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FROM WASTE TO GROWTH: MUSHROOM RESIDUES IN HORTICULTURE

SUMMARY

The rapid global expansion of mushroom cultivation has established it as an important agribusiness sector and a promising strategy for sustainable management of agricultural residues. Nevertheless, this growth has resulted in the annual accumulation of millions of tons of spent mushroom substrate (SMS), creating significant environmental and logistical challenges. On average, approximately five kilograms of SMS are generated for every kilogram of fresh mushrooms harvested. In North Macedonia, the mushroom industry similarly produces considerable quantities of SMS, which presents an opportunity for its reutilization as a growing substrate for horticultural crops. In this context, the present study investigated the physical and chemical properties of SMS derived from the fast-growing oyster mushroom (*Pleurotus ostreatus*). The results demonstrated that the substrate exhibits favorable physical characteristics, including low bulk density, homogeneous texture, and low electrical conductivity, making it suitable for incorporation into horticultural substrate mixes. Chemically, the substrate was found to be low in nitrogen and phosphorus but contained moderate to sufficient levels of potassium, while its exceptionally high organic matter content enhances its potential as a soil conditioner. Literature review indicates that mushroom residues are primarily employed as components of growing media in vegetable and ornamental crop production. Additionally, SMS can serve as a fertilizer, soil amendment, or mulch, providing multifunctional benefits in sustainable horticultural practices. Overall, oyster mushroom SMS represents a valuable resource for horticulture, combining desirable physical properties with nutrient supplementation potential and contributing to circular waste management strategies in the mushroom industry.

Keywords: spent mushroom substrate, growing medium, composition, *Pleurotus ostreatus*, horticulture

