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Research article

Effect of Composting on *Volvariella volvacea* Yield Cultivated Using Oil Palm Frond (OPF) and Empty Fruit Bunch (EFB)

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Abstract: *Volvariella volvacea* is a fast-growing edible mushroom that can be easily cultivated on lignocellulosic agricultural waste, making it it is a good source of food. This study aimed to evaluate the effect of composting duration and substrate type using substrates from oil palm frond (OPF) and empty fruit bunch (EFB) on the growth performance and biological efficiency (BE) of *Volvariella volvacea.* A pot experiment was conducted under indoor cultivation with three replicates of nine experimental treatment combinations involving OPF, EFB, and EFB+OPF, each subjected to three different composting durations (Day 0, 5, and 10), to determine the best substrate formulation and composting duration for optimizing the growth performance and biological efficiency of *Volvariella volvacea*. The highest BE values were recorded in T7 (0D + EFB; 17.87), followed by T8 (0D + OPF; 17.20) and T4 (5D + EFB; 16.53). T7 and T8 also showed shorter pinning times (15.33 days, 13.67 days) and harvesting times (18.33 days, 18.33 days) compared to the control T1 (10D+EFB), which required 22.67 days for pinning and 26 days for harvest. In contrast, although T4 (5D + EFB; 15.37) showed a high BE (16.53%), its delayed pinning time (21.67 days) and harvesting time (25.33 days) reduced its practical value. Moisture content and pH showed no significant differences across treatments. Uncomposted EFB and OPF can effectively optimize the production of *V. volvacea*, offering both early harvest and high efficiency. Its simplicity and minimal composting requirement make it ideal for commercial application.

Keywords: *Volvariella volvacea;* EFB; OPF; composting; yield

1. Introduction

Volvariella volvacea is an edible tropical mushroom widely cultivated in Southeast Asia due to its fast growth cycle and high market demand [1]. It is commonly produced on agricultural waste materials such as rice straw and empty fruit bunches (EFB) [2]. *Volvariella* has the ability to efficiently degrade lignocellulosic biomass, making it an important species for sustainable agriculture and organic recycling [3]. Unfortunately, mushroom cultivation faces limitations in achieving higher yields due to factors such as poor substrate utilization and the lack of an optimized preparation method [2]. The use of agricultural residues like oil palm fronds (OPF) and empty fruit bunches (EFB)

has become popular as alternative substrates for mushroom cultivation [4]. The oil palm industry serves as a vital foundation for Malaysia's socio-economic growth, playing a crucial role in maintaining national economic stability and acting as a significant contributor to the global oil market [5]. Researchers have concluded that Malaysia produces a large amount of oil palm biomass as agricultural waste, with around 40% of this waste consisting of EFB and trunks [6], while another 50% consists of frond waste generated from the Malaysian oil palm industry [7]. OPF and EFB benefit the growth of fungal crops, which require high cellulose content and other suitable properties [8,9]. On one hand, OPF contains high cellulose and hemicellulose contents, supporting good mycelial growth [10], while EFB offers a lignin-rich structure that, after composting, improves substrate aeration and water-holding capacity [11].

On the other hand, conventional practices have shown that composting is crucial in mushroom substrate preparation, as it helps break down complex fibers, making nutrients more available for the mushroom [12]. Composting duration, whether the substrate is composted or uncomposted, influences substrate quality in terms of lignocellulose degradation, which determines the potential colonization speed [13]. Moreover, the composting process reduces lignin, cellulose, and hemicellulose content, thereby supporting mycelial development [3]. It is also suggested that composting should not be extended beyond 8 days, as microbial activity begins to decline afterward [14]. Another study suggests that prolonging the composting period to approximately one month results in a pH range of 7–8.5, which provides favorable conditions for microbial development [15]. Zulkifli et al. [16] Concluded that both material type and composting duration critically affect the cultivation efficiency of *Volvariella*.

