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ENHANCED NUTRIENT COMPOSITION OF COMPOST AND VERMICOMPOST DERIVED FROM SPENT MUSHROOM SUBSTRATE: A SUSTAINABLE APPROACH TO SOIL ENRICHMENT

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Abstract: Spent mushroom substrate (SMS) is a nutrient-rich organic byproduct generated after mushroom cultivation. This study evaluates the macronutrient and micronutrient composition of compost and vermicompost derived from SMS of *Pleurotus ostreatus*, using different agricultural residues—paddy, soybean, and arhar (pigeon pea). The composting process was carried out over 120 days, followed by a 90-day vermicomposting phase using *Eisenia fetida*. Key physicochemical parameters, including moisture content, pH, electrical conductivity, total carbon, nitrogen (N), phosphorus (P), potassium (K), and micronutrients (Fe, Mn, Zn, Cu), were analysed. The results indicate that vermicompost exhibited significantly higher nitrogen (1.12%–1.40%), phosphorus (0.132%–0.442%), potassium (0.71%–0.82%), and micronutrient concentrations compared to compost. The highest nitrogen content was observed in paddy vermicompost (1.40%), while the highest phosphorus and potassium levels were found in soybean and arhar vermicomposts, respectively. Vermicomposting enhanced nutrient bioavailability, making it a superior soil amendment for sustainable agriculture. These findings highlight the potential of SMS-derived organic amendments in improving soil fertility and promoting eco-friendly waste management practices.

Keywords: Spent mushroom substrate, composting, vermicomposting, *Eisenia fetida*, nutrient composition, soil amendment, sustainable agriculture.

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1. Introduction:

Spent mushroom substrate (SMS) is an organic byproduct generated after the harvesting of mushrooms, particularly in large-scale commercial production systems. The increasing global production of edible mushrooms, such as *Pleurotus ostreatus* (oyster mushroom), has led to a significant accumulation of SMS, raising concerns about its sustainable disposal and potential applications (Rinker, 2017). Rather than being treated as waste, SMS has gained attention as a valuable resource in sustainable agriculture due to its rich organic matter and nutrient composition, making it an effective soil amendment (Philippoussis *et al.,* 2009).

Composting and vermicomposting are widely recognised biotechnological processes used to enhance the nutrient profile of organic wastes, including SMS, and to produce high-quality organic fertilisers. Traditional composting relies on microbial decomposition, whereas vermicomposting employs earthworms such as *Eisenia fetida* to accelerate the breakdown of organic matter and enhance nutrient bioavailability (Suthar 2009). These methods improve soil fertility by enriching the soil with macro- and micronutrients essential for plant growth while also enhancing soil structure, aeration, and microbial activity (Lazcano *et al.,* 2008).

The nutrient composition of compost and vermicompost derived from SMS varies based on factors such as the type of initial substrate, decomposition duration, and environmental conditions (Aira *et al.,* 2006). Different agricultural residues, including paddy, soybean, and arhar (pigeon pea), serve as SMS sources, influencing the chemical properties of the final compost product. Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) play a crucial role in plant development, while micronutrients like iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) contribute to enzymatic functions and stress tolerance in plants (Domínguez, 2004). The variation in nutrient levels among different SMS-based composts and vermicomposts highlights their potential application as tailored soil amendments suited for specific agricultural needs.

In this study, we assess the macronutrient and micronutrient composition of compost and vermicompost derived from spent mushroom substrate over defined decomposition periods. By analysing key physicochemical parameters, we aim to evaluate the suitability of these organic amendments in sustainable soil management and their role in improving soil health and crop productivity.

2. Materials and Methods:

2.1. Collection of Spent Mushroom Substrate (SMS) and Preparation of Compost

Spent mushroom substrate (SMS) was collected following the cultivation cycle of *Pleurotus ostreatus* (oyster mushroom). The SMS was obtained from three different agricultural residues: paddy straw (P1), soybean straw (S1), and pigeon pea (arhar) husk (A1). The substrates were air-dried and manually homogenised before being subjected to composting. The composting process was carried out over 120 days under controlled conditions, ensuring optimal moisture and aeration, as recommended by previous studies (Awasthi *et al.,* 2017; Singh *et al.,* 2020).

