Biological Approaches*, Elsevier Cham, pp. 37 − 57. DOI:10.1007/978-3-030-39137-9_2.

Owaid, M.N., Abed, I.A., & Al-Saeedi, S.S.S. (2017). Applicable properties of the bio-fertilizer spent mushroom substrate in organic systems as a byproduct from the cultivation of Pleurotus spp. *Information Processing in Agriculture*, *4*(1), 78 − 82. DOI:10.1016/j.inpa.2017.01.001.

Palamae, S., Dechatiwongse, P., Choorit, W., Chisti, Y., & Prasertsan, P. (2017). Cellulose and hemicellulose recovery from oil palm empty fruit bunch (EFB) fibers and production of sugars from the fibers. *Carbohydrate polymers*, *155*, 491 − 497. DOI:10.1016/j.carbpol.2016.09.004.

Pani, B.K., Chinara, N. & Mohapatra, K.B. (2017). Effect of substrate moisture on the production of straw mushroom, *Volvariella volvacea*. *Mushroom Research*, *26*(2). Avaiable at: https://epubs.icar.org.in/index.php/MR/article/view/70639.

Paredes, C., Medina, E., Bustamante, M.A., & Moral, R. (2016). Effects of spent mushroom substrates and inorganic fertilizer on the characteristics of a calcareous clayey-loam soil and lettuce production. *Soil Use and Management*, *32*(4), 487 − 494. DOI:10.1111/sum.12304.

Paula, F.S., Tatti, E., Abram, F., Wilson, J., & O'Flaherty, V. (2017). Stabilisation of spent mushroom substrate for application as a plant growth-promoting organic amendment. *Journal of Environmental Management*, *196*, 476 − 486. DOI:10.1016/j.jenvman.2017.03.038.

Pergola, M., Persiani, A., Palese, A.M., Di Meo, V., Pastore, V., D'Adamo, C., & Celano, G. (2018). Composting: The way for a sustainable agriculture. *Applied Soil Ecology*, *123*, 744 − 750. DOI:10.1016/j.apsoil.2017.10.016.

Purnawanto, A.M. & Ahadiyat, Y.R. (2022). Maize growth and yield characteristics with application of mushroom waste substrate vermicompost in Ultisol. *Agronomy Research, 20*(S1), 1090 − 1103. DOI:10.15159/AR.22.071.

Rajakal, J.P., Ng, F.Y., Zulkifli, A., How, B.S., Sunarso, J., Ng, D.K., & Andiappan, V. (2024). Analysis of current state, gaps, and opportunities for technologies in the Malaysian oil palm estates and palm oil mills towards net-zero emissions. *Heliyon*, *10*(10). DOI:10.1016/j.heliyon.2024.e30768.

Rajavat, A.S., Mageshwaran, V., Bharadwaj, A., Tripathi, S., & Pandiyan, K. (2022). Spent mushroom waste: An emerging bio-fertilizer for improving soil health and plant productivity. In Singh, B.H. and Vaishnav, M. (Eds.) *New and Future Developments in Microbial Biotechnology and Bioengineering*, Elsevier, pp. 345 − 354. DOI:10.1016/B978-0-323-85579-2.00010-1.

Rinker, D.L. (2017). Spent mushroom substrate uses. In Diego, C.Z. and Pardo-Gimérez, A. (Eds.) *Edible and medicinal mushrooms: technology and applications*, John Wiley & Sons Ltd, pp. 427 − 454. DOI:10.1002/9781119149446.ch20.

Roy, S., Barman, S., Chakraborty, U., & Chakraborty, B. (2015). Evaluation of spent mushroom substrate as biofertilizer for growth improvement of Capsicum annuum L. *Journal of Applied Biology and Biotechnology*, *3*(3), 022 − 027. DOI:10.7324/JABB.2015.3305.

Sabrina, S., Roshanida, A.R. & Norzita, N. (2013). Pretreatment of oil palm fronds for improving hemicelluloses content for higher recovery of xylose. *Jurnal Teknologi*, *62*(2). DOI:10.11113/jt.v62.1877.