Studies have shown that the application of oil palm biomass such as empty fruit bunch increases substrate porosity and microbial activity during composting [17]. In addition, composting under appropriate moisture and temperature conditions ensures better substrate consistency [18]. Integrating agricultural waste such as OPF and EFB supports a sustainable, zero-waste agricultural model, contributing to eco-friendly mushroom farming [19, 10]. The spawn run is also affected by the use of empty fruit bunch, with a shorter time required for substrate colonization [20]. The time to first harvest is faster with uncomposted substrates compared to composted substrates [21]. Substrate quality also influences the formation of fruiting bodies, which in turn affects yield [22, 23]. Regarding yield, biological efficiency (BE) is the most important parameter, calculated based on fresh mushroom weight per dry substrate weight [24]. Uncomposted EFB substrates have shown higher biological efficiency for Volvariella mushroom [2]. The dry matter content of mushrooms, which relates to market value and storage ability, tends to be higher when grown on composted EFB, but not beyond 8 days of composting [14]. Substrate moisture retention during growth is another critical factor, ensuring consistent mushroom quality [25]. In terms of substrate degradation, studies have reported a significant reduction in lignin and cellulose contents after mushroom harvesting, indicating effective substrate utilization [26]. One researcher highlighted that composted substrates provide nutrients needed for mycelium and mushroom development [9]. Hence, parameters such as pinhead initiation time, day to harvest, yield (BE), individual weight, and moisture content are all influenced by substrate type and composting duration [14, 21].

Previous studies have shown that agricultural waste such as paddy straw, banana leaves, and empty fruit bunches of oil palm can be effectively converted into mushroom substrates. For instance, Ibrahim et al. reported that OPF compost enhances mycelial growth in Pleurotus species [27], while Triyono et al. found that 8-day composted EFB improved yield and reduced contamination rates in mushroom farms [14]. Umor et al. demonstrated the synergy between OPF and EFB for better substrate structure and nutrient availability [21]. More recently, Chong et al. highlighted the potential of using partially composted OPF and EFB for sustainable mushroom cultivation [28]. Most research has focused on using EFB individually or with other substrates, but limited studies have tested the combined use of OPF and EFB at different composting durations, especially for *Volvariella volvacea*. Research is also scarce regarding how various composting periods (0, 5, and 10 days) affect growth parameters such as biological efficiency, weight, and weight per fruit. Furthermore, studies under tropical climates, including controlled indoor tropical conditions using local agricultural wastes for Volvariella cultivation, remain very limited.

The main challenge lies in the variable quality of OPF and EFB substrates, influenced by composting duration and material source. Therefore, evaluating different composting durations and substrates can help

identify the best strategy to enhance *Volvariella* growth and yield under local tropical conditions. This study is among the first to compare OPF, EFB, and OPF+EFB substrates composted at different durations for Volvariella volvacea. It provides new insights into how local agricultural residues can be optimized to support sustainable, high-yield mushroom production under tropical environments. In addition, the findings from this experiment will help identify the most suitable substrate formulation to be used later as spent mushroom substrate (SMS) for soil and crop improvement studies.

2. Materials and Methods

2.1 Experimental Site

A pot experiment was conducted for two months in the mushroom house and composting area of Universiti Teknologi MARA, Cawangan Melang, Kuala Pilah (2°44′07″ N, 102°14′11″ E), Negeri Sembilan, Malaysia. Laboratory analyses were carried out at the Soil Laboratory, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia (UPM), from January 2025 to July 2025.



