Species, Cultivation location Effects on Biological Efficiency and Carbon, Nitrogen, and Macronutrient Composition of Mushrooms Grown on Local Lignocellulosic Substrates

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Abstract. This investigation estimated the interaction effects of oyster mushroom species, cultivation location, and local lignocellulosic substrates on composition of Pleurotus fruiting bodies carbon, nitrogen, macro-mineral and biological efficiency (BE), *Pleurotus citrinopileatus, P. djamor,* and *P. pulmonarius* were growing under laboratory and greenhouse conditions on wheat straw, sawdust-based substrate, wood chips–sawdust blend, straw-based substrate, and rice straw. (BE) and fruiting-body C, N, Ca, Na, K, and Mg concentration were measurements and statistically analyzed using factorial comparisons with LSD at $P \leq 0.05$. The results showed that the *P. pulmonarius* is the highest BE (87.84%) and 3.29% nitrogen and 43.87% carbon content. The condition in laboratory under 25 C^{o} increased the overall the BE and carbon content, though wheat straw given the highest means BE 61.71% and rice straw the uppermost nitrogen content (3.32%). The highest carbon contents were in the wood chips–sawdust blend 45.41%, while the Calcium and Potassium showed no significant differences in main factors oyster strain genotypes, locations and substrates. *P. pulmonarius* had the highest sodium content, whereas *P. djamor* recorded the highest magnesium content. Overall, species–substrate–location interactions strongly influenced productivity and selected mineral traits, highlighting the importance of matching fungal genotype with cultivation environment and locally available substrates.

***Keywords*:** *Pleurotus* spp.; Biological Efficiency; Lignocellulosic Substrates; Macro mineral; Agricultural residues

1. INTRODUCTION

Oyster mushrooms belonging to the genus Pleurotus are amongst the most widely cultured edible fungi because of their nutritional value and its taste, relatively short production cycle, flexibility to changed climatic conditions, and ability to grow on a wide range of residual agriculture. Also, the oyster fruits bodies riches with protein, fibers, carbohydrates, vitamins, minerals and bioactive compounds.[1] Additionally, Pleurotus spp. cultivation is considered as Eco-friend process and biotechnology sustainable because it changes low-value lignocellulosic residues into valuable edible fungal biomass for there more the spent mushroom substrate can use as animal feeding , composting and produce bioenergy [2]. Oyster mushrooms are classified as

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white-rot fungi due to its extracellular lignocellulolytic enzymes, such as Laccases, cellulases and hemicelluloses these enzymes can help the fungal mycelium to decompose lignin, cellulose and hemicellulos and resales compounds for its fruit' bodies growth. Therefore, several locally available substances, including rice straw, sawdust, wheat straw, corn residues, wood chips and other agro-industrial by-products, can be used as substrates for cultivation. However, there is still difference between their ability to contents from lignocellulosic composition, mineral, C/N ratio, particle shape and size, capacity of water, and sensitivity to degradation enzymes [1, 3]. The cultivation substates play massive roles in mushroom production, generally the biological efficiency concept used for comparing the capacity of mushrooms to convert the organic substrate to dry compounds in its fruit bodies, different organic substates affecting on the fungal colonization, primordial initiation, incubation period, total yield and biological efficiency. For example, [4] reported that when cultivated P. ostreatus there are different growth and total yield on different substrates such as cottonseed, wheat straw, sawdust and paper waste demonstrating that lignocellulosic materials do not provide equivalent of levels moisture, reachable carbon, nitrogen, minerals, and physically supporting for mushroom productivity. The varying fungal growth response on different substates due to the variance in genetics strains, difference physiological, secretion of enzyme, nutrition requirements and temperature tolerance and element accumulation capacity, the substrate strongly support biological efficiency according to [5]. In addition to the type of substrates also the location of cultivation paly big role which affecting on fungal mycelium growth and colonization, enzyme secretions, Interior room or laboratory, cultivation chambers controlling, and greenhouses can vary in temperature stability, relative humidity, light intensity, aeration, co2 accumulation, and moisture loss from the substrate [1, 6, 7]. The chemical components of fruiting bodies for oyster mushroom are also influenced by the interaction between fungal genotype and cultivation conditions. Carbon and nitrogen represent major components of fungal mycelium and fruits bodies. One of the most important components is Carbon, which is found in structural and storage compounds, while nitrogen is necessary for amino acids, proteins, nucleic acids, enzymes, and other cellular components. The amounts of carbon and nitrogen available in the substrate, together with the capacity of the mycelium to absorb and metabolize them, may consequently influence biomass formation, biological efficiency, and fruiting-body composition. Determining carbon and nitrogen in harvested mushrooms can therefore provide useful information about nutrient incorporation and substrate-to-mycelium transformation [8]. Oyster mushrooms similarly contain nutritionally significant macrominerals, mainly K, Mg, Ca, and Na. The concentration of these elementals maybe varies according to the strain genetics and substate content and cultivation. A multi-element comparison of cultivated Pleurotus species, involving P. djamor, P. citrinopileatus, and P. pulmonarius, revealed significant species- and strain-related variation in elemental accumulation [9] . Similarly, adjustments in substrate structure and nitrogen form different the mineral composition of different Pleurotus species, even when many of the substrates had relatively similar elemental concentrations [3]. Latest investigates utilizing locally available agro-industrial by-products have confirmed that substrate formulation can concurrently effect on biological efficiency, nutritional properties, and mineral concentrations [10]. for pattern, found significant differences in the biological efficiency, yield, and mineral content of P. ostreatus cultivated on substrates prepared from sugarcane residues, cottonseed hulls, and animal-derived amendments. Potassium

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was the principal macromineral, followed by magnesium, calcium, and sodium. Such findings highlight the possibility of selecting local residues not only to increase the yield of mushroom but also to upgrade the nutritionary quality of the developing of fruiting bodies [11-13]. Even though the separate belongings of substrate type and species or on oyster mushroom production have been generally explored, moderately less attention has been given to the combined interaction among mushroom species, cultivation location, and local lignocellulosic substrates. Furthermore, biological efficiency and elemental composition are frequently examined separately, although both characteristics may be controlled by the same species–substrate–environment interactions. A factorial assessment of these factors is therefore necessary to determine whether differences in productivity are accompanied by changes in carbon, nitrogen, and macromineral accumulation. While species and substrate effects on oyster mushroom production are well reported, their mutual interface with location of cultivation remains not enough studied. Elemental composition and biological efficiency and are also often estimated individually, although being partial by the same species–substrate–environment interactions. The investigate targeted to identify fitting New species– new eco-frinds from local substrate–place combinations that provide superior biological efficiency during which retaining or improving the elemental and mineral quality of oyster mushrooms. The results may support the environmental utilization of local agricultural residues, improve substrate-assortment tactics, and impact to the development of cost-effective oyster mushroom production under local environmental conditions.

