International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Integrated Valorization of Banana Leaves and Sugarcane Bagasse into Oyster Mushrooms and Biofertilizer: Advancing a Circular Bioeconomy Approach

Lightness Eliamringi Mrema

Assistant Lecturer, Department of General Studies, Water Institute

ABSTRACT

Poorly managed banana leaves and sugarcane bagasse create sanitation and environmental concerns in urban and peri-urban areas, despite the presense of lignocellulosic material in these materials that can support food production and soil improvement. In Tanzania, banana leaves and sugarcane bagasse are abundant wastes often burned or dumped, causing pollution, emissions, and biomass loss. This study evaluated an integrated biomass valorization strategy that converts these residues into edible oyster mushrooms (Pleurotus ostreatus) and nutrient-rich biofertilizer within a circular bioeconomy framework. Four 400 g substrate treatments were assessed: 100% banana leaves (T1), 100% sugarcane bagasse (T2), banana leaves and bagasse mixture at 2:1 (T3), and 1:2 (T4). Prior to cultivation, substrates were characterized for moisture, pH, total organic carbon, total nitrogen and carbon to nitrogen (C:N) ratio. Mushroom performance was assessed using mycelial colonization, pinhead formation, biological efficiency, cap diameter, moisture, ash, crude protein and pH. Following harvesting, Spent mushroom substrate was evaluated for pH, nitrogen, phosphorus, potassium and Carbon to Nitrogen(C:N) ratio.

Substrate composition significantly influenced both mushroom productivity and compost quality within internationally reported acceptable ranges. Although T1 promoted the fastest mycelial colonization (21 days), blended substrate T3 colonized for 40 days with highest first-flush biological efficiency (60%), cap diameter (8.0 cm) and crude protein content (31.0%). T3 also yielded the most nutrient-rich compost, with 1.5% N, 0.7% P, 2.0% K and a C:N ratio of 16:1. T2 had the highest initial C:N ratio (86:1), the lowest biological efficiency (51%) and the least nutrient-rich compost. The results showed that, a 2:1 banana-leaf-to-bagasse blend provides a useful balance between nutrient supply and substrate structure that simultaneously enhances mushroom productivity and biofertilizer quality.

This study advances current knowledge by integrating waste valorization, sustainable food production, and nutrient recycling into a single circular bioeconomy framework. The proposed approach offers a practical, low-cost, and environmentally sustainable strategy for transforming underutilized agricultural residues into high-value products while reducing waste disposal, improving soil fertility, supporting climate-smart agriculture, and contributing to several Sustainable Development Goals (SDGs), particularly SDGs 2, 11, 12, and 13. The findings provide an adaptable model for institutions, municipalities, farming communities, and agro-processing industries seeking to promote sustainable organic waste management and resource-efficient agricultural production.

Keywords: Oyster mushroom, Pleurotus ostreatus, banana leaves, sugarcane bagasse, biological efficiency, circular economy.

1. INTRODUCTION

The transition from a linear economy, in which natural resources are extracted, used, and discarded, to a circular bioeconomy has become a global priority for achieving sustainable development (Gottinger et al., 2020; Tan & Lamers, 2021; Kardung et al., 2021; Venkatesh, 2022). Rapid population growth, urbanization, and increasing agricultural production have led to a substantial rise in biodegradable waste, much of which remains underutilized despite its significant potential for value addition. Recent studies indicate that global municipal solid waste generation is expected to exceed 3.8 billion tonnes annually by 2050 (World Bank, 2018, Kaza et al., 2018), with organic matter accounting for about 44% of the waste stream worldwide. Much of this biomass is openly burned, dumped in landfills, or left to decompose, releasing greenhouse gases, contributing to environmental pollution, and representing a considerable loss of nutrients and energy that could otherwise support sustainable production systems. Agricultural residues constitute one of the largest components of biodegradable waste worldwide. Materials such as rice straw, maize stalks, wheat straw, banana leaves, coconut husks, coffee pulp, and sugarcane bagasse are produced in millions of tonnes each year. While these materials are rich in cellulose, hemicellulose, and lignin, they remain largely underexploited, particularly in developing countries where waste management infrastructure is limited (Mujtaba et al., 2023; Rao et al., 2024; Sileshi et al., 2025). Contemporary circular bioeconomy strategies seek to transform these residues into valuable products including bioenergy, livestock feed, compost, biodegradable materials, enzymes, and edible mushrooms, thereby extending the life cycle of biological resources while reducing environmental impacts.