Figure 1. Indoor cultivation area

2.2 Experimental Design and Treatments

The oil palm empty fruit bunches (EFB) and oil palm frond (OPF) pallet-pressed fibers used in this study were supplied by the Malaysian Palm Oil Board (MPOB) Research Facility in Bangi, Selangor. The physical characteristics of the substrates are presented in Table 3.1. The suitable age of Volvariella volvacea spawn used for propagation was purchased from @DDC.shop, a Malaysian Shopee supplier based in Kedah. Chicken manure was obtained from a local farm in Tampin, Negeri Sembilan, and calcium carbonate ($CaCO_3$) was purchased from a local Shopee supplier. The EFB and OPF pallets were weighed at 4 kg dry weight for each treatment according to the experimental ratio. All substrates were mixed with 8% (320 g) chicken manure, 7% (280 g) rice bran, and 6% (240 g) $CaCO_3$, with approximately 7 L of water added to achieve 60–65% moisture content [29]. The composting process was carried out at different times, starting with Treatments T1, T2, and T3 on Day 1, followed by T4, T5, and T6 on Day 5, and finally T7, T8, and T9 on Day 10. All mixed formulations were tightly covered with plastic canvas during the composting period. The 10-day composted EFB treatment (T1) was considered as a reference treatment, as it represents the commonly practiced composting duration reported in previous studies [14,29]. On Day 10, each formulation was divided into three replications of approximately 3.5 kg wet weight per treatment and packed into plastic bags measuring 47 cm × 54 cm. Subsequently, 60 g (3%) of *Volvariella volvacea* spawn was inoculated into each sample. The ends of the plastic bags were tightly sealed and kept in a closed container for another 10 days. After that, all sample bags were opened and arranged in a completely randomized design on shelves in the indoor cultivation room [14,29] at the UiTM Melang Campus mushroom house. An automatic humidifier was operated daily at the lowest setting to maintain optimal moisture conditions. During the cultivation period, the relative humidity and temperature in the mushroom house ranged between 28–68% and 25.4–31.5 °C, respectively. The pinning stage occurred 3–5 days after the 10-day spawning period, and the mushrooms were harvested 3–5 days later at the

egg and button stages, which were recorded accordingly. The harvested mushrooms were counted and weighed daily when they reached an appropriate size for picking. Harvesting was terminated between Days 20 and 25 when production declined. The spent substrate was then air-dried, sieved to 2 mm, and subjected to further analyses of its properties.

Table 1 presents the treatments used in this experiment:

Table 1. Treatment Combination for Conducting the Experiment

Treatment	Substrates	Composting Day
T1	100% EFB	10
T2	100% OPF	10
T3	50% EFB + 50% OPF	10
T4	100% EFB	5
T5	100% OPF	5
T6	50% EFB + 50% OPF	5
T7	100% EFB	0
T8	100% OPF	0
T9	50% EFB + 50% OPF	0

*EFB: Oil palm empty fruit bunch, OPF: Oil palm frond

2.3 Characterization of fresh EFB and OPF

Table 2. Properties of EFB and OPF

Parameter	EFB	OPF
Moisture (%)	7.34 ± 0.15	7.37 ± 0.07
OM (%)	22.58 ± 4.48	21.83 ± 1.77
OC (%)	15.61 ± 0.65	12.66 ± 1.03
Total P(mg/kg)	124.96 ± 9.15	133.81 ± 4.26
Total N (%)	0.28 ± 0.06	0.19 ± 0.01

2.4 Mycelium running test

A total of 40 g of mixed substrate from each sample, taken from the prepared substrate prior to indoor cultivation, was transferred into a 13 cm × 3.5 cm clear plastic container. Approximately 3–4 g of spawn was added, and the end was tightly closed with a small cable tie. On Days 4, 5, 6, and 7, mycelial run was measured and recorded daily [29].