Sakinah, N.M., Misran, A., Mahmud, T.M.M., & Abdullah, S. (2019). A review: Production and postharvest management of *Volvariella volvacea*. *International Food Research Journal*, *26*(2), 367 − 376. Avaiable at: https://www.proquest.com/openview/edea24a5b029b6eebbd9dd446d4ae8c2.

Salachna, P., Wesołowska, A., Meller, E., & Piechocki, R. (2021). Mushroom waste biomass alters the yield, total phenolic content, antioxidant activity and essential oil composition of Tagetes patula L. *Industrial Crops and Products*, *171*, 113961. DOI:10.1016/j.indcrop.2021.113961.

Santi, L.P., Kalbuadi, D.N. & Goenadi, D.H. (2019). Empty fruit bunches as potential source for biosilica fertilizer for oil palm. *Journal of Tropical Biodiversity and Biotechnology*, *4*(3), 90 − 96. DOI:10.22146/jtbb.38749.

Saskiawan, I., Mangunwardoyo, W., Widyastuti, N., & Tjokrokusumo, D. (2023). The addition of Aspergillus flavus on composting process of cotton waste for cultivation of paddy straw mushroom [*Volvariella volvacea* (Bull.) Singer 1951]. *Food Research*, *7*(4), 46 − 50. DOI:10.26656/fr.2017.7(S4).5.

Singh, M., Kamal, S. & Sharma, V.P. (2020). Status and trends in world mushroom production-III-World Production of different mushroom species in 21st century. *Mushroom Research*, *29*(2). DOI:10.36036/MR.29.2.2020.113703.

Sirisuntornlak, N., Ullah, H., Sonjaroon, W., Anusontpornperm, S., Arirob, W., & Datta, A. (2021). Interactive effects of silicon and soil pH on growth, yield and nutrient uptake of maize. *Silicon, 13*(2), 289 − 299. DOI:10.1007/s12633-020-00427-z.

Sudha, A., Geetha, P. & Rajesh, M. (2019). Antioxidant properties of paddy straw mushroom [*Volvariella volvacea* (Bull. ex Fr.)] Sing. *International Journal of Current Microbiology and Applied Sciences*, *8*(02), 3031 − 3036. DOI:10.20546/ijcmas.2019.802.355.

Sudheer, S., Ali, A. & Manickam, S. (2016). Investigation of requisites for the optimal mycelial growth of the lingzhi or reishi medicinal mushroom, Ganoderma lucidum (Agaricomycetes), on oil palm biomass in Malaysia. *International Journal of Medicinal Mushrooms*, *18*(10). DOI:10.1615/IntJMedMushrooms.v18.i10.90.

Sun, C., Wei, Y., Kou, J., Han, Z., Shi, Q., Liu, L., & Sun, Z. (2021). Improve spent mushroom substrate decomposition, bacterial community and mature compost quality by adding cellulase during composting. *Journal of Cleaner Production*, *299*, 126928. DOI:10.1016/j.jclepro.2021.126928.

Suwannarach, N., Kumla, J., Zhao, Y., & Kakumyan, P. (2022). Impact of cultivation substrate and microbial community on improving mushroom productivity: A review. *Biology*, *11*(4), 569. DOI:10.3390/biology11040569.

Tao, Z., Liu, X., Sun, L., He, X., & Wu, Z. (2022). Effects of two types nitrogen sources on humification processes and phosphorus dynamics during the aerobic composting of spent mushroom substrate. *Journal of Environmental Management, 317,* 115453. DOI:10.1016/j.jenvman.2022.115453.

Triyono, S., Haryanto, A., Telaumbanua, M., Dermiyati, Lumbanraja, J., & To, F. (2019). Cultivation of straw mushroom (*Volvariella volvacea*) on oil palm empty fruit bunch growth medium. *International Journal of Recycling of Organic Waste in Agriculture*, *8*, 381 − 392. DOI:10.1007/s40093-019-0259-5.