2.2. Composting Process

The composting process involved periodic turning of the substrate piles to maintain aeration and prevent anaerobic conditions. Moisture content was maintained at approximately 50–60% throughout the process using distilled water when necessary. The compost piles were monitored for temperature and pH fluctuations using a digital thermometer and pH meter, respectively. The composting process was completed after 120 days, at which point nutrient analysis was conducted.

2.3. Vermicomposting Using Eisenia fetida

The vermicomposting experiment utilised *Eisenia fetida* (red wiggler earthworms), which were sourced from a recognised vermiculture facility. Pre-composted SMS from the three different substrates was placed in separate vermicomposting bins under ambient conditions. The earthworms were introduced at a standard stocking density of 10 g per kg of composted material, as per the protocol outlined by Edwards *et al.,* (2011). Moisture levels were maintained between 50–60%, and the bins were protected from direct sunlight to avoid desiccation. The vermicomposting process was carried out for 90 days, during which periodic observations were made regarding decomposition rate, earthworm activity, and compost stability.

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2.4. Nutrient Analysis of Compost and Vermicompost

Upon completion of the composting and vermicomposting processes, samples were collected and analysed for macronutrient and micronutrient composition. The following parameters were measured:

- *Moisture content (%):* Determined by oven drying at 105°C until a constant weight was achieved (AOAC, 2019).
- *pH and Electrical Conductivity (EC):* Measured using a pH meter and conductivity meter in a 1:10 compost-to-water extract (Jackson, 1973).
- *Total Carbon (%):* Estimated using the Walkley-Black method (Walkley & Black, 1934).
- *Total Nitrogen (%):* Determined by the Kjeldahl method (Bremner, 1960).
- *Phosphorus (%):* Measured by the Olsen method for available phosphorus (Olsen *et al.,* 1954).
- *Potassium (%):* Determined using a flame photometer (Richards, 1954).
- *Micronutrient content (Fe, Mn, Zn, Cu in ppm):* Analysed using atomic absorption spectrophotometry (AAS) following acid digestion (Lindsay & Norvell, 1978).

2.5. Data Analysis

All nutrient analyses were conducted in triplicate to ensure accuracy and reproducibility. The data were subjected to statistical analysis using one-way analysis of variance (ANOVA) followed by post-hoc Tukey's test to determine significant differences between compost and vermicompost nutrient compositions. Statistical significance was set at $p < 0.05$, and all analyses were performed using SPSS software (version 2.0).

3. Results:

The table 01 present study investigated the nutrient composition of compost and vermicompost derived from spent mushroom substrate (SMS) over different composting durations. The results highlight the variations in macronutrient and micronutrient content among compost and vermicompost samples prepared using different agricultural residues: paddy, soybean, and arhar.

3.1. *Nutrient Composition of Compost from Spent Mushroom Waste*

3.1.1.*Moisture Content and pH*

The moisture content of the compost samples varied from 48% to 59%, with the highest moisture level observed in Arhar SMS (A1) (59%) and the lowest in Soybean SMS (S1) (48%). The pH values of the compost samples ranged from 6.74 to 6.95, with all samples exhibiting a slightly acidic nature. Paddy SMS (P1) demonstrated the highest pH (6.95), while Arhar SMS (A1) had the lowest (6.74), indicating a favourable pH range for microbial activity and soil amendment potential.

3.1.2. *Electrical Conductivity (EC) and Carbon Content*

The EC values ranged between 3.87 and 6.13 µS/cm, with the highest recorded in Arhar SMS (A1) (6.13 µS/cm), followed closely by Soybean SMS (S1) (6.07 µS/cm), while Paddy SMS (P1) exhibited the lowest value (3.87 µS/cm). Higher EC values suggest an increased concentration of soluble salts, which may influence plant growth when applied to soil. The carbon content ranged from 22.47% to 24.01%, with Arhar SMS (A1) having the highest (24.01%) and Paddy SMS (P1) the lowest (22.47%). These variations suggest that Arhar SMS (A1) could contribute more organic matter, thereby improving soil structure and fertility.

