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RESEARCH ARTICLE

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Growth and Yield Performance of *Pleurotus ostreatus* Cultivated on Agricultural Residues

Hailu Gebru[a], Tolosa Belete[b] and Gezahegn Faye[c]

[a]Department of Horticulture, College of Agriculture and Natural Resources, Salale University, Fiche, Ethiopia; [b]Department of Biology, College of Natural Sciences, Salale University, Fiche, Ethiopia; [c]Department of Chemistry, College of Natural Sciences, Salale University, Fiche, Ethiopia

ABSTRACT

Food insecurity and malnutrition are among the major problems in most developing nations recently. Mushroom cultivation is one of the promising strategies to overcome these challenges. The growth and productivity of mushrooms differ because of their wide range of cultivation substrates. Cultivating *Pleurotus ostreatus* on suitable substrates is one of the key factors affecting its growth and productivity. This study was, therefore, conducted to investigate the effect of cultivation substrates, namely straws of *tef* (Trt1), barley (Trt2), and wheat (Trt3), husks of faba bean (Trt4) and field pea (Trt5), and sawdust (Trt6) alone, and their mixture (1:1, w/w) (Trt7) on the growth and yield of *P. ostreatus*. Mycelial colonization, primordial formation, and days to first harvest were faster (13.00, 19.67, and 22.67 days) for the *P. ostreatus* cultivated on Trt7 whereas those grown on Trt6 were delayed (18.00, 27.00, and 29.67 days), respectively. Trt7 gave a higher (67.33) fruiting body/bunch and total yield (2001.70 g/bag). Biological efficiency was also significantly ($p<0.05$) higher for Trt7 (238.64%). Strong relationships between cap diameter and mushroom yield ($r=0.84^{***}$), number of bunches ($r=0.76^{***}$), number of fruiting bodies ($r=0.80^{***}$), stipe length ($r=0.83^{***}$), and total yield ($r=0.84^{***}$) were among significant positive correlations observed. In conclusion, cultivating *P. ostreatus* on the Trt7 (mixed substrate) is recommended rather than using either of the residues alone.

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1. Introduction

Mushrooms are the fleshy, spore-bearing fruiting body of fungi [1], have no chlorophyll, and cannot process photosynthesis [2]. They get their energy through biochemical decomposition processes [3, 4]. Although hundreds of identified species of fungi have made a significant global contribution to human food and medicine [5], oyster mushrooms *Pleurotus ostreatus* (Jacq. Fr.) Kumm, button mushrooms [*Agaricus bisporus* (J. E. Lenge) Imbach] and shiitake mushrooms [*Lentinula edodes* (Berk.) Pegler] are the most commonly cultivated ones in many countries; for instance, in India [6] and in Ethiopia [7, 8]. *Pleurotus ostreatus* is among the most acceptable species cultivated for food and medicinal purposes and is relatively simple to cultivate compared to the other mushrooms [9–11]. They are the most adaptable genera of edible fungi as they can grow on a wide range of lignocellulose materials [12, 13] and can be cultivated using different agricultural residues depending on their availability in a particular region [14]. Wheat straw, for example, is a common substrate for oyster mushroom cultivation in areas where wheat is commonly produced [15], while rice straw is utilized where it is cultivated [16] and coffee husk where it is commonly processed as a by-product [8].

Mushroom cultivation in Ethiopia is important because food insecurity and malnutrition are among the common problems of the nation. Production and consumption of edible mushrooms can support the food and nutrition security program of a country [17–19] and their medicinal and nutritional values enable them to act as bioremediations [20]. In addition, mushrooms contain a high amount of protein [15, 21–24], vitamins and minerals [25, 26], fibers and lacking cholesterol [27, 28], flavor [29], aroma [30], immune enhancing [31], blood pressure lowering [32, 33], and anti-tumor products [34].

Since mushroom cultivation is labor intensive [21, 35, 36], it creates job opportunities, generates income, and for the management of agricultural wastes. Different authors further indicated that mushroom cultivation is also important for converting inedible plant biomass to nutritious food [37–40]; requires little land [41]; does

CONTACT Hailu Gebru hailu_gebru@slu.edu.et, gebruhailu0@gmail.com

not need light [42]; can be cultivated throughout the year [21, 43]; thrives on different agricultural and agro-industrial wastes [44–46]; they require short production period [47–49]; their need of availability of intensive manpower makes them an emerging agribusiness for self-employment and entrepreneur development [21, 35, 36]; they are high-value international crops with growing global and market access [50, 51]. Thus, these points make mushroom cultivation ideal for Ethiopia where food and nutrition insecurity, employment creation, and income generation are priority issues recently.

Among the main constraints hindering mushroom farming flourishing in Ethiopia are a lack of concept and skill in production technology [52, 53], lack of research and extension [7, 54], low level of information supply both on production and marketing aspects [55], lack of appreciation about its nutritional and medicinal importance, and the monotonous traditional diets and the conservative eating habit of Ethiopian people [56], lack of detailed understanding of the technical features for an appropriate and efficient production; because, it requires a fundamental understanding of their physical, chemical, biological and enzymatic properties [42].

To increase the production of *P. ostreatus,* more attention should be given to the factors affecting its yield. Finding the best substrate for each strain is vital [57–59]. *Pleurotus ostreatus* are primary decomposers and enable them to grow on a wide range of substrates [60]. So, farmers can use different kinds of readily available plant biomass. However, the yields vary greatly from one substrate to another [56, 59]. Unpredictable yields due to the use of unsuitable substrates have discouraged most small-scale farmers who are often, unable to keep on with the cultivation of the mushroom [4, 61]. Thus, using the right substrate is important to maximize mushroom yields [62–64]. This study was, therefore, conducted to evaluate the growth and productivity of *P. ostreatus* cultivated on locally available agricultural residues (substrates) and generate information in these regards.

2. Materials and methods

2.1. Substrate collection and preparation

The locally available agricultural residues were collected from the peasant associations and prepared following methods indicated by [65]. Accordingly, the collected residues were cleaned with tap water, air dried and chopped into pieces of about 3–5 cm size. Then, they were naturally dried by exposure to full sun for three days. Consequently, the residues were soaked in water overnight and then sterilized by hot water under the temperature range of 70–80 °C for 30 min. The residues were then spread on the clean plastic-covered floor to evaporate excess moisture. When the water stopped dripping, the residues were considered the ready stage for spawning.