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INTRODUCTION

Peat remains the predominant substrate in horticultural crop production; however, its unsustainable extraction and escalating cost have driven research and industry efforts toward identifying alternative substrates or partial substitutes (Zeljković *et al.,* 2015). Mushroom cultivation, a rapidly growing agricultural sector, utilizes various organic wastes but also generates around 100 million tons of spent mushroom compost annually, posing environmental and industry challenges (Mwangi *et al.,* 2024). For every 1 kilogram of fresh mushrooms produced, approximately 5 kilograms of fresh spent mushroom substrate (SMS) are generated (Diego *et al*., 2021). Although numerous mushroom species are cultivated globally, around 70% of total production comes from just three: the white button mushroom (*Agaricus bisporus*, 32%), the shiitake mushroom (*Lentinus edodes*, 25%), and the oyster mushroom (*Pleurotus* spp., 14%) (Uzun, 2004). Mushroom residues are commonly referred to as Spent Mushroom Substrate (SMS) or Spent Mushroom Compost (SMC). Spent mushroom substrate (SMS) refers to the fresh residual material left immediately after mushroom production, consisting of organic and mineral substances as well as microbial biomass and enzymes (Catal and Peksen, 2020; Prasad *et al*., 2021), whereas spent mushroom compost (SMC), also called weathered-SMS or composted SMS, is the same substrate after further decomposition or composting for several months (typically 3–24 months), a process recommended by many authors before its use in horticulture (Prasad *et al*., 2021; Alves *et al.,* 2024). The use of SMS offers notable advantages, particularly because its cost is approximately 20% of that of cattle manure compost, owing to reduced transportation requirements and the absence of a composting phase (Danai *et al*., 2011). In North Macedonia, mushroom cultivation is a growing industry and data on the availability of production residues are lacking. At the same time, the main cultivated species are *Pleurotus ostreatus* (oyster mushroom) and *Agaricus bisporus* (button mushroom). The most commonly used substrate for industrial oyster mushroom (*Pleurotus ostreatus*) cultivation in North Macedonia typically consists of 15 kg of wood pellets (derived from deciduous trees) and 10 liters of water, supplemented with calcium sulfate ($CaSO_4$) and calcium carbonate ($CaCO_3$). These additives stabilize pH, enhance substrate structure, and suppress the growth of undesirable microorganisms. The exact proportions of calcium sulfate and calcium carbonate can vary depending on the cultivated mushroom species and local agrochemical conditions, but generally constitute 2–5% of the total substrate mass. This substrate is also suitable for the cultivation of several other mushroom species, including Lion's Mane (*Hericium erinaceus*), Maitake (*Grifola frondosa*), Shiitake (*Lentinula edodes*), and Reishi (*Ganoderma lucidum*). In Israel, the substrate for mushroom cultivation typically consists of compost made primarily from poultry manure, wheat straw, and gypsum, along with a casing layer composed of black peat amended with lime (Danai *et al.,* 2011). The composition of spent mushroom substrate (SMS) in Turkey varies depending on the mushroom species cultivated (Çatal and Pekşen, 2020). For Pleurotus ostreatus, three different substrate mixtures have been reported: (1) 95% paddy straw and 5% poplar sawdust, (2) 60% wheat straw, 20% paddy straw, and 20% corn cobs, and (3) 70% oak sawdust, 20% wheat bran, 5% cottonseed pulp, 3% marble dust, and 2% gypsum. According to Rinker (2017), Pleurotus species are grown on wood sawdust and plant fibers supplemented with locally available proteins and carbohydrates. The main application of mushroom residues in vegetable production is as a component of growing media (Charles Heuser *et al.,* 2007; Younis *et al*., 2023) for seedling production of crops such as tomato (Medina *et al*, 2009; Eudoxie and Alexander, 2011; Zhang *et al*., 2012; Ünal, 2015; Priadi *et al.,* 2016; Collela *et al.,* 2019; Alves *et al.,* 2024), pepper (Medina *et al.,* 2009; Demir, 2017), lettuce (Kwack *et al*., 2012; Marques *et al.,* 2014; Liu *et al*., 2018), eggplant (Sönmez *et al*., 2016), cucumber (Zhang *et al.,* 2012), melon (Van Tam and Wang, 2015) and zucchini (Medina *et al*., 2009). In sustainable fruit production, mushroom residue is used as fertilizer, mulch, or an alternative pesticide and should be applied every few years (Uzun, 2004). A few studies have examined the use of spent mushroom substrate in fruit production (Danai *et al.,* 2011; Orluchukwu and Adedokun, 2015; Prasad *et al*., 2021). Although ornamental production is rapidly expanding, limited research has been conducted on the use of spent mushroom substrate, primarily focusing on woody ornamentals (Chong and Rinker, 1994), geraniums and surfinia (Zeljković *et al.,* 2015), and chrysanthemums (Atikmen *et al.,* 2014). Furthermore, spent mushroom substrate can enhance microbial diversity (Huang et al., 2023), aid in disease control (Mwangi *et al.,* 2024), support biogas production (Kumar *et al.,* 2022), contribute to bioremediation efforts (Rinker, 2017), and serve as a material for biodegradable containers in horticulture (Postemsky *et al.,* 2016).

Considering the potential value of mushroom residues and the need to minimize waste, this study addresses two objectives. The first objective is to characterize the physical and chemical properties of spent mushroom substrate from *Pleurotus ostreatus*, one of the fastest-growing cultivated mushrooms, which can be harvested within approximately one month after inoculation. The second objective is, based on available literature, to highlight the various applications of mushroom residues in horticultural practices.

MATERIAL AND METHODS

In order to achieve the first objective a detailed analysis of the physical and chemical properties of a spent mushroom substrate of oyster mushroom (*Pleurotus ostreatus*) was conducted at the accredited Laboratory for Soil and Fertilizer Analysis (L-04), Faculty of Agricultural Sciences and Food – Skopje. The laboratory is accredited according to ISO/IEC 17025, and the analytical procedures follow validated national (MKC), international (ISO, ASTM, EN) and internal AL methods.

1. Physical analyses

The following physical parameters were analyzed:

Moisture (%) – determined according to MKC ISO 8190:1992 by oven-drying at 105 °C to constant weight using a drying oven, with precision ±0.1 g.

Texture, color, and scent – determined by organoleptic evaluation, commonly used for characterizing compost-like organic substrates. Observations were performed under standard daylight conditions, following internal AL protocols.