Table No. 01 - Nutrient test of compost made from spent mushroom waste in 120 days.

Parameters	**Paddy SMS(P1)**	**Soyabean SMS(S1)**	**Arhar SMS(A1)**
Moisture (%)	54	48	59
pH	6.95	6.78	6.74
EC(µS/cm)	3.87	6.07	6.13
C(%)	22.47	23.45	24.01
N(%)	0.87	0.43	0.67
P(%)	0.26	0.91	0.74
K(%)	0.19	0.46	0.38
Fe (ppm)	219	216	208
Mn(ppm)	68.65	54.23	61.54
Zn(ppm)	24.3	26	25.1
Cu(ppm)	109	114	104

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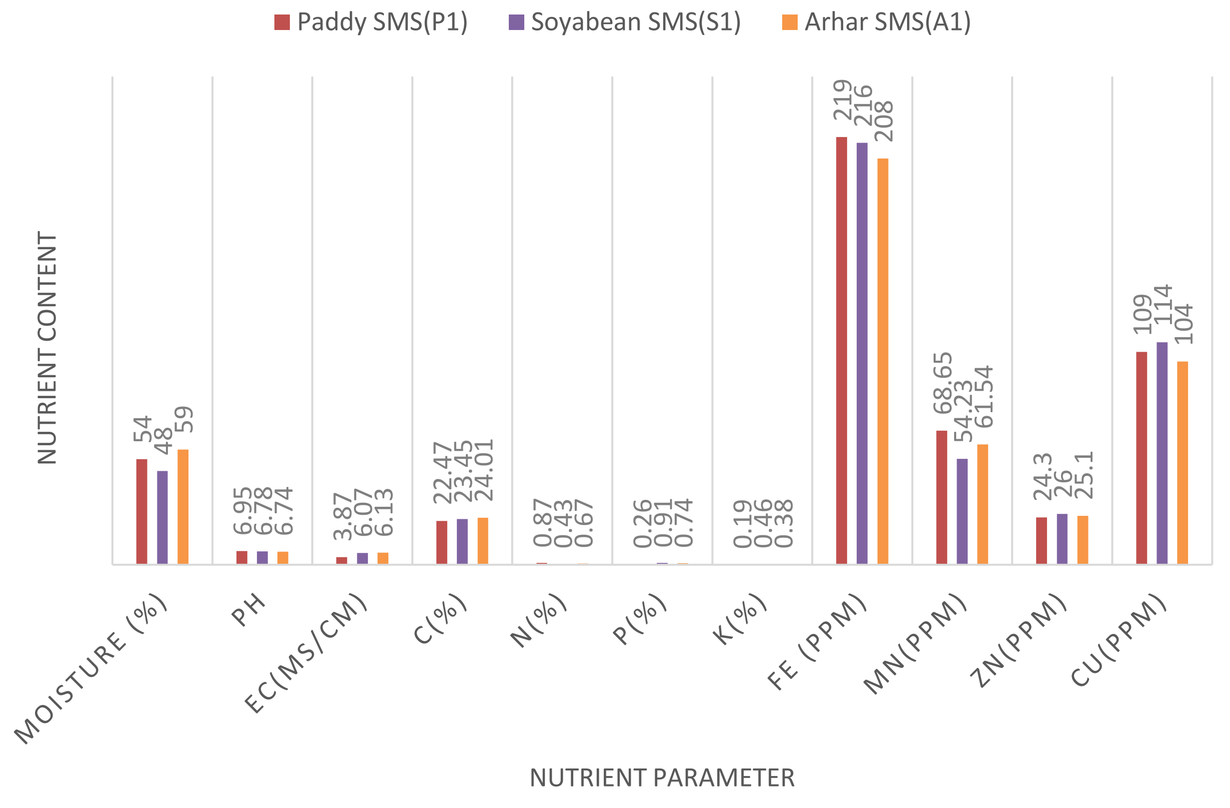
Note: Where is C=Carbon, N=Nitrogen, P=Phosphorus, K=Potassium, Fe=Iron, Mn=Manganese, Zn=Zinc, Cu=Copper, µS/cm=microsiemens per centimeter, ppm=Parts Per Million.