2.5 Growth and yield performance

The Day of First Pin Formation (DFPF) was counted from the day of substrate preparation until the first pin was observed on the substrate, while Days to First Harvest (DFFH) were counted from the day of substrate preparation until the first harvest of mushrooms for each sample [30]. The number of mushrooms harvested was counted and weighed daily based on the appropriate picking size and recorded [30]. The total fresh weight of mushrooms recorded for each sample was later converted into biological efficiency [29,31]. The initial weight of compost included the weight of substrate (4 kg), chicken manure (0.32 kg), rice bran (0.28 kg), and $CaCO_3$ (0.24 kg), which were divided into three samples. The formula is stated below:

$$Biological\ efficiency\ (\%) = \frac{Total\ weight\ of\ fresh\ mushroom}{Dry\ weight\ of\ substrates}\ X\ 100\%$$

2.6 Physico-chemical analysis

The air-dried substrate was sieved to 2 mm and mixed with distilled water. A total of 10 g of substrate was mixed with 50 mL of water, shaken for 30 minutes, and left for one day before measurement using a pH and EC meter. The raw post-harvest substrate was collected, placed into a crucible, and weighed (FW). It was

then dried in an oven at 65°C for 72 hours before being reweighed (DW). Moisture content (M) was calculated using the formula below:

$$Moisture\ content\ (\%) = \frac{Fresh\ weight(FW) - Dry\ weight(DW)}{Dry\ weight(DW)}\ X\ 100\%$$

For total N and P, the digestion method was used prior to measurement. Total N was determined using the Kjeldahl method, while P was diluted and measured using a spectrophotometer.

2.7 Percent Relative Data

The relative values were expressed as percentages relative to the control for each element using the following formula proposed by[4]:

$$Relative\ data\ (\%) = \frac{Treatment\ value - control\ value}{control\ value}\ X\ 100\%$$

where the treatment value refers to EFB and OPF under different composting durations, and the control value refers to EFB with 10 days of composting.

2.8 Statistical Analysis

The experiment was arranged in a two-factor completely randomized design, with composting duration (0, 5, and 10 days) and substrate type (100% EFB, 100% OPF, and 50% EFB + 50% OPF) as fixed factors. Data were analyzed using two-way analysis of variance (ANOVA) to evaluate the effects of both factors and their interaction. When significant differences were detected, Tukey's Honestly Significant Difference (HSD) test was used for mean separation at $p \leq 0.05$. All analyses were performed using JASP statistical software.

3. Result and Discussion

3.1 Effect of substrate type and composting duration on mycelial growth of *Volvariella*

As shown in Table 3, mycelial growth of *Volvariella volvacea* was significantly affected ($p < 0.05$) by the composting day and substrate type at 5 and 6 DAS, while at 4 DAS, only the substrate effect remained significant ($p < 0.05$), and composting day was not significant ($p > 0.05$). At 4 DAS, growth was still at the early stage, where T1 (2.50 cm), T6 (2.17 cm), and T7 (2.27 cm) recorded significantly higher mycelial length compared to other treatments (0.53–1.33 cm). At 5 DAS, T2 recorded the highest mycelial extension (6.47 cm), followed by T8 (6.13 cm), T9 (5.80 cm) and T7 (5.63 cm), while T6 showed the lowest (3.77 cm). At 6 DAS, T7 maintained the highest colonization (7.90 cm), followed by T2 (7.00 cm), T8 (7.47 cm), T9 (6.67 cm), and T5 (6.43 cm). At 6 DAS, mycelial length increased by 13.99% in T7 and 7.79% in T8 compared to T1, indicating a clear advantage of uncomposted substrates at the later stage of colonization.

This finding was consistent with previous studies reporting good development of mycelium with the use of uncomposted EFB [21]. It was also supported by studies highlighting the potential of EFB without composting for improved mushroom development through enhanced early mycelial growth [14]. The superior performance of uncomposted substrates may be attributed to the preservation of structural integrity and porosity, which facilitates oxygen diffusion and rapid hyphal penetration during the initial colonization phase. This may also be due to the lower compaction of substrates with fewer composting days, which allows the mycelium to penetrate more easily [32]. In contrast, prolonged composting can lead to partial degradation and compaction of substrate particles, potentially restricting aeration and slowing mycelial spread. Furthermore, longer composting may increase microbial activity in the substrates, leading to competition for available nutrients between microorganisms and fungal mycelia, thereby hindering mycelial development [33].