Density (g/L) – measured according to MKC ISO 1237:2009 by using graded 1 L volumetric cylinders, with the material compacted under standardized conditions to ensure reproducibility.

Electrical conductivity (EC, mS/cm) – measured according to ISO 11265:2004 with a conductivity meter, equipped with a 325 conductivity cell. Measurements were performed at 25 °C and corrected automatically for temperature.

2. Chemical analyses

The chemical analysis of the substrate included the following parameters:

pH (H_2O) – determined according to MKC ISO 13037:2011 using a meter with a electrode.

Organic matter (%) – determined by loss-on-ignition method following ASTM D2974-14, using a muffle furnace at 550 °C.

Ash (%) – obtained as a complementary parameter from the same ASTM procedure.

Total nitrogen (mg/L) – measured according to EN 15750:2009 using the Kjeldahl digestion–distillation method on digestion unit and distillation system, with titration performed using 0.01 N HCl.

Phosphorus (P_2O_5, mg/L) – extracted with ammonium-lactate solution following the validated AL method used at FASF-Skopje. Determination performed by UV-Vis spectrophotometry.

Potassium (K_2O, mg/L) – extracted identically (AL method) and measured using a flame photometer, calibrated with K standard solutions (0.5–10 mg/L K).

3. Sample preparation

For sample preparation it was used fresh spent mushroom substrate from oyster mushroom (Pleurotus ostreatus) from producer in Negotino just after oyster production. Substrate samples were air-dried at room temperature (22–25 °C), homogenized manually, and sieved through 2 mm mesh (for chemical assays) and 10 mm mesh (for physical structure characterization).

Moisture and density measurements were performed on fresh, non-dried samples to preserve the natural physical status of the spent mushroom substrate.

4. Quality Assurance / Quality Control (QA/QC)

All analyses were performed in duplicate, and results are reported as the mean. Standard reference materials (SRMs) for organic substrates and composts were used where available. Instruments were calibrated daily using certified calibration standards for pH, EC, N, P, and K.

Blank samples and control solutions were included in each analytical batch. The relative standard deviation (RSD) for repeated measurements was kept below 5%, fulfilling the laboratory's internal QA requirements.

In order to achieve the second objective utilization of mushroom residues in horticulture, information was gathered and presented from peer-reviewed articles published between 1994 and 2024. These articles were sourced from reputable journals indexed in databases such as Scopus, Web of Science, ResearchGate, and Google Scholar.

RESULTS AND DISCUSSION

Physical and chemical properties of the Spent mushroom substrate (SMS) of the oyster (Pleurotus ostreatus)

The physical analysis of the oyster mushroom substrate indicated that it possessed moderate moisture, a uniform texture, a mixed dark-to-light coloration, a characteristic odor, suitable density, and an electrical conductivity within an acceptable range. The chemical analysis further showed that the substrate exhibited slightly acidic pH, very high organic matter content, low ash levels, and a nutrient profile characterized by low nitrogen and phosphorus availability, along with moderate to sufficient potassium supply. Overall, the substrate demonstrates high organic quality, appropriate physical properties, and a generally favorable chemical composition for use in cultivation (Table 1).

Table 1. Physical and chemical properties of the Spent mushroom substrate (SMS) of the oyster (*Pleurotus ostreatus*)

	Parameter	Method	Values	Unite Measure
Physical parameters				
1.	Moisture	MKC ISO8190:1992	55,02	[%]
2.	Texture	organoleptic	homogeneous	/
3.	Color	organoleptic	brown-black-white	/
4.	Scent	organoleptic	characteristic	/
5.	Density	MKCISO 1237:2009	215	[g/L]
6.	EC	ISO 11265:2004	0,9	[mS/cm]
Chemical parameters				
1.	pH	MKCISO 13037:2011	5,60	/
2.	Organic matter	ASTM D2974 – 14	98,32	[%]
3.	Ash	ASTM D2974 – 14	3,02	[%]
4.	Total nitrogen (N)	EN 15750:2009	212	[mg/l]
5.	Phosphorus (P_2O_5)	AL Method validated at FASF - Skopje	178	[mg/l]
6.	Potassium (K_2O)	AL Method validated at FASF - Skopje	301	[mg/l]