2.2. Spawning and harvesting

The substrate treatments were spawned with 70-gram seeds of the *P. ostreatus* (Jacq. Fr.) Kumm M2153 strain obtained from Waginos Biotech Mushroom Spawn Production PLC, Addis Ababa, Ethiopia. The transparent plastic bags with the model number: 7# (Dongguan Shanghai Industrial Development Co., Ltd., Shanghai, China) which served for cultivation with the dimensions of 45 cm by 30 cm by 6 C (thickness) were filled with 1 kg of moist residues. Ten holes were made in each bag for adequate aeration and the plastic bags were tied and incubated in the dark in a well-ventilated room. After spawning, the bags were kept about 20 cm apart in the cropping room with a temperature and relative humidity of around 25 °C and 80–90%, respectively. Fruiting was started shortly after the residue was filled with mycelia growth. The relative humidity of the growing room was maintained at a high humidity level by sprinkling water on the floor and side-hanging sacks, 100% sisal (Meher Sisal Fiber Factory, Addis Ababa, Ethiopia) twice a day. The mushrooms were harvested from the residues when young, firm and fleshy (immature/juvenile stage) and the whole mushrooms were weighed the same day. Harvesting was performed by gently pulling the mushrooms from the residues and continued as long as the mycelia remained white and firm and three flushes were harvested.

2.3. Data collection

The days required to complete mycelial colonization, primordial formation, and first harvest were recorded. Data on cap diameter and stipe length were measured for each treatment in each cycle of harvest by using a ruler. Whereas the number of fruits/bag and several bunches/bag were recorded for each treatment in each cycle of harvests. The size of the mushroom (MS) was determined as the total weight of fresh mushrooms harvested/total number of mushrooms harvested.

$$\mathrm{MS}(\mathrm{g}) = \frac{\text{Wt of fresh mushroom harvested}(\mathrm{g})}{\text{Total number of mushroom harvested}} \quad (1)$$

Biological efficiency (BE) (%) was determined as the rate of the weight of fresh mushrooms harvested (g)

divided by the dry residue weight (g) multiplied by one hundred.

$$\mathrm{BE}(\%) = \frac{\text{Wt of fresh mushroom harvested (g)}}{\text{Dry residue Wt (g)}} \times 100 \quad (2)$$

The yield of the mushroom (MY) was also determined as the weight of fresh mushrooms harvested (g) per fresh residue weight (g).

$$\mathrm{MY} = \frac{\text{Wt of fresh mushroom harvested (g)}}{\text{Wt of the fresh residue (g)}} \quad (3)$$

The production rate (PR) (%) of the edible mushroom in each residue was calculated based on each residue's biological efficiency and the time taken in days from spawning to harvesting.

$$\mathrm{PR}(\%) = \frac{\mathrm{BE}(\%)}{\text{Time (days) from spawning to harvesting}} \times 100 \quad (4)$$

2.4. Data analysis

The data were subjected to analysis of variance (one-way ANOVA), using the software Statistix 8.0; the means were separated using the least significant difference comparison test at 5% [66]. A Person correlation and linear regression analysis were run to show the relationships among the parameters studied.

3. Results

3.1. Mycelial colonization, primordial formation, and the first harvest of P. ostreatus as affected by agricultural residues

The results in Table 1 show significant ($\rho < 0.05$) differences in the morphological traits of the mushroom cultivated on the residues. Mycelial colonization, primordial formation, and first harvest were completed between 13 to 18, 20 to 27, and 23 to 30 days after incubation. The use of Trt7 and Trt4 brought a significant difference in terms of morphological traits. The mycelial colonization, primordial formation, and first harvest of the fruiting body of the *P. ostreatus* cultivated on Trt7 and Trt4 treatments were faster than cultivating on the remaining treatments. The morphological traits of the mushroom cultivated on the Trt6 alone were significantly ($\rho < 0.05$) delayed.

Table 1. Effect of cultivation residues on mycelial colonization, primordial formation, and the first harvest of *Pleurotus ostreatus*.

	Morphological traits (day)		
Treatment	Mycelia colonization	Primordial formation	First harvest
Trt1	16.00^{ab}	25.33^{ab}	27.67^{ab}
Trt2	16.00^{ab}	22.33^{abc}	25.67^{bc}
Trt3	15.33^{bc}	22.67^{bc}	25.00^{cd}
Trt4	14.33^{bc}	21.67^{bc}	23.33^{cd}
Trt5	15.33^{bc}	23.67^{ab}	24.67^{cd}
Trt6	18.00^{a}	27.00^{a}	29.67^{a}
Trt7	13.00^{c}	19.67^{c}	22.67^{d}

Means with the different letters in the same column are significantly ($\rho < 0.05$) different.

3.2. Fruiting bodies of P. ostreatus as affected by agricultural residues

The cap diameter varied significantly ($\rho < 0.001$) among the treatments with the mean diameter ranging between 3.32 cm and 4.89 cm for Trt6 and Trt7, respectively. The results also showed that four out of the seven treatments (Trt1, Trt2, Trt3, and Trt5) were not significantly ($\rho > 0.05$) different in terms of cap diameter (Table 2). Agricultural residues had a significant ($\rho < 0.001$) influence on the stipe length with the shortest and the longest stems being observed on the Trt6 and Trt7, respectively.

The number of fruiting bodies/bunches and bunches harvested from each bag varied significantly ($\rho < 0.001$) among the seven substrates tested. The Trt6 had the lowest (31 and 3) while the Trt7 gave the highest (67.33 and 5.33) average number of fruiting bodies and bunches per bag of one kilogram of substrate among the seven substrates.

3.3. Effect of agricultural residues on yield of P. ostreatus

The yield is one of the main purposes of mushroom cultivators. The *P. ostreatus* grown on different locally available agricultural residues showed a significant ($\rho < 0.001$) difference in terms of mushroom yield (Table 3). The mushroom had three flushes.

Table 2. Influence of cultivation residues on fruiting bodies of *Pleurotus ostreatus*.

Treatment	Cap diameter (cm)	Stipe length (cm)	No. of fruiting bodies/ bunch	No. of bunch/bag
Trt1	4.07^{b}	3.00^{c}	34.00^{d}	3.30^{cd}
Trt2	4.20^{b}	3.00^{c}	44.67^{c}	3.67^{c}
Trt3	4.00^{b}	3.20^{bc}	46.00^{c}	4.30^{b}
Trt4	4.66^{a}	3.42^{b}	65.00^{a}	4.89^{a}
Trt5	4.10^{b}	3.17^{bc}	52.33^{b}	4.22^{b}
Trt6	3.32^{c}	2.32^{d}	31.00^{d}	3.00^{d}
Trt7	4.89^{a}	4.42^{a}	67.33^{a}	5.33^{a}

Means with the different letters in the same column are significantly ($\rho < 0.05$) different.

Table 3. Yields (g/bag) of *Pleurotus ostreatus* as affected by different agricultural residues.

Treatment	1st flush	2nd flush	3rd flush	Total yield
Trt1	567.33^{cd}	505.67^{de}	181.67^{d}	1254.70^{de}
Trt2	573.33^{cd}	538.33^{d}	238.67^{cd}	1350.30^{d}
Trt3	624.00^{c}	570.00^{cd}	253.67^{cd}	1447.70^{cd}
Trt4	734.33^{ab}	687.00^{ab}	392.00^{ab}	1813.30^{ab}
Trt5	655.00^{bc}	654.67^{bc}	302.67^{bc}	1612.30^{bc}
Trt6	504.00^{d}	434.67^{e}	154.33^{d}	1093.00^{e}
Trt7	799.67^{a}	765.67^{a}	436.33^{a}	2001.70^{a}

Means with the different letters in the same column are significantly ($\rho < 0.05$) different.