Table 3. Effect of substrate type and composting duration on mycelial running of Volvariella

Treatment	Mycelium length (cm)		
	4 DAS	5 DAS	6 DAS
T1	2.50a ± 0.29	4.43bc ± 0.12	6.93cd ± 0.38
T2	0.53d ± 0.13	6.47a ± 0.19	7.00cd ± 0.29
T3	1.10dc ± 0.06	4.30bc ± 0.27	5.40d ± 0.21
T4	0.80d ± 0.15	4.70abc ± 0.35	5.50d ± 0.25
T5	0.97d ± 0.35	5.47abc ± 0.48	6.43cd ± 0.30
T6	2.17bca ± 0.17	3.77c ± 0.37	5.93cd ± 0.30
T7	2.27ba ± 0.15	5.63ba ± 0.45	7.90c ± 0.59
T8	1.33bcd ± 0.33	6.13ba ± 0.57	7.47cd ± 0.79
T9	0.87d ± 0.124	5.80ba ± 0.36	6.67cd ± 0.58
Susbtrates	< .001	< .001	0.039
Day	0.636	0.003	0.005
Susbtrates* Day	< .001	0.103	0.221

Means within the same column followed by different letters are significantly different at $p \leq 0.05$ (Tukey's HSD test). The column represents the mean values ± standard error. T1 = 10D+EFB, T2= 10D+OPF, T3= 10D+(EFB+OPF), T4 = 5D+EFB, T5= 5D+OPF, T6= 5D+(EFB+OPF), T7 = 0D+EFB, T8= 0D+OPF and T9= 10D+(EFB+OPF).

3.2 Effect of substrate type and composting duration on growth yield performance of *Volvariella volvacea*

Table 4 shows that composting duration significantly affected ($p < 0.05$) the weight, number of fruiting bodies, average weight, days of pinhead formation (DOP), and days of harvest (DOH) of Volvariella volvacea, but did not significantly influence ($p > 0.05$) biological efficiency (BE). In contrast, substrate type showed no significant effect ($p > 0.05$) on weight, BE, DOP, and DOH, indicating a limited role in determining overall performance under the conditions of this study. The highest weight was recorded in T7 (268 g), followed by T8 (258 g), while T2 (198 g) recorded the lowest value. Biological efficiency ranged from 13.18% to 17.87%, with T7 (17.87%) showing the highest value and T2 (13.18%) the lowest; however, these differences were not statistically significant. Similarly, composting duration significantly influenced DOP and DOH ($p < 0.001$), where shorter composting durations resulted in earlier pinhead formation and harvest. This finding is consistent with previous reports showing that composting duration can influence mushroom growth dynamics, particularly in terms of yield and development period [21]. In contrast, other studies reported lower yield (70.67 g) and BE (7.07%) using 7-day composted EFB, suggesting that prolonged composting may reduce substrate efficiency [31]. In addition, studies highlighted that EFB enhances substrate activity compared to other combinations [34], while other researchers reported no significant difference among oil palm waste types in terms of weight and BE [35]. The significant effect of composting duration on yield-related parameters (weight, DOP, and DOH) suggests that the degree of substrate decomposition influences nutrient availability and crop cycle duration. Shorter composting periods may retain more readily available nutrients, accelerating mycelial colonization and fruiting, whereas longer composting may lead to partial nutrient loss through microbial activity. However, the absence of significant effects on BE indicates relatively stable substrate conversion efficiency across treatments, reflecting the adaptability of Volvariella volvacea to varying substrate conditions without substantial changes in biological efficiency [3,13].