2. MATERIALS AND METHODS

2.1. MATERIALS

2.1.1 Mushroom Mother Cultures

The strains of fungi used in the study involved *Pleurotus pulmonarius*, *Pleurotus djamor*, and *Pleurotus citrinopileatus*. were kindly obtained from the Agricultural Research Center, Dokki, Cairo, Egypt. Mushroom spawn was prepared at the Horticultural Laboratory, College of Agricultural Engineering Sciences, Salahaddin University-Erbil, using sterilized wheat grains.

2.1.2 Lignocellulosic Growing Substrates

The substrates local organic used for mushroom growing were collected from Ranya District, agricultural fields and. The substrates involved: Wheat straw, Sawdust-based, Wood chips and sawdust blend Straw-based substrate, Rice straw supplemented with 2% Gypsum ($CaSO_4$), 2% Lime ($CaCO_3$), 10% wheat bran.

3.1.3 Chemicals and Reagents:

The basic reagents used for chemical investigation included: Deionized water, Nitric acid, 70%, Reagents required for the Micro-Kjeldahl method Reagents required for

2.2 Methods

2.2.1 Experimental setting and duration

The experiment carried out from October 2024 to June 2025 at the College of Agricultural Engineering Sciences, Salahaddin University, located at latitude 36°07′10.44″ N and longitude 44°00′50.52″ E, at an elevation of 421 m above sea level.

2.2.2 Mushroom Spawn Preparation

P. pulmonarius, *P. djamor*, and *P. citrinopileatus* spawn were prepared on carrier which contented sterilized wheat grains. Three spawn concentrations, 10% (w/w), were used for inoculation of the different growing substrates.

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2.2.3 Lignocellulosic growing Substrates preparation

Soaked the selective substrate in water for overnight to achieve the content of moisture around 60–70%. Additional water was drained for around 2 h, after which the substrates were subjected to steam treatment for approximately 8 hrs. After treatment, the substrates were allowed to cool before inoculation. The added the supplemented; Gypsum ($CaSO_4$, 2%), lime ($CaCO_3$, 2%), and wheat bran (10%) were afterward contained as supplements.

Substrates code	Organic substrate	Carbon (C) %	Nitrogen (N)%	C/N ratio
S	Sawdust-Based substrate	36	2.70	13.27
W	Wood chips and Sawdust Blend	41	2.53	16.27
B	Straw-Based Substrate	45	2.63	17.07
R	Rice straw	42	2.50	16.87
W	Wheat straw	34	2.22	15.80

2.2.4 Spawning

The substrates when cooling to room temperature were put into 40 × 60 cm plastic cultivation bags. Around 2000 g of witted growing substrate was used /cultivation bag. Then 10% spawn rates (w/w) [15]. Then added the spawn in layers on substrate, each treatment was done using three replicates. The bags were inoculated folded and closed very well then incubated until the mycelial colonization complete and achieved.

2.2.5 Colonization of Mycelium and Fruiting production

After colonization completed by all *Pleurotus* spp., the cultivation bags were opened to start to fruiting. Cultivation was at two locations first one was laboratory ($25C^o$, 700-800 lux and automated foggy system) completely controlled anther one was Greenhouse with room temperature with particularly control

75–95% relative humidity was applied using an automated fogging system, temperature in green house and laboratory monitored daily during the cultivation period

2.2.6 Harvesting and Biomass Determination

The harvesting of fruiting bodies had regularly occurred over a period of nearly two months. The fresh weight was measurement directly after harvesting. The Fruiting bodies were putted in oven at 60°C for drying until constant weight.[16]

2.2.7 Biological Efficiency

To calculate the biological efficiency (BE) as the % between the total fresh weight of harvested fruiting bodies and cultivation substrate dry weight of the according to [17, 18].

2.2.8 Chemical Analysis of Fruiting Bodies

Chemical analyses of dried fruiting-body samples were endangered. All investigations were handled at the Central Laboratory, College of Agriculture and Forestry, University of Mosul.

2.2.8.1 Nitrogen determination

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Total nitrogen content was determined using the Micro-Kjeldahl method according to reference [17, 19]

2.2.8.2 Carbohydrates determination

Determination of total carbohydrate by spectrophotometrically according to reference [14]. Absorbance was measured at 490 nm using an EMC Lab 100V-1 spectrophotometer.

2.2.8.3 Mineral Elements determination

For mineral elements determination used 200 mg fungal mass powdered, was transferred into a digestion glass vessel. Then, 10 mL of 70% nitric acid and 5 mL of deionized water were added. The samples were left at room temperature overnight and subsequently heated at 90°C until a dry residue was obtained. The residue was dissolved in 25 mL of deionized water. The concentrations of calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg) were determined using an atomic absorption spectrophotometer according to references [20, 21].

2.3 Statistical Analysis

Experiment was designed according to factorial randomized complete block design (RCBD) with three replicates The data were statistically analysed using the General Linear Model (GLM). Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$). Statistical analyses were performed using SPSS version 27. Used LSD values to determine significant differences between the main treatment factors and their interactions.

3. RESULTS AND DISCUSSION

3.1. RESULTS

3.1.1 Biological Efficiency (BE, %):

There are significant differences with biological efficiency by *Pleurotus* spp., location of cultivation, types of substates, and their interactions as shown in (Table 1). The highest means recorded by *P. pulmonarius* (87.84 ± 6.55%), *P. citrinopileatus* was significantly (28.25 ± 1.45%) and *P. djamor* (27.66 ± 1.63%). The cultivation in lab produced a significantly greater main BE (51.38 ± 6.44%) more than cultivation in greenhouse (44.45 ± 3.89%). The highest recorded mean was by wheat straw (61.71 ± 13.06%), tracked by rice straw (55.07 ± 9.57%), although the lasting substrates showed lower statistically similar value. *P. pulmonarius* gave the highest BE achieved for on wheat straw in the lab condition with main (173.29 ± 8.99%), whereases rice straw ranking second below the same conditions (128.43 ± 4.54%). In contrast, *P. citrinopileatus* and *P. djamor* showed substantially lower and more substrate-specific responses.