In Sub-Saharan Africa, rapid urbanization and heavy reliance on agriculture mean that agricultural residues make up as much as 50% of municipal solid waste, yet these residues remain a largely untapped resource for circular bioeconomy initiatives (Khanna et al., 2024). At the same time, many countries continue to face food insecurity, declining soil fertility, and increasing dependence on expensive inorganic fertilizers. Weak regulatory frameworks (Debrah et al.,(2022), limited infrastructure and insufficient funding keep many nations locked into a linear waste model in which crop residues are openly burned or dumped releasing black carbon and greenhouse gases while destroying soil nutrients (World Bank, 2022, Ayeleru et al., 2022).These interconnected challenges highlight the need for innovative approaches that simultaneously address waste management, food production, and soil restoration within a single sustainable framework.

In Tanzania, where agriculture underpins the national economy, mismanagement of residues such as banana leaves and sugarcane bagasse through open burning or dumping continues to degrade the environment (NEMC, 2021). In Dar es Salaam , over 20,425 tonnes of solid waste are generated daily, a substantial share of which is lignocellulose material that clogs drainage systems and pollutes public areas (UCL, 2017). For example, within the Water Institute campus and the neighbouring Mabibo market, banana leaves used for packaging and sugarcane bagasse discarded by juice vendors accumulate as waste with no structured recovery pathway.

Previous studies have demonstrated that both banana residues and sugarcane bagasse can support the growth of oyster mushrooms (Carvalho et al., 2012; Dehariya, 2013; Bitew & Mandefro, 2018; Mhando et al., 2020; Mtui, 2020). Recent investigations have further shown that blending different agricultural residues often enhances biological efficiency as mixed substrates provide more balanced nutrient composition, improved moisture retention, and better physical structure than single materials (Alves da Silva et al., 2025). Similarly, increasing evidence indicates that compost produced from spent mushroom substrate can improve soil fertility while reducing dependence on synthetic fertilizers (De Bonis et al., 2025; Lin et al., 2025). However, most existing studies have evaluated either mushroom production or compost quality independently (Grimm and Wösten, 2018; Huwel et al., 2020; Alves da Silva et al., 2025; De Bonis et al., 2025), with relatively few adopting an integrated perspective that considers the entire biomass valorization chain. Moreover, limited information is available regarding the combined utilization of banana leaves and sugarcane bagasse under tropical conditions, particularly in Tanzania, where both residues are generated in large quantities but remain underutilized (Sagawa et al., 2008; Richard et al., 2020; Baitu et al., 2024; Joseph and Makwinja, 2026).

Addressing this gap is important because sustainable agricultural development increasingly requires technologies capable of producing multiple environmental and socioeconomic benefits simultaneously (Babu et al., 2022; Grimm and Wösten, 2018). Banana leaves and sugarcane bagasse are complementary feedstocks. Banana leaves decompose readily and provide comparatively more nitrogen and minerals, but their soft structure may compact during incubation. Bagasse is fibrous and porous, which favours aeration, but it is carbon-rich and may support slow growth when used without a nitrogen-bearing component. Recent work has confirmed that both residues can support oyster mushroom cultivation and that blending them can improve productivity and biodegradation (Alves da Silva et al., 2025; Bragadeeswaran et al., 2025, de Medeiros et al., 2024; De Bonis et al., 2025)

This study therefore investigated the integrated valorization of banana leaves and sugarcane bagasse for oyster mushroom production and biofertilizer development within a circular bioeconomy framework. Specifically, the study compared four substrate formulations to determine their characteristics, mushroom productivity, nutritional quality, and nutrient recovery through composting of spent mushroom substrate. Unlike previous studies that focused on a single product, this research evaluates the complete resource recovery pathway from agricultural residues to food production and nutrient recycling. By demonstrating how locally available biomass can be transformed into multiple value-added products, the study provides practical evidence supporting the transition toward circular agricultural systems in Tanzania and similar developing countries. In addition, the proposed approach contributes directly to the achievement of the United Nations Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land).