The number of fruiting bodies and average weight were significantly affected ($p < 0.05$) by both substrate type and composting duration. The number of fruiting bodies and average weight ranged from 10 to 25 and 11.15 g to 23.77 g, respectively. T6 recorded the lowest number of fruiting bodies (10), followed by T3 and T5 (15), while the highest was recorded in T7 (25), followed by T8 (20). In contrast, the highest average weight was recorded in T6 (23.77 g), followed by T5 (17.06 g), while the lowest was observed in T7 (11.30 g). This indicates a trade-off between fruit number and individual fruit size, where treatments producing more

fruiting bodies tended to have lower average weight per mushroom. This finding is consistent with previous studies reporting a higher number of fruiting bodies in uncomposted EFB compared to composted EFB [40]. The observed average weights fall within the range reported in previous studies (16.89 g to 23.31 g), indicating consistency with established growth patterns. Previous studies also suggested reducing composting duration as a practical approach to increase mushroom production [36]. The higher output observed in uncomposted substrates may be associated with improved energy efficiency and reduced competition or infection from other microorganisms, allowing Volvariella volvacea to colonize the substrate more effectively [37].

The day of pinning (DOP) and day of harvest (DOH) were significantly affected ($p < 0.05$) by composting duration. Treatments without composting (T7, T8, and T9) recorded significantly earlier DOP and DOH compared to those with longer composting periods. Specifically, T7 exhibited the earliest pinning (18.33 days), while T9 showed the earliest harvesting (18.67 days). In contrast, T3 (10-day composting) required 25.00 and 28.33 days for DOP and DOH, respectively. These findings indicate that uncomposted substrates can accelerate the cropping cycle of Volvariella volvacea, providing a practical advantage in reducing overall cultivation time. Similar trends were reported in previous studies, which observed variations in pinning time depending on composting duration [31,30]. Physiologically, earlier pinning in uncomposted substrates may be linked to higher availability of readily accessible nutrients and better substrate structure, which promotes faster mycelial establishment and fruiting initiation. In contrast, composting is known to stabilize substrates but may delay nutrient release, thereby slowing early growth stages. These results support the potential of using uncomposted lignocellulosic substrates in Volvariella volvacea cultivation without compromising performance [21].

Despite the higher biological efficiency and yield observed in the uncomposted treatments (T7–T9), the physicochemical properties of the spent mushroom substrate (SMS) remained relatively similar among treatments. This suggests that the increased mushroom production in uncomposted substrates was likely associated with greater nutrient accessibility and faster nutrient utilization during the early growth stage rather than substantial differences in the residual substrate composition after harvest. Uncomposted EFB and OPF may have maintained more readily available nutrients and a more favorable substrate structure during the early cultivation stage, thereby promoting faster mycelial colonization and fruiting body formation [21,37]. However, after cultivation, a considerable proportion of the available nutrients had already been utilized by the fungus across all treatments, resulting in relatively comparable residual physicochemical characteristics of the SMS. In addition, Volvariella volvacea primarily utilizes easily degradable substrate fractions during the initial cultivation phase, while more recalcitrant lignocellulosic components remain relatively stable after harvesting [20,38]. Therefore, differences in yield performance may not necessarily correspond to large variations in post-harvest substrate properties.

3.3 Effect of substrate type and composting duration on spent substrate physicochemical properties of *Volvariella*

Table 5 shows that the moisture content and pH of the spent substrate were not significantly ($p > 0.05$) affected by the application of EFB and OPF under different composting durations. However, the nitrogen (N) content of the spent mushroom substrate (SMS) was significantly affected ($p < 0.05$) by the treatments. The highest N content was recorded in T4 (0.53%), followed by T7 (0.48%), while the lowest was observed in T2 (0.24%) [13,40]. Both substrate type and composting duration significantly influenced ($p < 0.05$) the organic matter (OM) and carbon (C) content of the SMS. The highest values were recorded in T2 (79.10%, 46.24%), followed by T8 (79.31%, 46.00%), while the lowest were observed in T1 (74.02%, 42.94%). The OM content ranged from 74.02% to 79.31%, while carbon content ranged from 42.94% to 46.24%. In contrast, composting duration alone did not significantly affect OM and carbon content, suggesting that substrate type played a more dominant role in determining these properties.