Table 1: Interaction effect between *Pleurotus* Spp., location of cultivation, and substrate type on biological efficiency (BE, %)

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based substrate	Wood chips and sawdust	Straw-based substrate	Rice straw	
Pleurotus	Greenhouse	22.36 ± 0.04	25.00 ± 2.06	34.57 ± 1.81	37.86 ± 4.54	24.29 ± 0.82	28.81 ± 1.89

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citrinopileatus (P1)	Laboratory	36.19 ± 2.68	17.86 ± 0.41	31.71 ± 1.48	18.57 ± 0.82	34.14 ± 3.88	27.70 ± 2.27
Pleurotus djamor (P2)	Greenhouse	29.29 ± 0.41	29.29 ± 7.01	19.00 ± 2.72	24.29 ± 4.12	24.14 ± 5.53	25.20 ± 2.01
	Laboratory	28.57 ± 1.65	17.71 ± 1.98	27.29 ± 3.38	42.86 ± 2.97	34.14 ± 3.88	30.11 ± 2.47
Pleurotus pulmonarius (P3)	Greenhouse	80.57 ± 5.11	75.71 ± 0.82	83.00 ± 3.22	72.14 ± 0.41	85.29 ± 7.18	79.34 ± 2.05
	Laboratory	173.29 ± 8.99	70.00 ± 0.82	55.71 ± 7.42	54.29 ± 4.95	128.43 ± 4.54	96.34 ± 12.78
							Main P
P×M	**P1**	29.27 ± [illegible]	21.43 ± 1.85	33.14 ± [illegible]	28.21 ± [illegible]	29.21 ± [illegible]	28.25 ± [illegible]
	P2	28.93 ± [illegible]	23.50 ± 4.16	23.14 ± [illegible]	33.57 ± [illegible]	29.14 ± [illegible]	27.66 ± [illegible]
	P3	126.93 ± [illegible]	72.86 ± 1.38	69.36 ± [illegible]	63.21 ± [illegible]	106.86 ± [illegible]	87.84 ± [illegible]
							Main C
M×C	**C1**	44.07 ± [illegible]	43.33 ± 8.39	45.52 ± [illegible]	44.76 ± [illegible]	44.57 ± [illegible]	44.45 ± [illegible]
	C2	79.35 ± [illegible]	35.19 ± 8.73	38.24 ± [illegible]	38.57 ± [illegible]	65.57 ± [illegible]	51.38 ± [illegible]
Main M		61.71 ± [illegible]	39.26 ± 5.95	41.88 ± [illegible]	41.67 ± [illegible]	55.07 ± [illegible]	
LSD (5%)							
P×C×M		**C×M**	**P×M**	**P×C**	**M**	**C**	**P**
11.206		6.470	7.924	5.012	4.575	2.893	3.544

Values are mean ± SE calculated from X3,. P = strain, C = cultivation location, M = substrate; LSD values are given at P ≤ 0.05. P1 = P*leurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory.

3.1.2 Interaction effect between *Pleurotus* spp., location of cultivation, and substrate type on nitrogen content of *Pleurotus* fruiting bodies

Data show in table 2 The highest species with nitrogen content mean recorded by *P. pulmonarius* (3.29 ± 0.15%), which was significantly greater than *P. citrinopileatus* (2.64 ± 0.08%; $LSD_{0.05}$ = 0.34). for the cultivation location both greenhouse and laboratory were similar statistically at 3.10 ± 0.10 and 2.98 ± 0.11%, respectively. About substrate the rice straw gives highest nitrogen content mean (3.32 ± 0.23%), however Sawdust-based substrate showed lowest value with (2.78 ± 0.16%; $LSD_{0.05}$ = 0.45). The original treatments ranged from 1.86 ± 0.00% for *P. citrinopileatus* grown on substrate Sawdust-based substrate in the lab. 4.14 ± 0.58% for *P. pulmonarius* grown on rice straw in the greenhouse, demonstrating a significant species × location × substrate interaction.

Table 2. Effect of mushroom strain, cultivation location, and substrate on nitrogen content (%) in Fruiting Bodies

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based substrate	Wood chips and sawdust	Straw-based substrate	Rice straw	
Pleurotus citrinopileatus (P1)	Greenhouse	2.35 ± 0	3.04 ± 0	3.07 ± 0	2.55 ± 0	2.16 ± 0	2.63 ±
	Laboratory	2.25 ± 0	3.04 ± 0	3.06 ± 0	1.86 ± 0	3.04 ± 0	2.65 ±
Pleurotus djamor (P2)	Greenhouse	3.45 ±	3.04 ± 0	3.04 ± 0	3.04 ± 0	4.04 ±	3.32 ±
	Laboratory	2.55 ±	3.04 ± 0	3.04 ± 0	3.25 ±	3.43 ±	3.06 ±
Pleurotus pulmonarius (P3)	Greenhouse	3.14 ±	3.04 ± 0	3.33 ± 0.58	3.04 ± 0	4.14 ±	3.34 ±
	Laboratory	3.43 ±	3.04 ± 0	3.66 ± 0.88	2.94 ±	3.14 ±	3.24 ±
							Main P
P×M	**P1**	2.3 ±	3.04 ± 0	3.06 ± 0	2.2 ± 0.15	2.6 ±	2.64 ±
	P2	3 ± 0.42	3.04 ± 0	3.04 ± 0	3.15 ±	3.73 ±	3.19 ±
	P3	3.28 ±	3.04 ± 0	3.5 ± 0.48	2.99 ±	3.64 ±	3.29 ±
							Main C
M×C	**C1**	2.98 ±	3.04 ± 0	3.15 ± 0.17	2.88 ±	3.44 ±	3.1 ±
	C2	2.74 ±	3.04 ± 0	3.25 ± 0.27	2.68 ±	3.2 ±	2.98 ±
Main M		2.86 ±	3.04 ± 0	3.2 ± 0.16	2.78 ±	3.32 ±	
LSD (5%)							
P×C×M		**C×M**	**P×M**	**P×C**	**M**	**C**	**P**
1.089		0.629	0.77	0.487	0.445	0.281	0.344

Values are mean ± SE calculated from X3, Spwan rate . P = strain, C = cultivation location, M = substrate; LSD values are given at $P \leq 0.05$. P1 = *Pleurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory.

3.1.3 Effect of mushroom strain, cultivation location, and substrate on carbon content of *Pleurotus* spp. Fruiting Bodies

There are significant differences in Carbon content changed by oyster strain, location of cultivation, and growing substrates. The highest strain means was (43.87 ± 0.34%) belong to *P. pulmonarius*, tracked by *P. djamor* (42.72 ± 0.34%) and *P. citrinopileatus* (41.76 ± 0.32%; $LSD_{0.05}$ = 0.34). The cultivation in Laboratory gave a superior mean than cultivation in greenhouse with (43.04 ± 0.29% contrasted with 42.52 ± 0.30%; $LSD_{0.05}$ = 0.28. The highest carbon content in substrates was Wood chips and sawdust blend 45.41 ± 0.28% while the lowest carbon content value was 40.41 ± 0.24%; $LSD_{0.05}$ = 0.44 for rice straw. The three-treatment interaction varied from 39.23 ± 0.20% for *P. citrinopileatus* which cultivated on rice straw in the greenhouse to 46.63 ± 0.38% and *P. pulmonarius* cultivated on wood-ships in the greenhouse; this variance surpassed the three-factor $LSD_{0.05}$ of 1.07.