CHART 1: SHOWED NUTRIENT ANALYSIS OF COMPOST MADE FROM SPENT MUSHROOM WASTE



3.1.3.*Macronutrient Content (Nitrogen, Phosphorus, and Potassium)*

Nitrogen (N) content varied significantly among the samples, with the highest observed in Paddy SMS (P1) (0.87%) and the lowest in Soybean SMS (S1) (0.43%). Phosphorus (P) content was highest in Soybean SMS (S1) (0.91%) and lowest in Paddy SMS (P1) (0.26%), indicating that Soybean SMS (S1) may be more beneficial in promoting root development. Potassium (K) levels were highest in Soybean SMS (S1) (0.46%) and lowest in Paddy SMS (P1) (0.19%), suggesting better plant stress resistance potential in Soybean SMS (S1) compost.

3.1.4.*Micronutrient Content*

Among the micronutrients, iron (Fe) levels were highest in Paddy SMS (P1) (219 ppm), followed closely by Soybean SMS (S1) (216 ppm) and Arhar SMS (A1) (208 ppm). Manganese

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(Mn) was most abundant in Paddy SMS (P1) (68.65 ppm), with lower levels in Soybean SMS (S1) (54.23 ppm). Zinc (Zn) was highest in Soybean SMS (S1) (26 ppm) and lowest in Paddy SMS (P1) (24.3 ppm). Copper (Cu) was highest in Soybean SMS (S1) (114 ppm) and lowest in Arhar SMS (A1) (104 ppm). These micronutrients are essential for plant physiological functions, including enzyme activity, photosynthesis, and stress tolerance.

3.2. *Nutrient Composition of Vermicompost from Spent Mushroom Waste*

3.2.1.*Moisture Content and pH*

The moisture content of vermicompost samples ranged from 49% to 56%, with the highest observed in Paddy V-SMS (V-P2) (56%) and the lowest in Soybean V-SMS (V-S2) (49%). The pH of the vermicompost samples was slightly acidic to neutral, with values ranging from 6.69 to 6.89. The lowest pH was found in Soybean V-SMS (V-S2) (6.69), whereas Arhar V-SMS (V-A2) exhibited the highest (6.89). These values suggest that vermicomposting produced a more stable and balanced organic amendment.

3.2.2. *Electrical Conductivity (EC) and Carbon Content*

The EC values of the vermicompost samples ranged between 5.49 and 6.11 µS/cm, with Soybean V-SMS (V-S2) recording the highest EC (6.11 µS/cm) and Arhar V-SMS (V-A2) the lowest (5.49 µS/cm). The carbon content varied from 21.32% to 24.05%, with Soybean V-SMS (V-S2) containing the highest (24.05%) and Paddy V-SMS (V-P2) the lowest (21.32%).

3.2.3. *Macronutrient Content (Nitrogen, Phosphorus, and Potassium)*

Nitrogen content significantly increased in the vermicompost samples compared to compost, with values ranging from 1.12% to 1.40%. The highest nitrogen content was observed in Paddy V-SMS (V-P2) (1.40%), indicating better nitrogen retention through vermicomposting. Phosphorus content ranged from 0.132% (Paddy V-SMS (V-P2)) to 0.442% (Soybean V-SMS (V-S2)), highlighting enhanced phosphorus availability. Potassium content was highest in Arhar V-SMS (V-A2) (0.82%) and lowest in Soybean V-SMS (V-S2) (0.71%), demonstrating improved potassium enrichment through vermicomposting.