Tuhy, Ł., Samoraj, M., Witkowska, Z., Wilk, R., & Chojnacka, K. (2015). Using spent mushroom substrate as the base for organic-mineral micronutrient fertilizer–field tests on maize. *BioResources*, *10*(3), 5709 − 5719. Avaiable at:https://www.researchgate.net/profile/Katarzyna-Chojnacka-4/publication/280668185.

Umar, H.A., Sulaiman, S.A., Said, M.M., Gungor, A.F.Ş. İ.N., Shahbaz, M., Inayat, M., & Ahmad, R.K. (2021). Assessing the implementation levels of oil palm waste conversion methods in Malaysia and the challenges of commercialisation: Towards sustainable energy production. *Biomass and Bioenergy*, *151*, 106179. DOI:10.1016/j.biombioe.2021.106179.

Umor, N.A., Abdullah, S., Mohamad, A., Ismail, S.B., Ismail, S. I., & Misran, A. (2021). Energy potential of oil palm empty fruit bunch (EFB) fiber from subsequent cultivation of *Volvariella volvacea* (Bull.) Singer. *Sustainability, 13*(23), *13008*. DOI:10.3390/su132313008.

Umor, N.A., Abdullah, S., Mohamad, A., Ismail, S., Ismail, S.I., & Misran, A. (2024). Indoor cultivation of Volvariella volvacea (Bull.) Singer using oil palm empty fruit bunch (EFB) fiber. In Umor, N.A., Zainal, N.H., Yaser, A.Z. (Eds.) *Palm Oil Industry.* Springer, Singapore, pp. 127 − 136. DOI:10.1007/978-981-97-8277-2_10.

Umor, N.A., Ismail, S., Abdullah, S., Huzaifah, M.H.R., Huzir, N.M., Mahmood, N.A.N., & Zahrim, A.Y. (2021). Zero waste management of spent mushroom compost. *Journal of Material Cycles and Waste Management*, *23*(5), 1726 − 1736. DOI:10.1007/s10163-021-01250-3.

Urassa, J.K (2015). Factors influencing maize crop production at household levels: A case of Rukwa Region in the southern highlands of Tanzania. *African Journal of Agricultural Research, 10*(10), 1097 − 1106. DOI:10.5897/AJAR2014.9262.

Vakili, M., Rafatullah, M., Ibrahim, M.H., Salamatinia, B., Gholami, Z., & Zwain, H.M. (2015). A review on composting of oil palm biomass. *Environment, Development and Sustainability*, *17*, 691 − 709. DOI:10.1007/s10668-014-9581-2.

Van Tam, N. & Wang, C.H. (2015). Use of spent mushroom substrate and manure compost for honeydew melon seedlings. *Journal of Plant Growth Regulation*, *34*, 417 − 424. DOI:10.1007/s00344-015-9478-9.

Velusami, B., Jordan, S.N., Curran, T. & Grogan, H. (2022). Fertiliser characteristics of stored spent mushroom substrate as a sustainable source of nutrients and organic matter for tillage, grassland and agricultural soils. *Irish Journal of Agricultural and Food Research*, *60*(1), 1 − 11. DOI:10.15212/ijafr-2020-0121.

Vieira, F.R. & de Andrade, M.C.N. (2016). Optimization of substrate preparation for oyster mushroom (Pleurotus ostreatus) cultivation by studying different raw materials and substrate preparation conditions (composting: phases I and II). *World Journal of Microbiology and Biotechnology*, *32,* 190. DOI:10.1007/s11274-016-2152-y.

Wadchasit, P., Siripattana, C. & Nuithitikul, K. (2020). The effect of pretreatment methods for improved biogas production from oil-palm empty fruit bunches (EFB): Experimental and model. *IOP conference series: Earth and environmental science*, *463*(1), 012126. DOI:10.1088/1755-1315/463/1/012126.

Wahab, R., Rasat, M.S.M., Fauzi, N.M., Sulaiman, M.S., Samsi, H.W., Mokhtar, N., ... & Razak, M.H. (2021). Processing and properties of oil palm fronds composite boards from *Elaeis guineensis*. In Kamyab, H. (Ed.) *Elaeis guineensis,* IntechOpen. DOI:10.5772/intechopen.98222.