Table 3. Effect of mushroom strain, cultivation location, and substrate on carbon content (%)in fruiting bodies

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based substrate	Wood chips and sawdust blend	Straw-based substrate	Rice straw	
Pleurotus citrinopileatus (P1)	Greenhouse	40.9 ± 0.35	42.27 ± 0.2	44.2 ± 0.35	40.8 ± 0.17	39.23 ± 0.2	41.48 ± 0.46
	Laboratory	41.93 ± 0.41	43.07 ± 0.2	44.2 ± 0.47	41.17 ± 0.5	39.8 ± 0.62	42.03 ± 0.44
Pleurotus djamor (P2)	Greenhouse	41.93 ± 0.38	43.07 ± 0.2	45.47 ± 0.38	41.7 ± 0.17	40.13 ± 0.2	42.46 ± 0.48
	Laboratory	43 ± 0.44	43.93 ± 0.18	45.4 ± 0.53	42.07 ± 0.56	40.47 ± 0.5	42.97 ± 0.48
Pleurotus pulmonarius (P3)	Greenhouse	43.27 ± 0.35	44.17 ± 0.2	46.63 ± 0.38	42.8 ± 0.17	41.23 ± 0.2	43.62 ± 0.49
	Laboratory	44.3 ± 0.44	45.03 ± 0.18	46.53 ± 0.52	43.17 ± 0.56	41.6 ± 0.47	44.13 ± 0.48
							Main P
P×M	**P1**	41.42 ± 0.33	42.67 ± 0.22	44.2 ± 0.26	40.98 ± 0.25	39.52 ± 0.32	41.76 ± 0.33
	P2	42.47 ± 0.35	43.5 ± 0.23	45.43 ± 0.29	41.88 ± 0.27	40.3 ± 0.25	42.72 ± 0.34
	P3	43.78 ± 0.34	44.6 ± 0.23	46.58 ± 0.29	42.98 ± 0.27	41.42 ± 0.24	43.87 ± 0.34
							Main C
M×C	**C1**	42.03 ± 0.39	43.17 ± 0.29	45.43 ± 0.4	41.77 ± 0.3	40.2 ± 0.31	42.52 ± 0.3
	C2	43.08 ± 0.4	44.01 ± 0.3	45.38 ± 0.42	42.13 ± 0.4	40.62 ± 0.38	43.04 ± 0.39
Main M		42.56 ± 0.3	43.59 ± 0.23	45.41 ± 0.28	41.95 ± 0.25	40.41 ± 0.24	
LSD (5%)							
P×C×M		**C×M**	**P×M**	**P×C**	**M**	**C**	**P**
1.072		0.619	0.758	0.479	0.437	0.277	0.339

Values are mean ± SE calculated from X3, Spwan rate . P = strain, C = cultivation location, M = substrate; LSD values are given at $P \leq 0.05$. P1 = *Pleurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory.

3.1.4 Effect of mushroom strain, cultivation location, and substrate on minerals in mushroom fruits bodies

3.1.4 .1 Calcium (Ca) content (%) in fruiting bodies

Data in table 4 show there are no significant effects between the strain type in ca content with 2.31 ± 0.11 to 2.39 ± 0.14, $LSD_{0.05}$ of 0.42, The whole means for the greenhouse and laboratory were 2.36 ± 0.13 and 2.37 ± 0.11, respectively. Also, there are no significant different between different

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growing locations while their variation (0.01) was lower the location $LSD_{0.05}$ of 0.34, so the effect main in location was not significant. Gowing Substrate means too ranged from 2.22 ± 0.17 on wood chips-sawdust blend to 2.5 ± 0.27 on rice straw. This range (0.28) was below the substrate $LSD_{0.05}$ of 0.54, indicating no significant overall substrate effect. *Pleurotus pulmonarius* which grows in greenhouse on wheat straw in the opposite the same strain and location but in rice straw growing substrate gives lowest continent in fruit bodies 4.07 ± 0.88 and 1.5 ± 0.29 respectively.

Table 4: Effect of mushroom strain, cultivation location, and substrate on Calcium (Ca) content (%) in fruiting bodies

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based substrat	Wood chips and	Straw-based substrat	Rice straw	
Pleurotus citrinopileatus	Greenho	2 ± 0.58	2.36 ± 0	2.4 ±	2.2 ±	2.4 ±	2.27 ±
	Laborato	3.4 ±	2.36 ± 0	2 ± 0.58	2.4 ±	2.36 ± 0	2.5 ±
Pleurotus djamor (P2)	Greenho	2.4 ±	2.36 ± 0	2.36 ± 0	2.36 ± 0	2.2 ±	2.34 ±
	Laborato	2.5 ±	2.36 ± 0	2.36 ± 0	2.2 ±	2 ± 0.58	2.28 ±
Pleurotus pulmonarius (P3)	Greenho	1.5 ±	2.36 ± 0	2 ± 0.58	2.36 ± 0	4.07 ±	2.46 ±
	Laborato	2.4 ±	2.36 ± 0	2.2 ±	2.6 ±	2 ± 0.58	2.31 ±
							Main
P×M	**P1**	2.7 ±	2.36 ± 0	2.2 ±	2.3 ±	2.38 ±	2.39 ±
	P2	2.45 ±	2.36 ± 0	2.36 ± 0	2.28 ±	2.1 ±	2.31 ±
	P3	1.95 ±	2.36 ± 0	2.1 ±	2.48 ±	3.03 ±	2.39 ±
							Main
M×C	**C1**	1.97 ±	2.36 ± 0	2.25 ±	2.31 ±	2.89 ±	2.36 ±
	C2	2.77 ±	2.36 ± 0	2.19 ±	2.4 ±	2.12 ±	2.37 ±
Main M		2.37 ±	2.36 ± 0	2.22 ±	2.35 ±	2.5 ±	
LSD (5%)							
P×C×M		**C×M**	**P×M**	**P×C**	**M**	**C**	**P**
1.32		0.762	0.933	0.59	0.539	0.341	0.417

Values are mean ± SE calculated from X3, Spwan rate . P = strain, C = cultivation location, M = substrate; LSD values are given at P ≤ 0.05. P1 = *Pleurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory

3.1.4 .2 Effect of mushroom strain, cultivation location, and substrate on Sodium (Na) content (%) in fruiting bodies