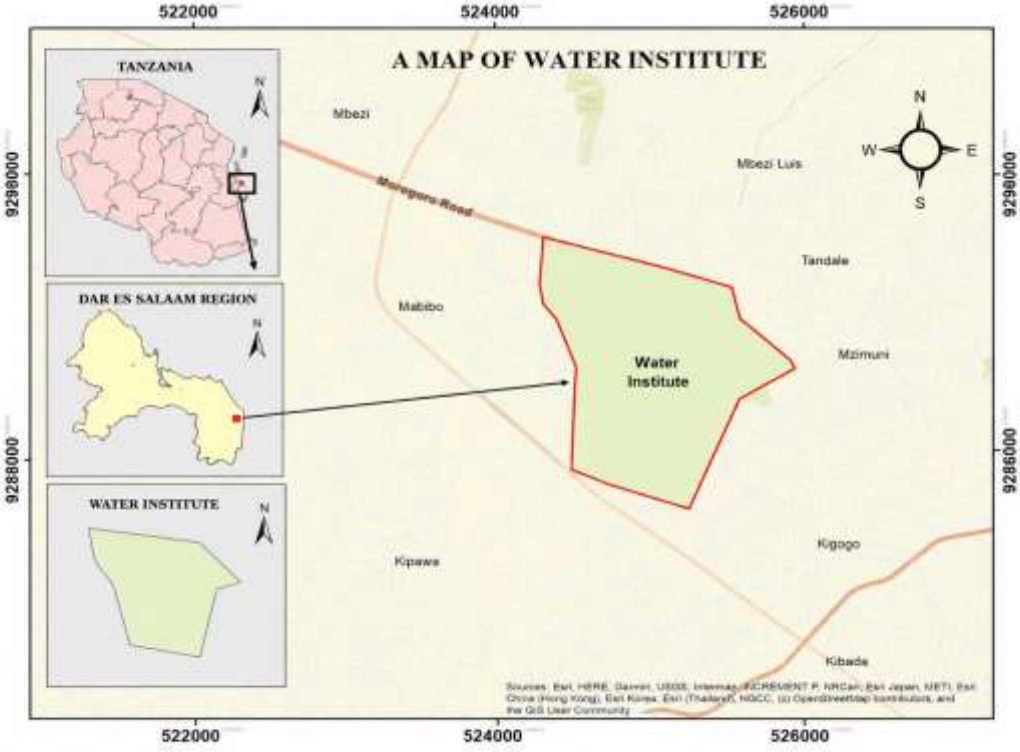
2. MATERIALS AND METHODS

2.1 Description of Study Area

The study was conducted at the Water Institute, Dar es Salaam, Tanzania (figure 1). Banana leaves were collected from Mabibo Market, one of the largest fresh markets in Dar es Salaam, where they are widely used for packaging fruits and vegetables before being discarded as waste while sugarcane bagasse was obtained from juice vendors operating within and around the Institute. The residues were selected because they were locally available throughout the year, poorly managed and represent an untapped source of lignocellulosic biomass suitable for biological valorization.

Dar es Salaam experiences a tropical climate characterized by average annual temperatures ranging from 25 to 32°C and relative humidity generally exceeding 70%, conditions that are favorable for cultivating *Pleurotus ostreatus*. Conducting the experiment under local environmental conditions enhances the practical applicability of the findings for institutions, urban farming initiatives and community-based waste recovery programs within Tanzania.

Figure 1: Map of the Study Area, Water Institute, Dar Es Salaam



2.2 Research Design

The study adopted an experimental research design to evaluate the suitability of banana leaves and sugarcane bagasse as substrates for oyster mushroom cultivation and subsequent biofertilizer production. Four substrate formulations were prepared using different proportions of banana leaves and sugarcane bagasse to determine their effects on mushroom productivity and compost quality (Table 1). Each substrate contained the same total weight, 400 g to ensure comparability among treatments. To minimize experimental bias, three samples were prepared for each substrate formulation. Standardized cultivation procedures, incubation conditions, and harvesting methods were applied across all treatments to ensure that observed differences resulted primarily from substrate composition rather than management practices.