The significantly highest (636.81 g/bag) average mushroom yield was obtained from the first flush, followed by the second (593.71 g/bag) flush, and the trend gradually decreased at the next, third (279.90 g/bag) flush.

Table 3 further shows that the total yield of mushrooms ranged from 1093 g to 2001.70 g/bag. Trt7 gave the highest total yield (2001.70 g/bag) followed by Trt4 (1813.30 g/bag) and Trt5 (1612.30 g/bag). Trt7 had the highest yield of mushrooms at almost all flushes. Thus, their total yield was higher than the mushrooms grown on the remaining substrates. The two treatments such as Trt4 and Trt5 are agricultural residues obtained from leguminous (faba bean and field pea). Similarly, the Trt7 also contained these leguminous residues as it contains their mixture, which is rich in protein content.

The yield of *P. ostreatus* at all flushes and the total yield varied significantly ($\rho < 0.001$) among the treatments with the mean gram per bag between 504.00 to 799.67, 434.67 to 765.67 and 154.33 to 436.33 during the first, second and third flushes on Trt6 and Trt7, respectively (Table 3). The same trend was observed in the total yield; i.e., it varied significantly ($\rho < 0.001$) among the treatments with the mean yield (g/bag) ranging between 1093 g to 2001.70 g on Trt6 and Trt7, respectively. Trt7 revealed maximum yield (g/bag) in the first (799.67), second (765.67), and third (436.33) flushes; but, Trt6 showed the minimum yield (g/bag) in the first (504.00), second (434.67) and third (154.33) flushes. Similarly, the total yield (g/bag) was maximum in the case of Trt7 (2001.70) over Trt6 (1093.00).

3.4. Productivity of P. ostreatus as affected by agricultural residues

The average biological efficiency was significantly ($\rho < 0.05$) different among the residues tested (Table 4). In general, treatments that gave a higher yield resulted in a higher value of biological efficiency; whereas, those returned with the lowest mushroom yield resulted in the lowest biological efficiency of the *P. ostreatus*. So, the highest biological efficiencies were obtained from Trt7 (238.50%) and Trt4 (238.50%) substrates (Table 4).

Table 4. Productivity of *Pleurotus ostreatus* as affected by different agricultural residues.

Treatment	Biological efficiency (%)	Mushroom Yield	Mushroom Size (g)	Production rate (%)
Trt1	166.67^{c}	17.92^{de}	418.22^{de}	714.57^{bc}
Trt2	208.57^{b}	19.29^{d}	450.11^{d}	812.89^{ab}
Trt3	200.21^{b}	20.68^{cd}	482.55^{cd}	834.26^{a}
Trt4	231.46^{a}	25.90^{ab}	537.44^{bc}	840.95^{a}
Trt5	195.06^{b}	23.04^{bc}	604.44^{ab}	791.36^{ab}
Trt6	150.21^{c}	15.62^{e}	364.33^{e}	663.64^{c}
Trt7	238.46^{a}	28.59^{a}	667.22^{a}	810.38^{ab}

Means with the different letters in the same column are significantly ($\rho < 0.05$) different.

3.5. Relationship among parameters of fruiting body and productivity indexes

Linear regression analysis was performed among fruiting bodies and productivity indexes of *P. ostreatus*. Briefly, linear regression relationships were observed among parameters of the fruiting body and productivity indices studied (Figure 1). The relationships between cap diameter, total yield and mushroom size were positively correlated with the regression equations of $y_1 = 0.58x - 0.90$ (0.83) and $y_2 = 0.199x - 0.30$ ($R^2 = 0.83$), respectively. Stipe length was also positively correlated with total yield $y_1 = 0.47x + 0.01$ ($R^2 = 0.83$) and mushroom size $y_2 = 0.15x + 0.004$ ($R^2 = 0.83$). In the same manner, the number of bunch/bag was positively correlated with total yield $y_1 = 0.37x - 0.02$ ($R^2 = 0.96$) and mushroom size $y_2 = 0.12x - 0.01$ ($R^2 = 0.96$).

Whereas, the linear regression relationships were further observed between the number of fruiting body/bunch and mushroom size $y_1 = 0.01x + 0.14$ ($R^2 = 0.97$) and total yield $y_2 = 0.02x + 0.42$ ($R^2 = 0.97$), between total yield and biological efficiency $y_1 = 91.14x + 61.00$ ($R^2 = 0.83$) and production rate $y_2 = 148.82x + 556.37$ ($R^2 = 0.51$), between the number of fruiting body/bunch and biological efficiency $y_1 = 2.16x + 93.62$ ($R^2 = 0.89$) and production rate $y_2 = 3.68x + 602$ ($R^2 = 0.60$) were among significant positive correlations observed.

3.6. Correlation among parameters of fruiting body and productivity indexes

A linear correlation test was performed to determine the relationships between the fruiting body, total yield and productivity indices in the *P. ostreatus* samples and summarized in Table 5. Biological