Table 2. Physical and chemical characteristics of spent mushroom substrate (SMS) and spent mushroom compost (SMC)

Parameter	SMS-PO[2] (Medina et al., 2009)	White button mushroom SMC (Kwack et al., 2012)	*Flam Mulina velutipes* SMS (Zhang et al., 2012)	100% SMW[3] (Sendi et al., 2013)	SMS (Van Tam and Wang, 2015)	Aged SMC (Sönmez et al., 2016)	Spent oyster mushroom compost (Priadi et al., 2016)	FSMC[1] (Demir, 2017)	Agaricus bisporus SMS (Collela et al., 2019)	*Agaricus bisporus* SMS (Catal, and Peksen,2020)	Fresh SMS of white button mushroom (Alves et al., 2024)
M	-	-	-	-	-	-	73.36 %	-	-	-	-
BD	-	0.12 g cm^{-3}	0.413 g cm^{-3}	-	0.308g cm^{-3}	-	-	-	325.0 kg/m^{3}	-	0.308kgL^{-1}
TPS	-	-	79.8%	-	89.73%	-	-	-	67%	-	-
AP	61(% (v/v)	-	24.5%	-	36.47%	-	-	-	-	-	-
WHC	324 mL L^{-1})	-	55.3%	-	53.26 %	-	-	-	62.3%	277.51%	-
pH	6.9	7.0	5.28	6.10	7.65	6.66	8.4	7.14	6.9	6.23	7.42
EC	1.03dS m^{-1}	4.97dS m^{-1}	2.45mScm^{-1}	1.33dS m^{-1}	3.50 dS m^{-1}	6.85dS m^{-1}	-	10.91dS m^{-1}	2.54	6.60dS m^{-1}	5.81dS m^{-1}
N	1.12 %	-	10.78	0.34%	0.218g kg^{-1}	1.663%	0.32 %	1.786%	8.7g kg^{-1}	2.32%	15.1g kg^{-1}
NO_3	2 mg L^{-1}	79 mg L^{-1}	-	-	-	-	-	-	-	-	-
P	252mg L^{-1}	34 mg L^{-1}	2.69gkg^{-1}	0.16%	11.49g kg^{-1}	25280mgkg^{-1}	0.29 %	28280mgkg^{-1}	542.96 mg/dm3	0.68%	5.0g kg^{-1}
K	1875mg L^{-1}	1879 mg L^{-1}	1.34gkg^{-1}	0.53%	13.85g kg^{-1}	13170mgkg^{-1}	0.11 %	20860 mgkg^{-1}	600.0 mg/dm3	2.43%	18.6g kg^{-1}
Ca	20.1gkg^{-1}	1317 mg L^{-1}	30.1gkg^{-1}	0.51%	33.45g kg^{-1}	43210mgkg^{-1}	-	41910 mgkg^{-1}	52.7 cmol/dm3	4.73%	66.2g kg^{-1}
Mg	3.9gkg^{-1}	231 mg L^{-1}	4.52gkg^{-1}	0.15%	7.79g kg^{-1}	6648.0mgkg^{-1}	-	5148.0 mgkg^{-1}	3.0 cmol/dm3	0.55%	6.6g kg^{-1}
CEC	-	-		-	-	-	-	-	58.73 cmol/dm3	-	-
BS	-	-	81.2%	-	-	-	-	-	-	-	-
OM	-	-		-	-	-	-	-	15.04 dag/kg	66.98%	-
C:N	-	-		-	-	-	32	-	-	16.74	-
C	-	-		-	-	-	10.35%	-	-	38.85%	-

M (Moisture), BD (Bulk density), TPS (Total pore space), AP (Air porosity), WHC (Water holding capacity), CEC (cation exchange capacity) OM (organic matter) [1]FSMC (fresh spent mushroom compost) [2]SMS-PO (Spent mushroom substrate of *Pleurotus ostreatus*) [3]SMW (Spent mushroom waste)

Table 2 presents the physical and chemical characteristics of mushrooms residues as reported in the reviewed literature. According to Medina *et al*. (2009) spent mushroom substrate from *Pleurotus ostreatus* has very high air porosity, pH near neutral, moderate EC, high N and P, but very high K content which make it not directly usable as growing media. On the other hand, composted oyster spent mushroom substrate showed higher moisture content (73.36%), high pH levels (8.4), low nitrogen levels, and moderate P and K content (Priadi *et al*., 2016).