Table 1: Experimental Setup for the Four Substrate Treatments

Treatment	Banana leaves (%)	Sugarcane bagasse (%)
T1	100	0
T2	0	100
T3	66.7	33.3
T4	33.3	66.7

2.3 Materials Collection and Preparation

Mature, uncontaminated banana leaves were collected from Mabibo Market and washed to remove external contaminants (figure 2a). Fresh sugarcane bagasse from local juice vendors was also washed to remove residual sugars (figure 2b). Both materials were cut into 2–4 cm pieces, and shade-dried before formulation. Drying improved storage stability, reduced microbial deterioration, and enabled accurate weighing, while uniform particle size promoted consistent mixing, better substrate structure, and improved aeration during oyster mushroom cultivation.

Figure 2: Substrate Preparation, (a) Banana Leaves and (b) Sugarcane Bagasse

(a)

(b)

2.4 Substrate Characterization

An analytical balance (Analytical model GH-200) was used to weigh material samples and measure moisture content during characterization. Moisture content was determined gravimetrically by drying samples at 105°C until constant weight. Substrate pH was measured using a calibrated digital pH meter after preparing a 1:10 (w/v) substrate water suspension.

Total organic carbon was determined using the Walkley–Black wet oxidation method, whereas total nitrogen was measured using the Kjeldahl digestion procedure. The carbon to nitrogen (C:N) ratio was calculated by dividing total organic carbon by total nitrogen. These analyses provided baseline information for evaluating the influence of substrate properties on mushroom growth and compost quality.

2.5 Preparation of Mushroom Substrates

The prepared banana leaves and sugarcane bagasse were weighed according to the treatment proportions shown in table 1. Water was gradually added until substrate moisture reached approximately 65–70%, a range considered suitable for oyster mushroom cultivation (Bellettini et al., 2019; Wiesnerová et al., 2023). Substrates were pasteurized by dry heat at 105 °C for 30 minutes in the oven to suppress competing microbes, then cooled to room temperature in a sterile setting.

Mushroom spawn was integrated into the pasteurized media under aseptic conditions using thorough mixing to achieve uniform mycelial distribution, then packed into perforated polyethylene bags to allow gas exchange for aerobic fungal respiration. Bagged substrates were transferred to a dedicated incubation facility characterized by total darkness and regulated ventilation (figure 3). During this spawn-run phase, mycelium secretes celluloses and hemicellulases that metabolize the carbon and nitrogen reserves in the agricultural waste, progressing to a dense white mycelial mat that transforms the loose fibres into a cohesive, biologically active block ready for pinhead formation (Kumla et al., 2020; Nurfitri et al., 2021). Colonization was monitored daily, and the number of days required for complete substrate colonization was recorded. Mature Oyster mushrooms were harvested when caps were fully expanded but before curling at the edges, by gently twisting and pulling clusters to avoid damaging the substrate. Fresh weight was recorded immediately.

Figure 3. Incubation and Mycelium Development Inside Substrate Bags

2.6 Evaluation of Mushroom Performance

Mushroom performance was assessed using both growth and quality parameters. Colonization time was recorded as the number of days required for complete mycelial coverage of the substrate, while biological efficiency (BE) was calculated as:

$$BE(\%) = \frac{\text{Fresh mushrooms harvested weight}}{\text{Dry substrate weight}} \times 100$$

Fresh mushrooms from each treatment were analyzed for cap diameter, moisture content, ash content, crude protein, and pH. Moisture content of harvested mushrooms was determined by oven-drying at 105 °C to constant weight. Ash content was determined from incinerated dried samples at 550 °C in a muffle furnace for 4 hours. Crude protein was determined by the Kjeldahl method and estimated by multiplying percentage nitrogen by a conversion factor of 6.25.

2.7 Biofertilizer Production and Characterization

After the first flush was harvested, the residual substrate from each of the four treatments (400 g initial dry mass per treatment) was sampled for laboratory analysis to assess its suitability as an organic soil amendment. Samples were oven-dried at 95 °C for 24 h and grounded to a fine powder before analysis. pH was measured in a 1:10 (w/v) suspension of 10 g dried sample in 100 mL distilled water, allowed to stand for 30 minutes, using a digital pH meter calibrated against pH 4.0 and pH 7.0 buffers. Total organic carbon was determined by the Walkley–Black wet oxidation method, in which 1 g of sample was oxidised with 10 mL of 1 N potassium dichromate and 20 mL of concentrated sulphuric acid for 30 minutes, and the residual dichromate back titrated against 0.5 N ferrous ammonium sulphate using diphenylamine indicator against a reagent blank. Total nitrogen was determined by the Kjeldahl method, in which 5 g of sample was digested with 5 g catalyst and 20 mL of concentrated sulphuric acid at 230 °C for 2 hours, distilled with 40% sodium hydroxide into 4% boric acid, and the distillate titrated against 0.1 N hydrochloric acid using methyl red indicator. Phosphorus was extracted from 5 g of sample with 20 mL of diluted Mehlich-2 extractant, shaken for 5 minutes and filtered, and determined instrumentally. Potassium determined by flame photometry following digestion of 2 g of sample in a nitric-perchloric acid mixture, with quantification against a calibration curve prepared from potassium standards of known concentration. The carbon-to-nitrogen ratio was computed as the ration of total carbon and total nitrogen, and interpreted relative to the corresponding ratio of the initial substrate rather than as an absolute maturity threshold.