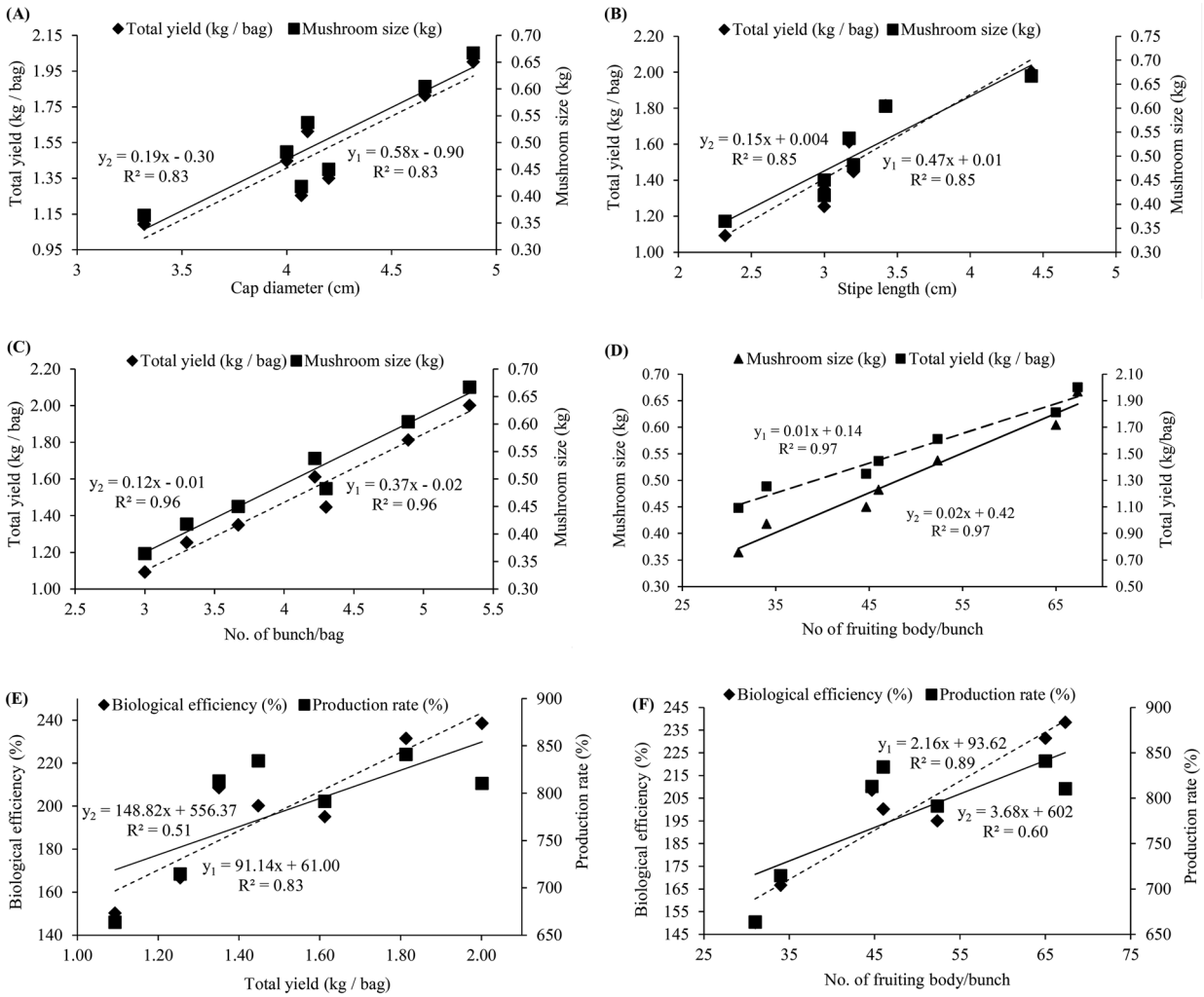

Figure 1. Linear regression relationship of (A) cap diameter (cm) with total yield (kg bag^{-1}) and mushroom size (kg); (B) stipe length (cm) with total yield (kg bag^{-1}) and mushroom size (kg); (C) number of bunch/bag with total yield (kg bag^{-1}) and mushroom size (kg); (D) number of fruiting body/bunch with mushroom size (kg) and total yield (kg bag^{-1}); (E) total yield (kg/bag) with biological efficiency (%) and production rate (%); and (F) number of fruiting body/bunch with biological efficiency (%) and production rate (%) with equations of best-fit lines.

Table 5. Correlation matrix among the measured parameters.

parameters	BE	CD	MS	MY	NB	NF	PR	SL	TY
BE	1.00								
CD	−0.83***	1.00							
MS	0.67***	−0.42 ns	1.00						
MY	−0.93***	0.84***	−0.47*	1.00					
NB	−0.92***	0.76***	−0.67***	0.89***	1.00				
NF	−0.96***	0.80***	−0.75***	0.93***	0.94***	1.00			
PR	0.78***	−0.60**	0.39 ns	−0.71***	−0.60**	−0.70***	1.00		
SL	−0.86***	0.83***	−0.46*	0.83***	0.88***	0.82***	−0.64**	1.00	
TY	−0.93***	0.84***	−0.47*	1.00***	0.89***	0.93***	−0.71***	0.83***	1.00

BE = Biological efficiency (%), CD = Cap diameter (cm), MY = Mushroom Yield (g/g), NB = No. of bunch/bag, NF = No. of fruiting bodies/bunch, PR = Production rate (%), SL = Stipe length (cm), TY = Total yield (g/bag); *, **, *** and ns = correlation is significant at $\rho < 0.05$, 0.01, 0.001 and non-significant, respectively.

efficiency was significant ($\rho < 0.01$) and positively correlated with the mushroom yield (0.83***, $\rho < 0.00$) and with the production rate (0.90***, $\rho < 0.00$). Similarly, cap diameter was significantly $\rho < 0.01$) and positively correlated with the number of bunch/bag (0.76***, $\rho < 0.001$), number of fruiting body/bag (0.80***, $\rho < 0.00$), stipe length (0.83***, $\rho < 0.00$) and total yield (0.84***, $\rho < 0.00$). Likewise, significant ($\rho < 0.01$) and positive correlations were observed between mushroom yield and production rate (0.79***, $\rho < 0.00$), between the number of bunch/bag and number of fruiting body/bag (0.9401***, $\rho < 0.00$), stipe length (0.88***, $\rho < 0.00$), and total yield (0.89***, $\rho < 0.00$). In the same fashion, the number of fruiting bodies/bag significantly ($\rho < 0.01$) and positively correlated with stipe length (0.82***,

$\rho < 0.00$), and total yield (0.93***, $\rho < 0.00$). Furthermore, stipe length significantly ($\rho < 0.01$) and positively correlated with total yield (0.83***, $\rho < 0.00$) (Table 5).

In another way, significantly ($\rho < 0.01$) negative correlations were observed between biological efficiency and cap diameter (−0.55**, $\rho < 0.01$), between biological efficiency and several bunch/bag (−0.45, $\rho < 0.04$), between biological efficiency and total yield (−0.48*, $\rho < 0.03$), between production rate and stipe length (−0.44*, $\rho < 0.04$) (Table 5).

4. Discussion

Treatment seven (Trt7) enabled the *P. ostreatus* to attain 100% mycelial colonization, primordial formation, and the first harvest of the fruiting body within 13, 20, and 23 days, respectively. This might be due to the supply of different nutrients contained in the different components of the Trt7 (i.e., synergistic effect). Similarly, [42] supposed that the mixture of agro-wastes can be interesting in making mushrooms fast-growing and productive with a consequent loss and cost reduction. In addition, [59] observed that mixing substrate can help to increase yield and, as a result, a higher benefit-cost ratio. Furthermore, [67] reported that nutrient contents were increased in the mixture substrate when compared with the single (wheat straw) substrate alone for the reason that the higher chemical contents (carbon and C: N ratio) were achieved on the mixture substrate at values 244.33 g/kg and 40.20; while wheat straw alone substrate decreased to 239.00 g/kg and 38.50 significantly ($\rho < 0.05$), respectively, which are responsible for the advanced improvement of the recorded morphological traits in the case of *P. ostreatus* grown on the mixture substrate in the present study. Also [1] reported that the incubation period (required days for formation of primordia) was delayed (30 days) in the sawdust substrate alone compared to the mixture substrates which formed within less than 16 days.