The physical and chemical properties of spent mushroom substrate from white button mushroom (*Agaricus bisporus*) vary considerably, but it is generally characterized by elevated pH and electrical conductivity, moderate to high nitrogen concentrations, medium to high phosphorus levels, and consistently high potassium content (Kwack *et al*., 2012; Collela *et al*., 2019; Catal and Peksen, 2020; Alves *et al.,* 2024). *Flammulina velutipes* SMS exhibits a pH comparable to that of the oyster mushroom substrate, but it has a notably higher electrical conductivity and substantially greater concentrations of nitrogen, phosphorus, and potassium, indicating a richer nutrient profile that could influence its suitability for use as a growing medium or soil amendment (Zhang *et al.,* 2012).

Utilization of Mushroom residues in horticulture

The use of low-cost, renewable materials such as spent mushroom substrate and spent mushroom compost offers an environmentally sustainable alternative to chemical inputs and peat, supporting the sustainable production of potted plants and seedlings (Mwangi *et al.,* 2024; Younis *et al*., 2023). Overall, media containing spent mushroom compost enhanced tomato seedling growth, with the best results observed in media containing spent paddy straw mushroom compost (Priadi *et al.,* 2016). The addition of 100% spent mushroom compost to the growing media significantly improved tomato seedling quality, yielding the best results in hypocotyl length, seedling length, root length, and both shoot and root fresh weights (Ünal, 2015). Seedlings grown in spent mushroom substrate (SMS) from *Agaricus bisporus* exhibited faster germination rates and speeds, and outperformed other substrates in terms of tomato seedling quality (Collela *et al.,* 2019). Tomato seedlings grown in SMS were 32% taller and had 12% more leaves at 5 weeks after seeding compared to those grown in peat at 6 weeks, demonstrating that SMS is a more effective medium for seedling production (Eudoxie and Alexander, 2011). Using 100% composted SMS as a substrate did not impair cherry tomato seedling growth, while fresh SMS negatively affected germination and growth, likely due to excess salts, though it significantly increased chlorophyll content (SPAD), leading to the recommendation that fresh SMS can be used at 20% as a peat substitute without harming seedling development (Alves *et al*., 2024). The optimal substrate for tomato and cucumber seedlings is a spent mushroom substrate (SMS) mixed with perlite at a 2:1 ratio or with vermiculite at a 4:1 ratio, depending on the amendment used (Zhang *et al.,* 2012). Spent mushroom media (SMM) from *Flammulina velutipes* mixed with 0–30% vermiculite showed a high germination rate in pepper, while SMM from *Pleurotus eryngii* with 20% vermiculite achieved 100% germination. Pepper growth improved with increasing vermiculite content, indicating that Flammulina velutipes SMM with up to 30% vermiculite can be effectively used as a horticultural growing medium for pepper cultivation (Chan-Jung *et al.,* 2009). Similar results were obtained by Demir, 2017 where a mixture of 70% aged spent mushroom compost with 30% perlite and aged spent mushroom compost alone performed comparably to a 70% peat and 30% perlite mixture as a seedling medium for pepper, based on germination rate, stem diameter, height, leaf number, and seedling macroelement content. Fresh spent mushroom substrate (SMS) should not be used alone for pepper cultivation; instead, it is recommended to mix it with commercial peat at a 25% ratio for successful horticultural use (Medina *et al.,* 2009; Zhu *et al*., 2019). Among six tested spent mushroom composts (SMCs), white button mushroom SMC was the most suitable growing medium for lettuce transplant production when properly mixed, while sawdust-based SMCs require careful treatment to improve their physical and chemical properties for use as growing media (Kwack *et al*., 2012). According to Liu *et al.* (2018), a substrate mixed with 50% spent mushroom substrate (SMS) effectively improves the growth of lettuce seedlings. Using spent mushroom compost at a 45% ratio provides the best conditions for lettuce seedling germination and growth, leading to greater biomass and vigor in 27-day-old plants (Marque *et al.,* 2014). Growing media significantly affected seedling quality, with peat and perlite mixtures generally yielding the best results, while eggplant seedlings grown in a mixture of new and old spent mushroom compost (70% SMC + 30% perlite) had the highest nutrient content, leading to the conclusion that spent mushroom compost can be effectively used in seedling growing media (Sönmez *et al*., 2016). Spent mushroom substrate (SMS) can be used up to 80% in mixtures with manure compost for honeydew melon seedling production, but 40% SMS provides the most suitable conditions for seedling growth (Van Tam and Wang, 2015). In addition to seedling production, spent mushroom substrate or compost can be used as manure (Ahlawat *et al*., 2009), to improve microbial diversity (Huang *et al.,* 2023), and even for biogas production (Kumar *et al*., 2022).