Result in table 5 observed that the *P. pulmonarius* had the highest mean (0.05 ± 0.01) and was greater than *P. citrinopileatus* and *P. djamor* (0.03 ± 0 and 0.03 ± 0) respectively were comparable statistically with ($LSD_{0.05}$ = 0.01). The laboratory produced a higher overall mean (0.04 ± 0.01) than the greenhouse (0.03 ± 0.00). The observed difference (0.01) was equal to the location $LSD_{0.05}$ (0.01), demonstrating an average significant location effect. *P. citrinopileatus* which grown in greenhouse on wheat straw flowed by *P. pulmonarius*

which grown in laboratory on wood chips-sawdust blend 0.2 ± 0.06 and 0.02 ± 0.01respictively. There are significant differences in the interaction between strains, substates and the cultivation location (0.18) go above $LSD_{0.05}$ of 0.03, for *P. citrinopileatus* on sawdust-based substrate (0.04 ± 0); *P. djamor* on sawdust-based substrate (0.04 ± 0); *P. pulmonarius* on wood chips-sawdust blend (0.12 ± 0.04). The sodium element was low but was valuable significant. The highest main means was (*P. pulmonarius*× laboratory condition × wood chips-sawdust blended). This result exhibits the original materials for Na concentration of, genotype strains, transportation of ion, and dilution or concentration were correlated with dry-matter accumulation. The fruiting bodies of *Pleurotus* minerals compositing various with the substate's compositions and fungal genotypes [5, 22], the dynamics of nutrients contract among straw substrate during mushroom cultivation [23]. Since the statistical values are lesser, contamination from salts, analytical blanks glassware, or water or can considerably affect the result that is why the quality control play important role in mushroom cultivation process.

Table 5: Effect of mushroom strain, cultivation location, and substrate on sodium (Na) content (%) in fruiting bodies

Strain (P)	**Location (C)**	**Substrate (M)**					**P×C**
		Wheat straw	**Sawdust-based substrate**	**Wood chips and sawdust**	**Straw-based substrate**	**Rice straw**	
Pleurotus citrinopileatus (P1)	Green house	0.02 ± 0.01	0.04 ± 0	0.04 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0
	Laboratory	0.04 ± 0.01	0.04 ± 0	0.02 ± 0.01	0.02 ± 0.01	0.04 ± 0	0.03 ± 0
Pleurotus djamor (P2)	Green house	0.03 ± 0.01	0.04 ± 0	0.04 ± 0	0.04 ± 0	0.04 ± 0.01	0.04 ± 0
	Laboratory	0.02 ± 0.01	0.04 ± 0	0.04 ± 0	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0
Pleurotus pulmonarius (P3)	Green house	0.02 ± 0.01	0.04 ± 0	0.05 ± 0.01	0.04 ± 0	0.03 ± 0.01	0.04 ± 0
	Laboratory	0.03 ± 0.01	0.04 ± 0	0.2 ± 0.06	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.02
							Main P
P×M	**P1**	0.03 ± 0.01	0.04 ± 0	0.03 ± 0.01	0.02 ± 0	0.03 ± 0	0.03 ± 0
	P2	0.03 ± 0	0.04 ± 0	0.04 ± 0	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0
	P3	0.02 ± 0	0.04 ± 0	0.12 ± 0.04	0.04 ± 0	0.04 ± 0.01	0.05 ±
							Main C
M×C	**C1**	0.02 ± 0	0.04 ± 0	0.04 ± 0	0.03 ± 0	0.03 ± 0	0.03 ± 0
	C2	0.03 ± 0	0.04 ± 0	0.09 ± 0.03	0.03 ± 0.01	0.04 ± 0	0.04 ±
Main M		0.03 ± 0	0.04 ± 0	0.06 ± 0.02	0.03 ± 0	0.03 ± 0	
LSD (5%)							

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Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based substrate	Wood chips and sawdust	Straw-based substrate	Rice straw	
P×C×M		C×M	P×M	P×C	M	C	P
0.032		0.019	0.023	0.014	0.013	0.008	0.01

Values are mean ± SE calculated from X3, Spwan rate . P = strain, C = cultivation location, M = substrate; LSD values are given at P ≤ 0.05. P1 = *Pleurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory

3.1.4 .3 Effect of mushroom strain, cultivation location, and substrate on potassium (K) content (%) in fruiting bodies

Data in table 6 showed no significant differences in potassium content between virous kinds of three fruiting bodies oyster mushroom strains vary between from 2.37 ± 0.13 to 2.43 ± 0.13, but the range did not surpass the strain $LSD_{0.05}$ of 0.41.as well as no significant differences between two growing locations and different kind of substrates, 2.29 ± 0.18 on rice straw to 2.44 ± 0.17 on wood chips-sawdust blend. This range (0.15) was below the substrate $LSD_{0.05}$ of 0.53. the interaction between three factors also there were no significant differences whereases extended from 2.12 ± 0.58 for *P. pulmonarius* in the greenhouse on rice straw to 2.7 ± 0.58 for *P. pulmonarius* in the laboratory on wood chips-sawdust blend. The difference was (0.58) did not reach to 1.3that the P×C×M $LSD_{0.05}$ value.

Table 6: Effect of mushroom strain, cultivation location, and substrate on potassium (K) content (%) in fruiting bodies

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based	Wood chips and	Straw-based	Rice straw	
Pleurotus citrinopileatus (P1)	Greenhouse	2.55 ± 0.58	2.39 ± 0	2.47 ± 0.58	2.56 ± 0.58	2.49 ± 0.58	2.49 ± 0.2
	Laboratory	2.34 ± 0.58	2.39 ± 0	2.2 ± 0.58	2.51 ± 0.58	2.39 ± 0	2.37 ± 0.17
Pleurotus djamor (P2)	Greenhouse	2.52 ± 0.58	2.39 ± 0	2.39 ± 0	2.39 ± 0	2.24 ± 0.58	2.39 ± 0.14
	Laboratory	2.36 ± 0.58	2.39 ± 0	2.39 ± 0	2.36 ± 0.58	2.3 ± 0.58	2.36 ± 0.17
Pleurotus pulmonarius (P3)	Greenhouse	2.4 ± 0.58	2.39 ± 0	2.47 ± 0.58	2.39 ± 0	2.12 ± 0.58	2.35 ± 0.17
	Laboratory	2.22 ± 0.58	2.39 ± 0	2.7 ± 0.58	2.35 ± 0.58	2.23 ± 0.58	2.38 ± 0.2
							Main P
P×M	P1	2.44 ±	2.39 ± 0	2.33 ±	2.53 ±	2.44 ±	2.43 ±
	P2	2.44 ±	2.39 ± 0	2.39 ± 0	2.38 ±	2.27 ±	2.37 ±

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based	Wood chips and	Straw-based	Rice straw	
	P3	2.31 ±	2.39 ± 0	2.58 ±	2.37 ±	2.18 ±	2.37 ±
							Main C
M×C	C1	2.49 ±	2.39 ± 0	2.44 ±	2.45 ±	2.28 ±	2.41 ±
	C2	2.31 ±	2.39 ± 0	2.43 ±	2.41 ±	2.31 ±	2.37 ±
Main M		2.4 ± 0.2	2.39 ± 0	2.44 ±	2.43 ±	2.29 ±	
LSD (5%)							
P×C×M		C×M	P×M	P×C	M	C	P
1.3		0.75	0.919	0.581	0.531	0.336	0.411

Values are mean ± SE calculated from X3, Spwan rate . P = strain, C = cultivation location, M = substrate; LSD values are given at P ≤ 0.05. P1 = *Pleurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory.