While, the use of sawdust (Trt6) alone as a cultivation substrate delayed mycelial colonization, primordial formation, and the first harvest of the fruiting body by 5 days (i.e., in 18, 27, and 30 days), in that order, compared to the Trt7. In contrast, [68] reported that total mycelia colonization and first harvest periods were earlier for the sawdust (30.03) and (42.27) days, respectively, compared to the mixture substrates that took 35.08 and 44.02 days for mycelia colonization and first harvest, respectively.

The longest stipe length observed on the Trt7 might be due to suitability of the mixture substrate for the cultivation of *P. ostreatus* compared to the use of a substrate alone. Similarly, [69] reported the success of growing oyster mushrooms on the mixture substrates in the Kingdom of Saudi Arabia. Moreover, [68] reported their thorough review that the mixture substrates were the most suitable ones for the cultivation of oyster mushrooms in which they gave the highest values of cap diameter (80.87–83.56 mm) and stipe thickness (9.84–10.86 mm) compared to the control treatment, 100% sawdust, cap diameter (70.62 mm) and stipe thickness (8.52 mm). This finding is also in conformity with [70] who showed that cap diameter, stipe thickness, and mushroom weight g/bunch of both *Pleurotus ostreatus* and *Pleurotus cystidiosus* mushrooms were decreased in sawdust substrate when compared with some mixture substrates. However, [68] found significant ($\rho < 0.\ 05$) contrasting results that the number of effective fruiting bodies/bunch for sawdust (control) treatment was superior (10.32) to some mixture treatments (8.07–8.55).

The highest yields recorded from the *P. ostreatus* grown on the Trt7, Trt4, and Trt5 treatments might be attributed to their rich protein contents compared to the other ones. In agreement with these results, an early study by [71] stated that the higher productivity might be attributed to the high amounts of crude protein in them, which could have stimulated the growth of the mushroom. Furthermore, [57] reported that different nitrogen-rich substrates and their combination affected the yield performance of oyster mushrooms.

The increased yield of mushrooms in the Trt7 might also be due to cellulosic and lignocellulose materials increased in different constituents of the mixture residue. Similarly, the results of [72] showed that maize straw mixed with 20% bean straw produced a better yield of grey oyster mushrooms. [68] also observed that mixing substrate (1.289 kg) can help to increase yield by 56.24% compared to the yield obtained from wheat straw (0.825 kg) alone. The addition of cotton seeds to paddy straw gave the maximum yield of fruit bodies (1.48 kg/kg) substrate [71]. Because, if different substrates were mixed, nutrients supplement each other and significantly affect the mushroom's general performance. The same results were also further reported by [73] that the highest yield of mushrooms was recorded on the mixture of cotton stalks with wheat straw (796.12 g/kg substrate).

The highest productivity of *P. ostreatus* obtained from Trt7 might be due to the highest amount of lignocellulose components present in them. Likewise, [1] found that mixed substrate was more suitable for oyster mushrooms in terms of biological efficiency

compared to other substrate formulas. Accordingly, the highest value of biological efficiency (100.57 g) was obtained from the shaft mixture with wheat bran, while sawdust gave the lowest (13.08%) value of biological efficiency. Other scholars, [68] also reported that the highest biological efficiency of mushroom *P. ostreatus* was obtained from substrate formulas 100% corncob and 100% sugarcane bagasse (66.08% and 65.65%, respectively). But the 100% sawdust substrate showed the lowest biological efficiency of *P. ostreatus* oyster mushrooms.

Furthermore, although [74] and [75] found contrasting results, [75–77] reported similar results that the use of a single substrate alone is not effective for mushroom productivity. However, if different supplements were mixed, nutrients prepared in such a way have significant influences on yield and biological efficiency of mushroom too. The study results by [1] further suggested that the amount of lignocellulose component present in the substrate may determine how effective the substrate will be for mushroom cultivation.

The regression equations indicating positive and statistically significant impacts on their respective parameters imply that those pairs of variables are connected; and an increase in one results in an increase in others. These findings are in agreement with many findings of the scholars. Accordingly, the average number of the fruiting body and biological yield are influenced by different levels of wheat bran supplemented with sugarcane bagasse [77]. Similar results were also reported by [78] that linear regression relationships were observed between economic yield and the number of primordia/packet, effective fruiting and biological efficiency. Furthermore, [79] reported the relationships between several pairs of variables in their investigation of the complex genetic architecture of yield-related traits in *Agaricus bisporus* through the mapping of quantitative trait loci. In general, the R^2 value indicated that the dependent parameters (Ys) of *P. ostreatus* are attributed to the average values of independent parameters (Xs) as detailed in Figure 1(A-F).

On the other hand, the negative regressions suggest that those pairs of variables were unrelated; and an increase in one results in a decrease in others. Similar results were reported that the correlation coefficients among studied traits were found to be highly significant [80]. Furthermore, linear correlations between pairs of mushroom traits were observed [4, 80, 81].

In conclusion, morphological, fruiting bodies, yield, and productivity of *P. ostreatus* were substrate-dependent based on the results obtained. Thus, selecting an appropriate substrate is very important for producers. It seems probable that the mixed residue provides a more balanced supply of nutrients to the mushroom than the residue alone. Because the Trt7 was found to be the most suitable one. *Pleurotus ostreatus* producers in the study area can, therefore, cultivate by mixing the agricultural residues as a better substrate for sustainable productivity of the mushroom while obtaining satisfactory yield and properly managing the wastes. Generally, the cultivation of *P. ostreatus* is a simple and environmentally friendly practice, which can be implemented both in urban and rural areas; especially, where jobless people are high because the substrate used for mushroom cultivation is economically feasible and readily available. Thus, the use of mixed agro-residues as substrates for the cultivation of *P. ostreatus* is advantageous over single residues and recommended to the farmers of the study area.

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Authors' contribution

H.G.: Lead the project as principal investigator (PI), facilitate budget, participate in any activities (investigation, supervision, preparing reports and submitting accordingly, data collection, and formal analysis, writing original draft, review, and editing); T.B.: participate in activities such as conceptualization and drafting proposal); G.F.: participate in laboratory analysis, data collection, and interpretation). All authors have read and agreed to the published version of the manuscript.

Declaration

This research is our original work and has not been presented for the award of a degree in any other institution.

Disclosure statement

No potential competing interest was reported by the authors.

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ORCID

Hailu Gebru http://orcid.org/0000-0001-6027-3789

References

[1] Adebayo EA, Elkanah FA, Afolabi FJ, et al. Molecular characterization of most cultivated *Pleurotus* species in sub-western region Nigeria with development of cost effective cultivation protocol on palm oil waste. Heliyon. 2021;7(2):e06215. doi: 10.1016/j.heliyon.2021.e06215.

[2] Chang ST, Wasser SP. The cultivation and environmental impact of mushrooms. In: Oxford Research Encyclopedia of Environmental Science. Oxford University Press; 2017.1–39.