Table 4. Effect of substrate type and composting duration on growth yield performance of *Volvariella volvacea*

Treatment	Weight (g)	No fruit body	Average weight (g)	Biological efficiency (%)	DOP	DOH
T1	214.00ab ± 15.059	16ab ± 1.202	13.71b ± 0.46	14.29 ± 1.005ab	22.67abc ± 0.33	26.00ba ± 0.00
T2	198.00b ± 12.991	16ab ± 2.082	12.58b ± 0.95	13.18 ± 0.866a	24.67ba ± 2.67	30.67a ± 2.33
T3	235.00ab ± 15.677	15ab ± 1.155	15.72ab ± 0.22	15.69 ± 1.045ab	25.00a ± 2.52	28.33ba ± 2.33
T4	248.00ab ± 19.63	23a ± 3.18	11.15b ± 0.75	16.53 ± 1.308ab	21.67abc ± 1.67	25.33ba ± 2.33
T5	235.00ab ± 10.97	15ab ± 3.055	17.06ab ± 3.43	15.67 ± 0.73ab	20.00abc ± 0.00	23.00ba ± 0.00
T6	229.00ab ± 9.849	10b ± 0.333	23.77a ± 1.47	15.27 ± 0.657ab	21.67abc ± 2.19	26.67ba ± 3.12
T7	268.00a ± 12.49	25a ± 3.333	11.30b ± 1.68	17.87 ± 0.833b	15.33cb ± 2.33	18.33b ± 2.33
T8	258.00ab ± 8.083	20ab ± 4.333	14.79ab ± 3.82	17.20 ± 0.541ab	13.67c ± 0.67	18.33b ± 2.33
T9	234.00ab ± 10.263	19ab ± 0.577	12.33b ± 0.60	15.60 ± 0.682ab	15.00c ± 2.52	18.67b ± 2.19
Susbtrates	0.446	0.018	0.014	0.009	0.798	0.753
Day	0.009	0.023	0.027	0.445	< .001	< .001
Susbtrates* Day	0.185	0.21	0.031	0.184	0.772	0.535

Means within the same column followed by different letters are significantly different at $p \leq 0.05$ (Tukey's HSD test). The column represents the mean values ± standard error. T1 = 10D+EFB, T2= 10D+OPF, T3= 10D+(EFB+OPF), T4 = 5D+EFB, T5= 5D+OPF, T6= 5D+(EFB+OPF), T7 = 0D+EFB, T8= 0D+OPF and T9= 10D+(EFB+OPF).

Table 5. Effect of substrate type and composting duration on spent substrate physicochemical properties of *Volvariella*

Treatment	Moisture (%)	pH	Nitrogen(%)	Organic matters(%)	Carbon(%)	Total p (mg/kg)
T1	9.57a ± 1.81	6.97a ± 0.05	0.3a ± 0.01	74.02b ± 1.13	42.94b ± 0.65	155.45ab ± 14.47
T2	13.85a ± 0.99	6.42a ± 0.14	0.24a ± 0.02	79.71a ± 0.40	46.24a ± 0.23	171.27a ± 29.16
T3	10.98a ± 2.23	6.56a ± 0.17	0.34a ± 0.04	76.57ab ± 0.85	44.42ab ± 0.49	86.12ab ± 1.27
T4	10.96a ± 3.181	6.73a ± 0.27	0.53a ± 0.08	76.87ab ± 0.67	44.59ab ± 0.39	133.45ab ± 16.27
T5	9.53a ± 0.65	6.41a ± 0.05	0.31a ± 0.05	77.65ab ± 0.66	45.04ab ± 0.38	71.92b ± 8.62
T6	12.62a ± 1.07	6.82a ± 0.32	0.47a ± 0.11	76.05ab ± 0.67	44.11ab ± 0.39	166.36ab ± 9.55
T7	9.03a ± 2.56	6.73a ± 0.03	0.48a ± 0.10	75.39b ± 0.60	43.73b ± 0.35	157.86ab ± 39.94
T8	11.64a ± 0.90	6.57a ± 0.24	0.34a ± 0.04	79.31a ± 0.86	46.00a ± 0.50	141.43ab ± 10.03a
T9	9.94a ± 1.14	6.69a ± 0.04	0.46a ± 0.01	77.16ab ± 0.84	44.75ab ± 0.49	167.58a ± 12.71
Susbtrates	0.461	0.087	0.021	< .001	< .001	0.159
Day	0.692	0.994	0.019	0.684	0.684	0.436
Susbtrates* Day	0.459	0.61	0.756	0.057	0.057	0.004