3.1.4 .4 Effect of mushroom strain, cultivation location, and substrate on magnesium (Mg) content (%) in fruiting bodies

The highest significant difference according to this study showed there are significant differences with genotype strains for oyster mushroom *P. djamor* had the highest main mean 0.59 ± 0.02 greater than *P. citrinopileatus* and *P. pulmonarius* 0.52 ± 0.02 and 0.49 ± 0.02 respectively were statistically equivalent ($LSD_{0.05}$ = 0.06). there was no significant difference in the main location and substrate when compare with its $LSD_{0.05}$, while there is significant difference in the combination between three factors were 0.39 ± 0.06 for *P. pulmonarius* in the greenhouse on wheat straw to 0.75 ± 0.14 for *P. citrinopileatus* in the lab location on wheat straw substrate was 0.36 compared with P×C×M $LSD_{0.05}$ of 0.17 , The strain and substrate means were highest for *P. citrinopileatus* on wheat straw 0.64 ± 0.09 ; *P. djamor* on rice straw 0.67 ± 0.08; *P. pulmonarius* on wood chips-sawdust blend 0.56 ± 0.04. *P. djamor* observed the higher Mg content in may indicate a greater strain-supported effectiveness of up taking magnesium, translocation, and saved in the fruiting bodies. Variations in physiology of fungi, the mechanisms of mineral transport, pH of growing substrate, and rivalry between ions may promote modification in Mg accumulation among *Pleurotus* spp. [5, 22, 23].

Table 7: Effect of mushroom strain, cultivation location, and substrate on magnesium (Mg) content (%) in Fruiting Bodies

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based	Wood chips and	Straw-based	Rice straw	
Pleurotus	Greenhous	0.53 ± 0.06	0.53 ± 0	0.4 ± 0.06	0.52 ± 0.06	0.51 ± 0.03	0.5 ± 0.02

Strain (P)	Location (C)	Substrate (M)					P×C
		Wheat straw	Sawdust-based	Wood chips and	Straw-based	Rice straw	
citrinopileatus	Laboratory	0.75 ± 0.14	0.53 ± 0	0.44 ± 0.06	0.46 ± 0.06	0.53 ± 0	0.54 ± 0.04
Pleurotus djamor (P2)	Greenhous	0.75 ± 0.14	0.53 ± 0	0.53 ± 0	0.53 ± 0	0.75 ± 0.14	0.62 ± 0.04
	Laboratory	0.57 ± 0.06	0.53 ± 0	0.53 ± 0	0.54 ± 0.05	0.58 ± 0.06	0.55 ± 0.02
Pleurotus pulmonarius	Greenhous	0.39 ± 0.06	0.53 ± 0	0.55 ± 0.06	0.53 ± 0	0.42 ± 0.06	0.49 ± 0.02
	Laboratory	0.43 ± 0.06	0.53 ± 0	0.56 ± 0.06	0.48 ± 0.06	0.51 ± 0.06	0.5 ± 0.02
							Main P
P×M	**P1**	0.64 ±	0.53 ± 0	0.42 ±	0.49 ±	0.52 ±	0.52 ±
	P2	0.66 ±	0.53 ± 0	0.53 ± 0	0.54 ±	0.67 ±	0.59 ±
	P3	0.41 ±	0.53 ± 0	0.56 ±	0.51 ±	0.47 ±	0.49 ±
							Main C
M×C	**C1**	0.56 ±	0.53 ± 0	0.49 ±	0.53 ±	0.56 ±	0.54 ±
	C2	0.58 ±	0.53 ± 0	0.51 ±	0.49 ±	0.54 ±	0.53 ±
Main M		0.57 ±	0.53 ± 0	0.5 ± 0.02	0.51 ±	0.55 ±	
LSD (5%)							
P×C×M		**C×M**	**P×M**	**P×C**	**M**	**C**	**P**
0.174		0.1	0.123	0.078	0.071	0.045	0.055

Values are mean ± SE calculated from X3, Spwan rate . P = strain, C = cultivation location, M = substrate; LSD values are given at P ≤ 0.05. P1 = *Pleurotus citrinopileatus*; P2 = *Pleurotus djamor*; P3 = *Pleurotus pulmonarius*; C1 = Greenhouse; C2 = Laboratory

3.2DISCUSSION

3.2.1 Biological Efficiency (BE, %):

Acorrdint to the results that shown in table 1. Found the great performance for *P. pulmonarius,* The greater performance of *P. pulmonarius* may be related to remarkable nutrient utilization, lignocellulose-degrading capacity, and modification to wheat and rice straw. The cultivation in laboratory gain was probably correlated with more static temperature, moisture situations, humidity, airing, similar species-, substrate-, and environment-dependent differences in BE have been described before [24-26] considering all treatments, the results confirm a strong species × substrate × location interaction, with *P. pulmonarius* showing the greatest conversion efficiency under laboratory conditions.

3.2.2 Interaction effect between *Pleurotus* spp., location of cultivation, and substrate type on nitrogen content of *Pleurotus* fruiting bodies

Data in table 2 show the higher nitrogen content for *P. pulmonarius. P. pulmonarius* show the higher nitrogen content may reflect more efficient nitrogen

uptake, translocation, and transformation into fungal mycelium and fruits bodies. The higher values on rice straw may be correlated with its nutrient accessibility, moisture preservation, and compatibility with species-specific metabolic constraints, which can upgrade nitrogen utilization during lignocellulose degradation. Parallel substrate-reliant on adaptations in the adjacent components of *Pleurotus* fruiting bodies have been stated beforehand [5, 8, 23].

3.2.3 Effect of mushroom strain, cultivation location, and substrate on carbon content of *Pleurotus* spp. Fruiting Bodies

P. pulmonarius had high content of carbon as shown in (table 3) due to enhance efficiency capacity to assimilate and save carbon in fruiting-body tissues which uptake from substrate-derived. the wood chips–sawdust blend was superior in carbon content and was perfect for mushroom cultivation due to its content of higher content of lignocellulosic which suitable for fungal colonization and degradation with fungal enzymes. Assimilating carbon from the growing substrate is integrated into polysaccharides of cell-wall and carbohydrates in fungi, proteins, lipids, and other cellular compounds. Prior searches have correspondingly confirmed that growing substrates have significant composition influences the *Pleurotus* fruiting bodies carbohydrate, protein, fiber, ash, and mineral configuration [5, 8, 27]. Nevertheless, the concentration of carbon only cannot characterize total carbon transformation for the amount transferred to mushrooms also depends on substrate mass loss and yield of dry matter.