[3] Semwal KC, Lemma H, Dhyani A, et al. Mushroom: nature's treasure in Ethiopia. mejs. 2014;6(2):138–147. doi: 10.4314/mejs.v6i2.109715.

[4] Chukwu SC, Ibeji CA, Ogbu C, et al. Primordial initiation, yield and yield component traits of two genotypes of oyster mushroom (*Pleurotus* spp.) as affected by various rates of lime. Sci Rep. 2022;12(1):19054. doi: 10.1038/s41598-022-16833-9.

[5] Milenge Kamalebo H, Nshimba Seya Wa Malale H, Masumbuko Ndabaga C, et al. Uses and importance of wild fungi: traditional knowledge from the Tshopo province in the Democratic Republic of the Congo. J Ethnobiol Ethnomed. 2018;14(1):13. doi: 10.1186/s13002-017-0203-6.

[6] Elbagory M, El-Nahrawy S, Omara AE, et al. Sustainable bioconversion of wetland plant biomass for *Pleurotus ostreatus* var. *florida* cultivation: studies on proximate and biochemical characterization. Agriculture. 2022;12(12):2095. doi: 10.3390/agriculture12122095.

[7] Tolera KD, Abera S. Nutritional quality of oyster mushroom (*Pleurotus ostreatus*) as affected by osmotic pretreatments and drying methods. Food Sci Nutr. 2017;5(5):989–996. doi: 10.1002/fsn3.484.

[8] Dissasa G. Cultivation of different oyster mushroom (*Pleurotus* species) on coffee waste and determination of their relative biological efficiency and pectinase enzyme production in Ethiopia. Int J Microbiol. 2022;2022:5219939. doi: 10.1155/2022/5219939.

[9] Li H, Zhang Z, Li M, et al. Yield, size, nutritional value, and antioxidant activity of oyster mushrooms grown on perilla stalks. Saudi J Biol Sci. 2017;24(2):347–354. doi: 10.1016/j.sjbs.2015.10.001.

[10] Gupta S, Summuna B, Gupta M, et al. Edible mushrooms: cultivation, bioactive molecules, and health benefits. In Mérillon JM, Ramawat K, editors. Bioact Mol Food. Switzerland: Springer Nature; 2018. p. 1815–1847. doi: 10.1007/978-3-319-78030-6_86.

[11] Tavarwisa DM, Govera C, Mutetwa M, et al. Evaluating the suitability of baobab fruit shells as substrate for growing oyster mushroom (*Pleurotus ostreatus*). Int J Agron. 2021;2021:1–7. doi: 10.1155/2021/6620686.

[12] Adebayo EA, Martinez-Carrera D. Oyster mushrooms (*Pleurotus*) are useful for utilizing lignocellulosic biomass. Afr. J. Biotechnol. 2015;14(1):52–67. doi: 10.5897/AJB2014.14249.

[13] Reyes H, Rodríguez JA. The lignin of the *Angustifolia Kunth* guadua incorporated into the substrate of the fungus *Pleurotus ostreatus*. Entre Cienc e Ing. 2019;13:9–13. doi: 10.31908/19098367.4009.

[14] Bugarski D, Djuro G, Takac A, et al. Influence of substrates on fructification of oyster mushroom (*Pleurotus ostreatus*) strain NS-16. I Balkan Symposium on. Acta Hortic. 1997;(462):891–894. doi: 10.17660/ActaHortic.1997.462.142.

[15] Doroški A, Klaus A, Režek Jambrak A, et al. Food waste originated material as an alternative substrate used for the cultivation of oyster mushroom (*Pleurotus ostreatus*): A review. Sustain. 2022;14(19):12509. doi: 10.3390/su141912509.

[16] Zhang R, Li X, Fadel JG. Oyster mushroom cultivation with rice and wheat straw. Bioresour Technol. 2002;82(3):277–284. doi: 10.1016/S0960-8524(01)00188-2.

[17] Zhang Y, Geng W, Shen Y, et al. Edible mushroom cultivation for food security and rural development in China: bio-innovation, technological dissemination and marketing. Sustain. 2014;6(5):2961–2973. doi: 10.3390/su6052961.

[18] Adedokun OM, George-David M. Nutritional profile and yield of oyster mushroom cultivated on selected agricultural wastes. Afr. Crop Sci. J. 2016;24(3):259. doi: 10.4314/acsj.v24i3.4.

[19] Pandey VV, Kumari A, Kumar M, et al. Mushroom cultivation: substantial key to food security. JANS. 2018;10(4):1325–1331. doi: 10.31018/jans.v10i4.1941.

[20] Lesa KN, Khandaker MU, Mohammad Rashed Iqbal F, et al. Nutritional value, medicinal importance, and health-promoting effects of dietary mushroom (*Pleurotus ostreatus*). J Food Qual. 2022;2022:1–9. doi: 10.1155/2022/2454180.

[21] Thakur MP. Advances in mushroom production: key to food, nutritional and employment security: a review. Indian Phytopathol. 2020;73(3):377–395. doi: 10.1007/s42360-020-00244-9.

[22] Fernandes T, Garrine C, Ferrão J, et al. Mushroom nutrition as preventative healthcare in sub-Saharan Africa. Appl Sci. 2021;11(9):4221. doi: 10.3390/app11094221.

[23] Assemie A, Abaya G. The effect of edible mushroom on health and their biochemistry. Int J Microbiol. 2022;2022:8744788. doi: 10.1155/2022/8744788.

[24] Phillips JM, Ooi SL, Pak SC. Health-promoting properties of medicinal mushrooms and their bioactive compounds for the COVID-19 era—an appraisal: do the pro-health claims measure up? Molecules. 2022;27(7):2302. doi: 10.3390/molecules27072302.

[25] Mattila P, Könkö K, Eurola M, et al. Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. J Agric Food Chem. 2001;49(5):2343–2348. doi: 10.1021/jf001525d.

[26] Mattila P, Lampi AM, Ronkainen R, et al. Sterol and vitamin D2 contents in some wild and cultivated mushrooms. Food Chem. 2002;76(3):293–298. doi: 10.1021/jf001525d.

[27] Jeong SC, Jeong YT, Yang BK, et al. White button mushroom (*Agaricus bisporus*) lowers blood glucose and cholesterol levels in diabetic and hypercholesterolemic rats. Nutr Res. 2010;30(1):49–56. doi: 10.1016/j.nutres.2009.12.003.

[28] Valverde M, Hernández T, Paredes O. Edible mushrooms: improving human health and promoting quality life. Int J Microbiol. 2015;2015:1–14. doi: 10.1155/2015/376387.