3.2.4. *Micronutrient Content*

Vermicompost exhibited a notable increase in micronutrient concentrations compared to compost. Iron (Fe) ranged from 218 ppm to 241 ppm, with Arhar V-SMS (V-A2) having the highest. Manganese (Mn) levels increased substantially, with the highest concentration in Arhar V-SMS (V-A2) (85.18 ppm). Zinc (Zn) levels also increased, with Arhar V-SMS (V-A2)

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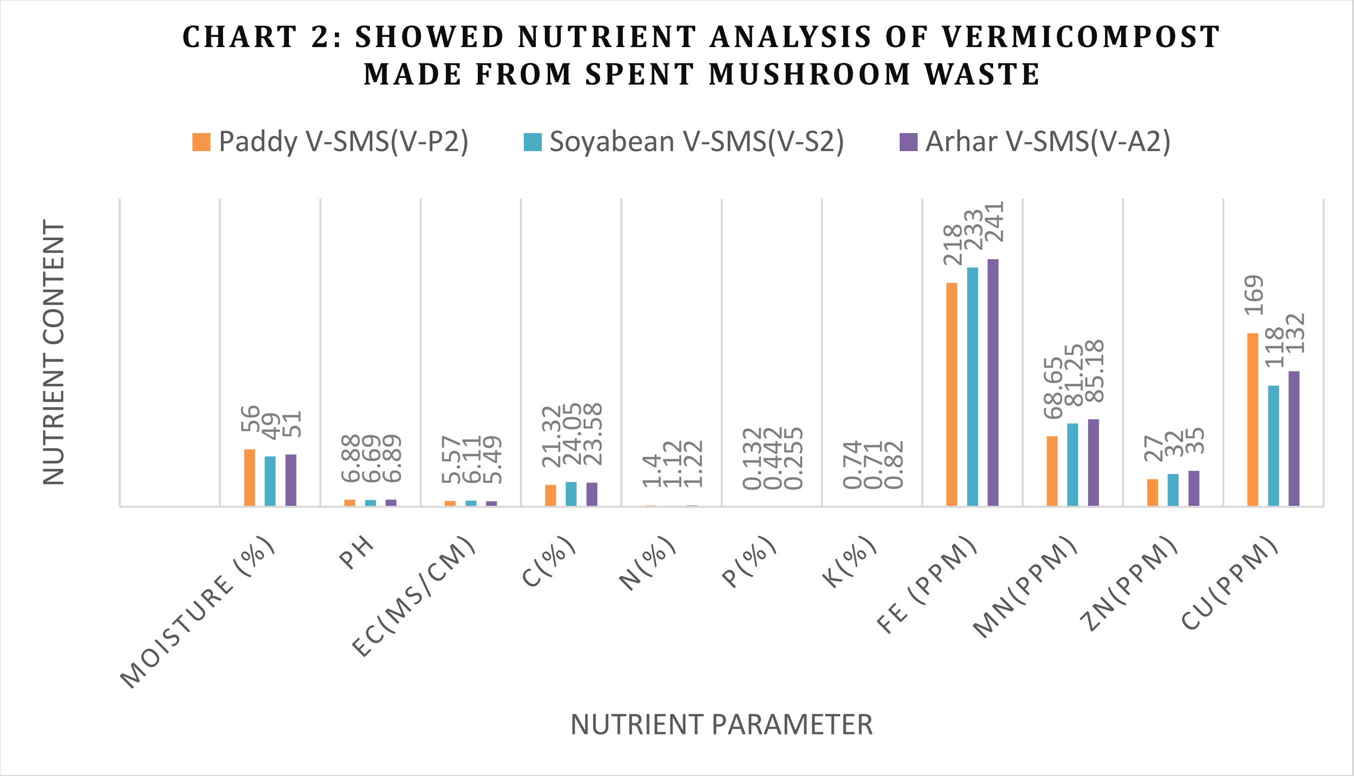
showing the highest concentration (35 ppm). Copper (Cu) was significantly enriched in Paddy V-SMS (V-P2) (169 ppm), demonstrating an increased availability of essential trace elements post-vermicomposting.