3.2.4 Effect of mushroom strain, cultivation location, and substrate on minerals in mushroom fruits bodies

3.2.4 .1 Calcium (Ca) content (%) in fruiting bodies

The content of Calcium showed in fruits bodies showed no significant whole growing substate, type of strain and growing location, showing that median Ca accumulation was reasonably stable. However, the difference between the highest and lowest combinations exceeded the three-way LSD, showing that specific interactions can affect calcium uptake. The accumulation of minerals in mushrooms fruits bodies regulated on genotype of fungi, substrate, pH, comparing ions, translocation efficiency and supplementation, [5, 22, 23] Environmental conditions may additionally influence mineral composition through effects on growth and water relations [28]. The lack of a substrate main impact does not imply that all substrate combinations were the same; rather, similar overall means were produced by opposing strain and location responses. In addition to reporting the analytical unit, digestion process, instrument, certified reference material, and moisture basis, calcium values should be interpreted using dry yield and ash content.

3.2.4 .2 Effect of mushroom strain, cultivation location, and substrate on Sodium (Na) content (%) in fruiting bodies

According to (table 4) the sodium element was low but was valuable significant. The highest main means was (*P. pulmonarius*× laboratory condition × wood chips-sawdust blended). This result exhibits the original materials for Na concentration of, genotype strains, transportation of ion, and dilution or concentration were correlated with dry-matter accumulation. The fruiting bodies of *Pleurotus* minerals compositing various with the substate's compositions and fungal genotypes [5, 22], the dynamics of nutrients contract among straw substrate during mushroom cultivation [23]. Since the statistical values are lesser, contamination from salts, analytical blanks glassware, or water or can considerably affect the result

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that is why the quality control play important role in mushroom cultivation process.

3.2.4 .3 Effect of mushroom strain, cultivation location, and substrate on potassium (K) content (%) in fruiting bodies

Statistically, the constant of potassium was state in three factors and its interaction under the reported LSD thresholds values. The content of potassium content was different but did not vary significant differences established on genotypes of strain, growing location, or substates type, indicating a relatively stable potassium accumulation in the fruiting bodies. This may be attributed to the efficiency of *Pleurotus* in potassium uptake and physiological regulation, coupled with the availability of sufficient potassium in the culture media used that is mean when mushroom stimulation and uptake potassium the substates was very closed to each other's in K contents in other hand other references said there are great effect of substates on provide the mushroom with potassium [5, 22, 23]. Similarly confirmed that concentrations of elemental in *Pleurotus* fruiting bodies do not always rise comparably with the concentration of the consistent elements in the growing substrate, indicating that mineral accumulation is controlled by interactions among substrate availability, species-specific uptake, and physiological regulation [3]. However, the present discovery does not indicate that substrate content has no influence on K accumulation in *Pleurotus*. Slightly, the effect figures to depend on the magnitude of differences in K availability including substrates and on the particular fungal species or strain. for example, [8] reported differences in potassium concentrations of P. ostreatus fruiting bodies cultivated on different formulated agricultural substrates, with K values varying according to substrate composition. Similarly, [12] found significant differences of substrate-dependent in K concentration in *P. ostreatus*, varying from around 30.67 to 38.00 mg/100 g among formulations which content cassava-peel-, sawdust-, and rice-bran-based. These studies support the view that substrates can modify fungal K accumulation when their mineral composition and bioavailability are sufficiently different.

3.2.4 .4 Effect of mushroom strain, cultivation location, and substrate on magnesium (Mg) content (%) in fruiting bodies

Observed the higher Mg content in may indicate a greater strain-supported effectiveness of up taking magnesium, translocation, and saved in the fruiting bodies. Variations in physiology of fungi, the mechanisms of mineral transport, pH of growing substrate, and rivalry between ions may promote modification in Mg accumulation among *Pleurotus* spp. [5, 22, 23]. In *Pleurotus* fruiting bodies observed the higher content of magnisum that is may reflect the Mg uptakeing with the different species capacity -dependent for, translocation, and accumulation in fruits bodies [29].

4. Conclusion

The finding results of this study indicate that mushroom species, growing cultivation location, and lignocellulosic substrate combinations to measurement both the production in biological efficiency and chemical contents of *Pleurotus* fruiting bodies. *P. pulmonarius* showed the greatest performance among others *Pleurotus* genotypes with high content in caron, nitrogen additionally the biological efficiency. In general, favorite biological efficiency and carbon accumulation were in laboratory-controlled room 25C^{o}, demonstrating that more controlled environmental conditions preserve increase substrate conversion and mushroom mycelium growth. For biological efficiency, the most superior substrate was wheat straw.

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although higher nitrogen accumulation goose to rice straw while highest carbon content in fruits bodies when cultivation on the wood chips–sawdust blend. The accumulation of Mineral confirmed a more variable response. Calcium and potassium remained relatively stable across three Pleurotus spp., growing locations, and five substrates, however sodium and magnesium were more strongly prejudiced by fungal strain and specific treatment interaction. The greatest magnesium accumulation showed with *P. djamor,* however *P. pulmonarius* recorded highest sodium content. Significant three factor combinations detected for numerous traits extreme show that substrate performance cannot be evaluated separately of oyster mushroom strain and cultivation environment. Generally, the findings support the use of locally accessible agriculture residues for sustainable oyster mushroom growth and identify P. pulmonarius, particularly under controlled laboratory-cultivation, as the most promising species for maximizing substrate conversion and biological efficiency

References

[1] Bellettini MB, Fiorda FA, Maieves HA, Teixeira GL, Ávila S, Hornung PS, et al. (2019). Factors affecting mushroom *Pleurotus* spp. *Saudi Journal of Biological Sciences*, 26(4):633–46.

[2] Raman J, Jang K-Y, Oh Y-L, Oh M, Im J-H, Lakshmanan H, et al. (2021). Cultivation and nutritional value of prominent *Pleurotus* spp.: an overview. *Mycobiology*, 49(1):1–14.

[3] Mleczek M, Gąsecka M, Budka A, Niedzielski P, Siwulski M, Kalač P, et al. (2021). Changes in mineral composition of six strains of *Pleurotus* after substrate modifications with different share of nitrogen forms. *European Food Research and Technology*, 247(1):245–57.

[4] Girmay Z, Gorems W, Birhanu G, Zewdie S (2016). Growth and yield performance of *Pleurotus ostreatus* (Jacq. Fr.) Kumm (oyster mushroom) on different substrates. *AMB Express*, 6(1):87.

[5] Hoa HT, Wang C-L, Wang C-H (2015). The effects of different substrates on the growth, yield, and nutritional composition of two oyster mushrooms (*Pleurotus ostreatus* and *Pleurotus cystidiosus*). *Mycobiology*, 43(4):423–34.