[29] Maga JA. Mushroom flavor: review. J Agric Food Chem. 1981;29(1):1–4. doi: 10.1021/jf00103a001.
[30] Sun L, bin Zhang Z, Yong Xin G, et al. Advances in umami taste and aroma of edible mushrooms. Trends Food Sci Technol. 2020;96:176–187. doi: 10.1016/j.tifs.2019.12.018.
[31] Patel DK, Dutta SD, Ganguly K, et al. Mushroom-derived bioactive molecules as immunotherapeutic agents: a review. Molecules. 2021;26(5):1359. doi: 10.3390/molecules26051359.
[32] Hagiwara SY, Takahashi M, Shen Y, et al. A phytochemical in the edible Tamogi-take mushroom (*Pleurotus cornucopiae*), D-mannitol, inhibits ACE activity and lowers the blood pressure of spontaneously hypertensive rats. Biosci Biotechnol Biochem. 2005;69(8):1603–1605. doi: 10.1271/bbb.69.1603.
[33] Guillamón E, García-Lafuente A, Lozano M, et al. Edible mushrooms: role in the prevention of cardiovascular diseases. Fitoterapia. 2010;81(7):715–723. doi: 10.1016/j.fitote.2010.06.005.
[34] Pandya U, Dhuldhaj U, Sahay NS. Bioactive mushroom polysaccharides as antitumor: an overview. Nat Prod Res. 2019;33(18):2668–2680. doi: 10.1080/14786419.2018.1466129.
[35] Wuest PJ. Resources needed to farm the 'Champignon. Mycologia. 1983;75(2):340–350. doi: 10.1016/j.fitote.2010.06.005.
[36] Fernandez CE, Viehmannova I, Bechyne M, et al. The cultivation and phenological growth stages of yacon [*Smallanthus sonchifolius* (Poepp. et Endl.) H. Robinson.]. Agric Trop Subtrop. 2007;40:71–77. doi: 10.1080/14786419.2018.1466129.
[37] Tesfay T, Godifey T, Mesfin R, et al. Evaluation of waste paper for cultivation of oyster mushroom (*Pleurotus ostreatus*) with some added supplementary materials. AMB Express. 2020;10(1):15. doi: 10.1186/s13568-020-0945-8.
[38] Mihai RA, Melo Heras EJ, Florescu LI, et al. The edible gray oyster fungi *Pleurotus ostreatus* (Jacq. ex Fr.) P. Kumm a potent waste consumer, a biofriendly species with antioxidant activity depending on the growth substrate. J Fungi (Basel). 2022;8(3):274. doi: 10.3390/jof8030274.
[39] Moshtaghian H, Parchami M, Rousta K, et al. Application of oyster mushroom cultivation residue as an upcycled ingredient for developing bread. Appl Sci. 2022;12(21):11067. doi: 10.3390/app122111067.
[40] Hultberg M, Asp H, Bergstrand KJ, et al. Production of oyster mushroom (*Pleurotus ostreatus*) on sawdust supplemented with anaerobic digestate. Waste Manag. 2023;155:1–7. doi: 10.1016/j.wasman.2022.10.025.
[41] Obaa B, Nshemereirwe F. Assessing the potential of mushroom cultivation in improving household incomes of smallholder farmers. Uganda J Agric Sci. 2004;9:656–662.
[42] Bellettini MB, Fiorda FA, Maieves HA, et al. Factors affecting mushroom *Pleurotus* spp. Saudi J Biol Sci. 2019;26(4):633–646. doi: 10.1016/j.sjbs.2016.12.005.
[43] Ferdousi J, Riyadh Z, Al Hossain MI, et al. Mushroom production benefits, status, challenges and opportunities in Bangladesh: a review. ARRB. 2020;34:1–13. doi: 10.9734/arrb/2019/v34i630169.
[44] Sahayaraj K, Namasivayam SKR. Mass production of entomopathogenic fungi using agricultural products and by products. Afr J Biotechnol. 2008;7(12):1907–1910. doi: 10.5897/AJB07.778.
[45] Pelletier MG, Holt GA, Wanjura JD, et al. An evaluation study of pressure-compressed acoustic absorbers grown on agricultural by-products. Ind Crops Prod. 2017;95:342–347. doi: 10.1016/j.indcrop.2016.10.042.
[46] Sakellari A, Karavoltsos S, Tagkouli D, et al. Trace elements in *Pleurotus ostreatus*, *P. Eryngii*, and *P. nebrodensis* mushrooms cultivated on various agricultural by-products. Anal Lett. 2019;52(17):2692–2709. doi: 10.1080/00032719.2019.1594865.
[47] Sánchez C. Cultivation of *Pleurotus ostreatus* and other edible mushrooms. Appl Microbiol Biotechnol. 2010;85(5):1321–1337. doi: 10.1007/s00253-009-2343-7.
[48] Lechner BE, Albertó E. Search for new naturally occurring strains of *Pleurotus* to improve yields. *Pleurotus albidus* as a novel proposed species for mushroom production. Rev Iberoam Micol. 2011;28(4):148–154. doi: 10.1016/j.riam.2010.12.001.
[49] Wan Mahari WA, Peng W, Nam WL, et al. A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry. J Hazard Mater. 2020;400:123156. doi: 10.1016/j.jhazmat.2020.123156.
[50] Benziger V. Small fields, big money: two successful programs in helping small farmers make the transition to high value-added crops. World Dev. 1996;24(11):1681–1693. doi: 10.1016/0305-750X(96)00070-8.
[51] Belcher B, Ruíz-Pérez M, Achdiawan R. Global patterns and trends in the use and management of commercial NTFPs: implications for livelihoods and conservation. World Dev. 2005;33(9):1435–1452. doi: 10.1016/j.worlddev.2004.10.007.
[52] Asfaw S, Shiferaw B, Simtowe F, et al. Impact of modern agricultural technologies on smallholder welfare: evidence from Tanzania and Ethiopia. Food Policy. 2012;37(3):283–295. doi: 10.1016/j.foodpol.2012.02.013.
[53] Sileshi M. Assessment of mushroom production and marketing in Ethiopia: the case of Addis Ababa. Ethiopia St. Mary's University; 2014.
[54] Dejene T, Oria-De-Rueda JA, Martín-Pinto P. Wild mushrooms in Ethiopia: a review and synthesis for future perspective. For. syst. 2017;26(1):eR02. doi: 10.5424/fs/2017261-10790.
[55] Kiflemariam Y. Potentials and constraints of mushroom production in Ethiopia. National Mushroom Conference. Ethiopia: Addis Ababa University; 2008.
[56] Girmay Z, Gorems W, Birhanu G, et al. Growth and yield performance of *Pleurotus ostreatus* (Jacq. Fr.) Kumm (oyster mushroom) on different substrates. AMB Express. 2016;6(1):87. doi: 10.1186/s13568-016-0265-1.
[57] Rizki M, Tamai Y. Effects of different nitrogen rich substrates and their combination to the yield performance of oyster mushroom (*Pleurotus ostreatus*). World J Microbiol Biotechnol. 2011;27(7):1695–1702. doi: 10.1007/s11274-010-0624-z.
[58] Hoa HT, Wang CL, Wang CH. The effects of different substrates on the growth, yield, and nutritional composition of two oyster mushrooms (*Pleurotus ostreatus* and *Pleurotus cystidiosus*). Mycobiology. 2015;43(4):423–434. doi: 10.5941/MYCO.2015.43.4.423.