Wang, J. & Hu, X. (2021). Research on corn production efficiency and influencing factors of typical farms: Based on data from 12 corn-producing countries from 2012 to 2019. *Plos one, 16*(7), e0254423. DOI:10.1371/journal.pone.0254423.

Wei, Y., Jin, Z., Zhang, M., Li, Y., Huang, S., Liu, X., ... & Qu, J. (2020). Impact of spent mushroom substrate on Cd immobilization and soil property. *Environmental Science and Pollution Research*, *27*(3), 3007 − 3022. DOI:10.1007/s11356-019-07138-y.

Wiafe-Kwagyan, M. & Odamtten, G.T. (2018). Use of Pleurotus eous strain P-31 spent mushroom compost (SMC) as soil conditioner on the growth and yield performance of Capsicum annuum L. and Solanum lycopersicon L. seedlings under greenhouse conditions in Ghana. *Tropical Life Sciences Research*, *29*(1), 173. DOI:10.21315/tlsr2018.29.1.12.

Yadav, M.C., Singh, S.K., Verma, R.N., & Vijay, B. (2015). Effect of spawn mushroom (Agaricus bisporus) compost on yield of hybrid maize. *Mushroom Research*, *10*(2). Avaiable at: https://epubs.icar.org.in/index.php/MR/article/view/53381.

Yang, W., Yan, H., Zhang, J., Meng, Y., Wang, X., Ji, L., & Luo, Y. (2017). Response of rhizosphere microbial diversity and soil physico-chemical properties in a rotation of cucumber with *Volvariella volvacea*. *Biocontrol Science and Technology*, *27*(3), 311 − 323. DOI:10.1080/09583157.2016.1252313.

Yang, Y. R., Guo, Y. X., Wang, Q. Y., Hu, B. Y., Tian, S. Y., Yang, Q. Z., ... & Zhang, G. Q. (2022). Impacts of composting duration on physicochemical properties and microbial communities during short-term composting for the substrate for oyster mushrooms. *Science of the Total Environment*, *847*, 157673. DOI:10.1016/j.scitotenv.2022.157673.

Yella, V. K., Chadrapati, A., Kuri, A., Miglani, I., Andrews, A. A., & Singh, S. (2021). Cultivation technology and spawn production of *Volvariella volvacea*: Paddy straw mushroom. *The Pharma Innovation Journal*, *10*(5), 1184 − 1190. Avaiable at: https://www.researchgate.net/profile/Yella-Vinay/publication/352441355.

Yu, Y. Y., Li, S. M., Qiu, J. P., Li, J. G., Luo, Y. M., & Guo, J. H. (2019). Combination of agricultural waste compost and biofertilizer improves yield and enhances the sustainability of a pepper field. *Journal of Plant Nutrition and Soil Science*, *182*(4), 560 − 569. DOI:10.1002/jpln.201800223.

Zied, D. C., de Abreu, C. G., Alves, L. D. S., Prado, E. P., Pardo-Gimenez, A., de Melo, P. C., & Dias, E. S. (2021). Influence of the production environment on the cultivation of lettuce and arugula with spent mushroom substrate. *Journal of Environmental Management*, *281*, 111799. DOI:10.1016/j.jenvman.2020.111799.

Zikriyani, H., Saskiawan, I. & Mangunwardoyo, W. (2018). Utilization of agricultural waste for cultivation of paddy straw mushrooms (*Volvariella volvacea* (Bull.) Singer 1951), *14*(5), 805 − 814. Avaiable at: https://www.thaiscience.info/Journals/Article/IJAT/10992402.pdf.

Malaysian Palm Oil Board (MPOB) (2024). *Annual Report 2023*. Available at: https://www.mpoc.org.my/annual-report-2023/ [Accessed18 May. 2025].

Statista (2024). *Production of Mushrooms and Truffles Worldwide from 1990 to 2022*. Available at: https://www.statista.com/statistics/1018488/global-mushrooms-and-truffles-production/ [Accessed18 May. 2025].

Received: January 28, 2025
Accepted: July 18, 2025