[6] Lin R, Zhang L, Yang X, Li Q, Zhang C, Guo L, et al. (2022). Responses of the mushroom *Pleurotus ostreatus* under different CO□ concentration by comparative proteomic analyses. *Journal of Fungi*, 8(7):652.

[7] Hu Y, Xue F, Chen Y, Qi Y, Zhu W, Wang F, et al. (2023). Effects and mechanism of the mycelial culture temperature on the growth and development of *Pleurotus ostreatus* (Jacq.) P. Kumm. *Horticulturae*, 9(1):95.

[8] Elkanah F, Oke M, Adebayo E (2022). Substrate composition effect on the nutritional quality of *Pleurotus ostreatus* (MK751847) fruiting body. *Heliyon*, 8(11):e11841.

[9] Siwulski M, Mleczek M, Rzymski P, Budka A, Jasińska A, Niedzielski P, et al. (2017). Screening the multi-element content of *Pleurotus* mushroom species using inductively coupled plasma optical emission spectrometer (ICP-OES). *Food Analytical Methods*, 10(2):487–96.

[10] Desisa B, Muleta D, Dejene T, Jida M, Goshu A, Negi T, et al. (2024). Utilization of local agro-industrial by-products based substrates to enhance production and dietary value of mushroom (*P. ostreatus*) in Ethiopia.

World Journal of Microbiology and Biotechnology, 40(9):277.

[11] Azzam CR, Mburu M, Hussein AM, Arafa RA, Rizk MS, Latef AAA, et al. (2025). Novel chia (*Salvia hispanica* L.) residue-based substrate formulations for oyster mushroom (*Pleurotus ostreatus*) cultivation. *World Journal of Microbiology and Biotechnology*, 41(11):455.

[12] Olaniyan S, Hussein J, Oke M, Akinwande B, Workneh T, Maziya-Dixon B, et al. (2025). Evaluating cassava peel-based substrates on the yield and nutritional quality of oyster mushroom (*Pleurotus ostreatus*). *Discover Food*, 5(1):80.

[13] de Albuquerque VTN, Fernandes JVF, Grisi CVB, Vasconcelos U, de Almeida AF, de Luna Freire KR, et al. (2026). Valorization of agro-industrial residues for the cultivation of *Pleurotus ostreatus* var. *florida*: yield, nutritional quality, and physicochemical assessment. *Mycological Progress*, 25(1):13.

[14] DuBois M, Gilles KA, Hamilton JK, Rebers PA, Smith F (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, 28(3):350–6.

[15] Roy S, Jahan MAA, Das KK, Munshi SK, Noor R (2015). Artificial cultivation of *Ganoderma lucidum* (Reishi medicinal mushroom) using different sawdusts as substrates. *American Journal of BioScience*, 3(5):178–82.

[16] Heleno SA, Barros L, Martins A, Queiroz MJR, Morales P, Fernández-Ruiz V, et al. (2015). Chemical composition, antioxidant activity and bioaccessibility studies in phenolic extracts of two *Hericium* wild edible species. *LWT-Food Science and Technology*, 63(1):475–81.

[17] Chen F, Xiong S, Sundelin J, Martin C, Hultberg M (2020). Potential for combined production of food and biofuel: cultivation of *Pleurotus pulmonarius* on soft- and hardwood sawdusts. *Journal of Cleaner Production*, 266:122011.

[18] Bandura I, Kulik A, Bisko N, Khareba O, Tsyz O, Khareba V (2020). Analysis of the biological efficiency and quality factors of mushrooms of the genus *Pleurotus* (Fr.) P. Kumm as a model of effective cultivation of lignicolous fungi with high functional value. *Plant Varieties Studying and Protection*, 16(4):334–42.

[19] Helrich K (1990). Official methods of analysis of the Association of Official Analytical Chemists: 2. Food composition; additives; natural contaminants. *Association of Official Analytical Chemists*.

[20] Radulescu C, Stihi C, Busuioc G, Popescu IV, Gheboianu AI, Cimpoca VG (2010). Evaluation of essential elements and heavy metal levels in fruiting bodies of wild mushrooms and their substrate by EDXRF spectrometry and FAA spectrometry. *Romanian Biotechnological Letters*, 15(4):5444–56.

[21] Kadnikova IA, Costa R, Kalenik TK, Guruleva ON, Yanguo S (2015). Chemical composition and nutritional value of the mushroom *Auricularia auricula-judae*. *Journal of Food and Nutrition Research*, 3(8):478–82.

[22] Mattila P, Könkö K, Eurola M, Pihlava J-M, Astola J, Vahteristo L, et al. (2001). Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. *Journal of Agricultural and Food Chemistry*, 49(5):2343–8.

[23] Iossi MR, Júnior WGV, Caitano CE, da Silva Alves L, Palú IdA, Heinrichs R, et al. (2023). Macromineral consumption by *Pleurotus ostreatus* var. *Florida* in

ISSN 2072-3857

different straws. *Archives of Biological Sciences*, 75(1):19–25.

[24] Akcay C, Ceylan F, Arslan R (2023). Production of oyster mushroom (*Pleurotus ostreatus*) from some waste lignocellulosic materials and FTIR characterization of structural changes. *Scientific Reports*, 13(1):12897.

[25] Aghajani H, Bari E, Bahmani M, Humar M, Ghanbary MAT, Nicholas DD, et al. (2018). Influence of relative humidity and temperature on cultivation of *Pleurotus* species. *Maderas. Ciencia y Tecnología*, 20(4):571–8.

[26] Wiafe-Kwagyan M, Odamtten GT, Kortei NK (2022). Influence of substrate formulation on some morphometric characters and biological efficiency of *Pleurotus ostreatus* EM-1 (Ex. Fr) Kummer grown on rice wastes and "wawa" (*Triplochiton scleroxylon*) sawdust in Ghana. *Food Science & Nutrition*, 10(6):1854–63.

[27] Carrasco-González JA, Serna-Saldívar SO, Gutiérrez-Uribe JA (2017). Nutritional composition and nutraceutical properties of the *Pleurotus* fruiting bodies: potential use as food ingredient. *Journal of Food Composition and Analysis*, 58:69–81.

[28] Zawadzka A, Janczewska A, Kobus-Cisowska J, Dziedziński M, Siwulski M, Czarniecka-Skubina E, et al. (2022). The effect of light conditions on the content of selected active ingredients in anatomical parts of the oyster mushroom (*Pleurotus ostreatus* L.). *PLoS ONE*, 17(1):e0262279.

[29] Zięba P, Sękara A, Bernaś E, Krakowska A, Sułkowska-Ziaja K, Kunicki E, et al. (2021). Supplementation with magnesium salts—a strategy to increase nutraceutical value of *Pleurotus djamor* fruiting bodies. *Molecules*, 26(11):3273.

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