Table No.2 –Nutrient test of Vermicomposted (*Eisenia fetida*) made from spent mushroom waste in 90 days:

Parameters	**Paddy V-SMS(V-P2)**	**Soyabean V-SMS(V-S2)**	**Arhar V-SMS(V-A2)**
Moisture (%)	56	49	51
pH	6.88	6.69	6.89
EC(mS/cm)	5.57	6.11	5.49
C (%)	21.32	24.05	23.58
N (%)	1.40	1.12	1.22
P (%)	0.132	0.442	0.255
K (%)	0.74	0.71	0.82
Fe (ppm)	218	233	241
Mn(ppm)	68.65	81.25	85.18
Zn(ppm)	27	32	35
Cu(ppm)	169	118	132

(*EC=Electric conductivity, C=Carbon, N=Nitrogen, P=Phosphorus, K=Potassium, Fe=iron, Mn=Manganese, Zn=Zinc, Cu=copper)



3.3. *Comparative Analysis: Compost vs. Vermicompost*

Overall, vermicompost showed an enhanced nutrient profile compared to compost. The nitrogen, phosphorus, and potassium levels were significantly higher in vermicompost, confirming its superior fertilisation potential. Additionally, the increased micronutrient concentrations indicate improved bioavailability, which can enhance plant growth and soil microbial activity. The findings affirm that vermicomposting effectively enhances the nutrient content of spent mushroom substrate, making it a valuable organic soil amendment for sustainable agriculture.

4. Discussion:

The findings from the nutrient analysis of compost and vermicompost derived from spent mushroom substrate (SMS) highlight significant variations in physicochemical properties and nutrient composition across different agricultural residues. The comparative assessment of compost and vermicompost reveals enhancements in nutrient content following vermicomposting, underscoring its potential as a sustainable soil amendment.

4.1. *Moisture Content and pH*

Moisture content plays a crucial role in microbial activity and organic matter decomposition during composting and vermicomposting (Dominguez, 2004). The moisture content of compost samples ranged from 48% to 59%, with the highest observed in Arhar SMS (A1) (59%) and the lowest in Soyabean SMS (S1) (48%). Vermicomposting led to a relative stabilisation of moisture levels, with values ranging from 49% to 56%, demonstrating its capacity to maintain optimal moisture conditions for microbial proliferation and earthworm activity (Aira *et al.,* 2007).

The pH values of the compost samples indicated a slightly acidic nature, ranging from 6.74 to 6.95. A minor reduction was observed in vermicompost samples, where values ranged from 6.69 to 6.89. This slight decline in pH aligns with previous studies demonstrating that vermicomposting leads to acidification due to microbial metabolic processes and organic acid production (Ndegwa & Thompson, 2001).

4.2. *Electrical Conductivity (EC) and Organic Carbon (C) Content*

Electrical conductivity (EC), which reflects the concentration of soluble salts, increased in all samples following vermicomposting. The highest EC was recorded in Soyabean V-SMS (V-S2) (6.11 μS/cm), while the lowest was in Arhar V-SMS (V-A2) (5.49 μS/cm). The increase in EC post-vermicomposting is consistent with previous reports indicating that earthworm activity enhances mineralisation and ion exchange processes (Suthar, 2009).

Organic carbon content showed marginal reductions post-vermicomposting, with values ranging from 21.32% to 24.05%. The decrease is attributed to enhanced microbial respiration and carbon mineralisation facilitated by earthworm activity (Suthar 2009). The highest carbon content was recorded in Soyabean V-SMS (V-S2) (24.05%), signifying its superior organic matter retention potential compared to other substrates.

4.3. *Macronutrient Content (Nitrogen, Phosphorus, and Potassium)*

The nitrogen content increased substantially in vermicompost samples, with Paddy V-SMS (V-P2) exhibiting the highest nitrogen content (1.40%), followed by Arhar V-SMS (V-A2) (1.22%) and Soyabean V-SMS (V-S2) (1.12%). The increase in nitrogen content is attributed to the stabilisation of nitrogenous compounds during earthworm digestion and microbial decomposition (Lazcano *et al.,* 2008).