In sustainable fruit production, spent mushroom compost (SMC) serves as a fertilizer, soil amendment, mulch, or alternative pesticide, and is recommended for application at intervals of several years to maintain soil health and productivity (Uzun, 2004). Using spent mushroom substrate as a soil enrichment material for pineapple resulted in better growth and yield, with no significant difference in fruit number and fresh weight compared to inorganic fertilizer (Orluchukwu and Adedokun, 2015). SMS offers significant advantages, minimal transport and no composting, making it beneficial for both avocado and mushroom growers; however, its commercial use in avocado orchards requires careful monitoring of soil electrical conductivity (salinity) to prevent potential damage (Danai *et al*., 2011). Growing media greatly affects overall strawberry performance; replacing peat with 15% and 25% (v/v) fresh *Agaricus bisporus* spent mushroom substrate (A-SMS) and *Lentinula edodes* spent mushroom substrate (L-SMS) in soilless strawberry production resulted in better growth and compatibility compared to commercial peat and Pleurotus spent mushroom substrate (P-SMS) (Prasad *et al*., 2021).

Research on woody ornamentals has shown that incorporating spent mushroom substrate (SMS) at rates of 25% or 50%, which are preferred in commercial container nursery practices, significantly promotes excellent growth of nursery crops (Chong and Rinker, 1994). The use of spent mushroom compost from button mushroom (*Agaricus bisporus*) cultivation, combined with a proportion of commercial substrates, is recommended for producing *Pelargonium peltatum* L. and *Petunia hybrida* Juss. seedlings due to its positive effects on root and shoot development, economic viability, and environmental suitability (Zeljković *et al.,* 2015). Fresh and exhausted mushroom composts were used without pretreatment as growth substrates for chrysanthemum cultivation. The results indicate that fresh mushroom compost is most effective at a 12.5% ratio, with 25% as a secondary option, while exhausted mushroom compost is best used at 25%, with 50% as an alternative in later stages (Atikmen *et al.,* 2014).

Compared to other organic materials, spent mushroom substrate offers three key benefits for intensive horticulture: no weed seeds, slow nutrient release, and a beneficial microbial community that helps protect plants from pathogens (Diego *et al*., 2021).

CONCLUSIONS

Based on the results of this study, it can be concluded that the spent mushroom substrate (SMS) of oyster mushroom possesses favorable physical properties, including low bulk density, favorable structure, and low electrical conductivity. Regarding chemical properties, the substrate is relatively low in nutrients, except for potassium, and exhibits a slightly acidic pH, making it suitable for a wide range of horticultural crops. Its extremely high organic matter content further enhances its value as a soil conditioner. Oyster mushroom SMS can be incorporated into substrate mixes for vegetable production. According to the reviewed literature on the utilization of mushroom residues in horticulture, its primary application in vegetable production is as a substrate substitute for seedling cultivation. In fruit production, these residues can be used as a 25% component of growing substrates, as a fertilizer, soil amendment, mulch, or alternative pest control agent. For ornamental horticulture, oyster mushroom SMS can be applied at rates of 25–50% as a substitute for conventional growing media.

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