Means within the same column followed by different letters are significantly different at $p \leq 0.05$ (Tukey's HSD test). The column represents the mean values ± standard error. T1 = 10D+EFB, T2= 10D+OPF, T3= 10D+(EFB+OPF), T4 = 5D+EFB, T5= 5D+OPF, T6= 5D+(EFB+OPF), T7 = 0D+EFB, T8= 0D+OPF and T9= 10D+(EFB+OPF).

This finding is consistent with previous reports of carbon content in OPF, which remained within a similar range to the present study [15]. Although slight variations were observed among treatments, the carbon levels remained within the acceptable range for mushroom substrate development, where approximately 40% carbon is considered optimal for substrate suitability [39]. The relatively stable carbon content across treatments suggests that lignocellulosic components were not extensively depleted during cultivation, indicating efficient but not excessive substrate degradation. A significant interaction effect between substrate type and composting duration on total phosphorus (P) content was observed ($p < 0.05$), while the main effects of substrate type ($p > 0.05$) and composting duration ($p > 0.05$) were not significant. The total P content ranged from 71.92 to 171.27 mg/kg across treatments. The highest values were recorded in T2 (171.27 mg/kg) and T9 (167.58 mg/kg), whereas the lowest value was observed in T5 (71.92 mg/kg), indicating considerable variability among treatment combinations.

The significant interaction effect suggests that phosphorus availability was governed by the combined influence of substrate composition and composting stage rather than by individual factors alone. The higher P values observed in T2 and T9 indicate that certain combinations of substrate and decomposition stage enhanced phosphorus mineralization, while the lower value in T5 may reflect conditions that favored microbial immobilization or limited P release. This variation demonstrates that the transformation of organic phosphorus into available forms is strongly dependent on the synchronization between material quality and the progression of decomposition. Previous studies on EFB composting also reported increasing phosphorus levels with composting progression [29]. Similarly, phosphorus availability in composting systems has been shown to be significantly influenced by interactions between substrate type and composting duration [34,38]. Another study confirmed that composting processes significantly affect nutrient contents such as phosphorus and nitrogen [40]. The observed interaction can be explained by microbial regulation of phosphorus mineralization during organic matter decomposition, which depends on both substrate quality and decomposition stage [38]. In addition, phosphorus is closely correlated with the carbon content of the substrate during the composting process [32].

4. Conclusions

The current study results showed that T7 (0D + EFB) and T8 (0D + OPF) were the best treatments compared to other composting durations and substrate combinations, as they increased biological efficiency and reduced the days to pinning and harvesting. Uncomposted EFB and OPF produced earlier pinning and harvesting compared to composted treatments, while moisture content and pH did not show significant differences among treatments. Although T4 (5D + EFB) recorded a good biological efficiency, the longer days required for pin formation and harvesting reduced its practical value. Thus, T7 (0D + EFB) and T8 (0D + OPF) were selected as potential residue sources for soil amendment in the next study.

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