Phosphorus content was significantly enhanced post-vermicomposting, particularly in Soyabean V-SMS (V-S2) (0.442%). The increased phosphorus availability can be linked to enhanced microbial solubilisation and mineralisation of phosphorus compounds by earthworm gut microbiota (Ghosh *et al.,* 1999).

Similarly, potassium levels increased across all vermicompost samples, with Arhar V-SMS (V-A2) exhibiting the highest potassium concentration (0.82%). This trend is consistent with previous findings indicating that vermicomposting enhances potassium solubilisation through the breakdown of complex organic molecules (Kale *et al.,* 1982).

4.4. *Micronutrient Content (Fe, Mn, Zn, Cu)*

Vermicomposting resulted in notable increases in micronutrient concentrations. Iron (Fe) levels increased across all vermicompost samples, with Arhar V-SMS (V-A2) containing the highest Fe concentration (241 ppm). Similarly, manganese (Mn) content was highest in Arhar V-SMS (V-A2) (85.18 ppm), signifying enhanced bioavailability through vermicomposting processes (Bhat *et al.,* 2017).

Zinc (Zn) and copper (Cu) levels also showed increases in vermicomposted samples, with Arhar V-SMS (V-A2) recording the highest Zn content (35 ppm) and Paddy V-SMS (V-P2) exhibiting the highest Cu content (169 ppm). These findings align with existing literature indicating that vermicomposting enhances micronutrient bioavailability through earthworm-mediated enzymatic degradation (Edwards & Arancon, 2004).

5. Conclusion:

The present study investigated the nutrient composition of compost and vermicompost derived from spent mushroom substrates (SMS) of *Pleurotus ostreatus* using different agricultural residues, including paddy, soybean, and arhar. The findings indicate that both composting and vermicomposting processes significantly influence the physicochemical properties and nutrient profiles of the organic amendments.

The composting process over 120 days resulted in substantial variations in macronutrient and micronutrient concentrations among the different SMS types. Notably, the compost samples exhibited a slightly acidic pH, with electrical conductivity (EC) values indicating moderate salinity levels. Carbon content ranged from 22.47% to 24.01%, and nitrogen content varied between 0.43% and 0.87%, suggesting differences in organic matter decomposition. Phosphorus and potassium levels varied among SMS types, with soybean

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SMS showing the highest phosphorus content (0.91%) and the highest potassium content (0.46%), indicating its potential for enhancing soil fertility.

Vermicomposting over 90 days with *Eisenia fetida* further enhanced the nutrient composition of the organic amendments. Vermicompost exhibited a relatively stable pH (6.69–6.89), improved nitrogen content (1.12%–1.40%), and increased micronutrient concentrations, particularly iron, manganese, zinc, and copper. The enhanced nitrogen and phosphorus availability in vermicompost, as compared to compost, suggests improved nutrient mineralisation due to earthworm activity. The highest copper content was observed in paddy vermicompost (169 ppm), while the highest iron, manganese, and zinc concentrations were recorded in arhar vermicompost (241 ppm, 85.18 ppm, and 35 ppm, respectively).

These findings highlight the potential of SMS-based compost and vermicompost as valuable organic soil amendments. Vermicomposting, in particular, enhances nutrient bioavailability, making it a superior alternative for sustainable agricultural practices. The study underscores the importance of optimising composting and vermicomposting conditions to maximise nutrient retention and improve soil health. Future research should focus on the long-term impact of these organic amendments on soil fertility and crop productivity under field conditions.

- **SMS –** Spent Mushroom Substrate
- **P –** Phosphorus
- **K –** Potassium
- **N –** Nitrogen
- **Fe –** Iron
- **Mn –** Manganese
- **Zn –** Zinc
- **Cu –** Copper
- **EC –** Electrical Conductivity
- **C –** Carbon
- **ppm –** Parts Per Million
- **µS/cm –** Microsiemens per Centimetre
- **AOAC –** Association of Official Analytical Chemists
- **AAS –** Atomic Absorption Spectrophotometry
- **ANOVA –** Analysis of Variance
- **SPSS –** Statistical Package for the Social Sciences
- **V-SMS –** Vermicompost-Spent Mushroom Substrate

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