[59] Muswati C, Simango K, Tapfumaneyi L, et al. The effects of different substrate combinations on growth and yield of oyster mushroom (*Pleurotus ostreatus*). Int J Agron. 2021;2021:1–10. doi: 10.1155/2021/9962285.
[60] Akyüz M, Yildiz A. Cultivation of *Pleurotus eryngii* (DC. ex FR.) Quel. on agricultural wastes. Philipp Agric Sci. 2007;90:346–350.
[61] Kazige OK, Chuma GB, Lusambya AS, et al. Valorizing staple crop residues through mushroom production to improve food security in eastern Democratic Republic of Congo. J Agric Food Res. 2022;8:1–11. doi: 10.1016/j.jafr.2022.100285.
[62] Rodriguez Estrada AE, Jimenez-Gasco M del M, Royse DJ. Improvement of yield of *Pleurotus eryngii* var. *eryngii* by substrate supplementation and use of a casing overlay. Bioresour Technol. 2009;100(21):5270–5276. doi: 10.1016/j.biortech.2009.02.073.
[63] Yang WJ, Guo FL, Wan ZJ. Yield and size of oyster mushroom grown on rice/wheat straw basal substrate supplemented with cotton seed hull. Saudi J Biol Sci. 2013;20(4):333–338. doi: 10.1016/j.sjbs.2013.02.006.
[64] López-Manzanares B, Martínez-Villar E, Marco-Mancebón VS, et al. Compatibility of the entomopathogenic fungus *Beauveria bassiana* with etoxazole, spirodiclofen and spiromesifen against *Tetranychus urticae*. Biol Control. 2022;169:104892. doi: 10.1016/j.biocontrol.2022.104892.
[65] Thuc LV, Corales RG, Sajor JT, et al. Rice-straw mushroom production. In: Gummert v, Van Hung N, Pauline Chivenge BD, editors. Sustainable Rice Straw Management. Switzerland: Springer Nature; 2020. p. 93–110. doi: 10.1007/978-3-030-32373-8.
[66] Gomez KA, Gomez AAG. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons, Inc; 1984.
[67] Owaid MN, Abed IA, Al-Saeedi SSS. Applicable properties of the bio-fertilizer spent mushroom substrate in organic systems as a byproduct from the cultivation of *Pleurotus* spp. Inf Process Agric. 2017;4(1):78–82. doi: 10.1016/j.inpa.2017.01.001.
[68] Hoa HT, Wang C, Wang C. The effects of different substrates on the growth, yield, and nutritional composition of two oyster mushrooms (*Pleurotus ostreatus and Pleurotus cystidiosus*). Mycobiology. 2015;43:423–434. doi: 10.5941/MYCO.2015.43.4.423
[69] Alananbeh KM, Bouqellah NA, Al Kaff NS. Cultivation of oyster mushroom *Pleurotus ostreatus* on date-palm leaves mixed with other agro-wastes in Saudi Arabia. Saudi J Biol Sci. 2014;21(6):616–625. doi: 10.1016/j.sjbs.2014.08.001.
[70] Hoa HT, Wang CL. The effects of temperature and nutritional conditions on mycelium growth of two oyster mushrooms (*Pleurotus ostreatus* and *Pleurotus cystidiosus*). Mycobiology. 2015;43(1):14–23. doi: 10.5941/MYCO.2015.43.1.14.
[71] Bisaria R, Madan M, Bisaria VS. Biological efficiency and nutritive value of *Pleurotus sajor-caju* cultivated on different agro-wastes. Biol Wastes. 1987;19(4):239–255. doi: 10.1016/0269-7483(87)90058-9.
[72] Musara A, Gasura E, Ngadze E, et al. Effect of mixing cereal and legume straws on yield of grey oyster mushroom under controlled conditions. Afr. Crop Sci. J. 2018;26(2):175–187. doi: 10.4314/acsj.v26i2.2.
[73] Mane VP, Patil SS, Syed AA, et al. Bioconversion of low quality lignocellulosic agricultural waste into edible protein by *Pleurotus sajor-caju* (Fr.) Singer. J Zhejiang Univ Sci B. 2007;8(10):745–751. doi: 10.1631/jzus.2007.B0745.
[74] Chai WY, Krishnan UG, Sabaratnam V, et al. Assessment of coffee waste in formulation of substrate for oyster mushrooms *Pleurotus pulmonarius* and *Pleurotus floridanus*. Futur Foods. 2021;4:100075. doi: 10.1016/j.fufo.2021.100075.
[75] Fufa BK, Tadesse BA, Tulu MM. Cultivation of *Pleurotus ostreatus* on agricultural wastes and their combination. Int J Agron. 2021;2021:1–6. doi: 10.1155/2021/1465597.
[76] Liang CH, Wu CY, Lu PL, et al. Biological efficiency and nutritional value of the culinary-medicinal mushroom *Auricularia* cultivated on a sawdust basal substrate supplement with different proportions of grass plants. Saudi J Biol Sci. 2019;26(2):263–269. doi: 10.1016/j.sjbs.2016.10.017.
[77] Hasan MT, A, Khatun MH, M, Sajib, et al. Effect of wheat bran supplement with sugarcane bagasse on growth, yield and proximate composition of pink oyster mushroom (*Pleurotus djamor*). Am J Food Sci Technol. 2015;3:150–157. doi: 10.12691/ajfst-3-6-2.
[78] Urme AS. Effect of different amounts and combinations of substrates on yield and contamination of spawn packet in oyster mushroom cultivation (Pleurotus ostreatus). Dhaka: Sher-E-Bangla Agricultural University; 2021.
[79] Foulongne-Oriol M, Rodier A, Rousseau T, et al. Quantitative trait locus mapping of yield-related components and oligogenic control of the cap color of the button mushroom, *Agaricus bisporus*. Appl Environ Microbiol. 2012;78(7):2422–2434. doi: 10.1128/AEM.07516-11.
[80] Singh M, Kamal S. Validity of mycelial growth on malt extract agar and compost as selection criteria for initial screening of genotypes for yield and quality in *Agaricus bisporus*. Proc 7th Conf Mushroom Biol Mushroom Products (ICMBMP7). 2011;25:71–76.
[81] Kortei NK, Odamtten GT, Obodai M, et al. Correlations of cap diameter (pileus width), stipe length and biological efficiency of *Pleurotus ostreatus* (Ex.Fr.) Kummer cultivated on gamma-irradiated and steam-sterilized composted sawdust as an index of quality for pricing. Agric Food Secur. 2018;7:1–8. doi: 10.1186/s40066-018-0185-1.