2.8 Statistical Analysis

All experimental data were subjected to descriptive statistical analysis to summarize substrate characteristics, mushroom productivity, and biofertilizer quality. Statistical analyses were performed usinng IBM SPSS Statistics version 29, while graphical illustrations were prepared using Microsoft Excel.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Characteristics of Substrates

The physicochemical properties of cultivation substrates are among the most important factors influencing mushroom productivity because they determine nutrient availability, moisture retention, microbial activity, and enzymatic degradation of lignocellulosic materials (Hoa et al., 2015; Bellettini et al., 2019; Wiesnerová et al., 2023). Prior to inoculation, the four substrate formulations were characterized to determine their suitability for *Pleurotus ostreatus* cultivation (Table 2). Moisture content varied from 61% to 70%**,** with sugarcane bagasse retaining considerably more water than banana leaves likely due to its porous, fibrous structure, creating suitable condition for *Pleurotus ostreatus* (Chang & Miles, 2004).

All substrate treatments were slightly alkaline, with a narrow pH range of 7.7–7.8. This limited variation suggests that initial pH was unlikely to account for the observed differences in mushroom performance. Although the commonly reported optimum for *Pleurotus* mycelial growth is approximately pH 5.5–6.5, oyster mushrooms can successfully colonize moderately alkaline substrates. Khan et al. (2013) reported favourable colonization, early primordia formation, and yield at pH 7.8. Furthermore, moderate alkalinity can provide a selective advantage during incubation by restricting certain contaminating fungi and bacteria without substantially inhibiting *Pleurotus* development (Casteliano et al., 2022). Thus, the measured pH was acceptable for cultivation and may have contributed to contamination control.

The main chemical contrast was between the nitrogen-rich banana leaves and carbon-rich bagasse. T1 contained 1.7% N and had a C:N ratio of 24:1, whereas T2 contained only 0.6% N and had a ratio of 86:1. Nitrogen supports fungal protein and enzyme synthesis, while a very high C:N ratio can delay degradation even where carbon is abundant (Dias et al., 2012). Blended substrates moderated this imbalance whereby T3 had 1.4% N and a C:N ratio of 32:1, while T4 had 1.2% N and a ratio of 40:1. These values show that banana leaves improved nutrient availability, while bagasse contributed structural carbon and porosity. Substrate performance therefore depended on both composition and physical arrangement, consistent with factors identified for *Pleurotus* cultivation (Bellettini et al.,2019; Wan Mahari et al., 2020; Alves da Silva et al., 2025, Bragadeeswaran et al., 2025).

The observed improvements from blended substrate support the growing body of evidence that agricultural residues should not be used individually but rather according to their complementary characteristics. Previous studies have shown that blending complementary agricultural residues can improve oyster mushroom substrates by moderating the carbon-to-nitrogen ratio and increasing the availability of essential nutrients. Combining coarse, carbon-rich materials with nitrogen-rich biomass may also improve substrate structure, particularly porosity, aeration, and moisture retention, thereby supporting mycelial colonization and fruiting-body production (Hoa et al., 2015; Bellettini et al., 2019; Gebru et al., 2024). However, these benefits depend on the proportions and physicochemical characteristics of the materials used, because excessive moisture or nitrogen can restrict oxygen availability and inhibit mycelial development.

Table 2: Physicochemical Characteristics of Substrates Before Inoculation

Parameter	T1	T2	T3	T4
Moisture content (%)	61.01	70.00	66.00	68.00
pH	7.8	7.7	7.8	7.7

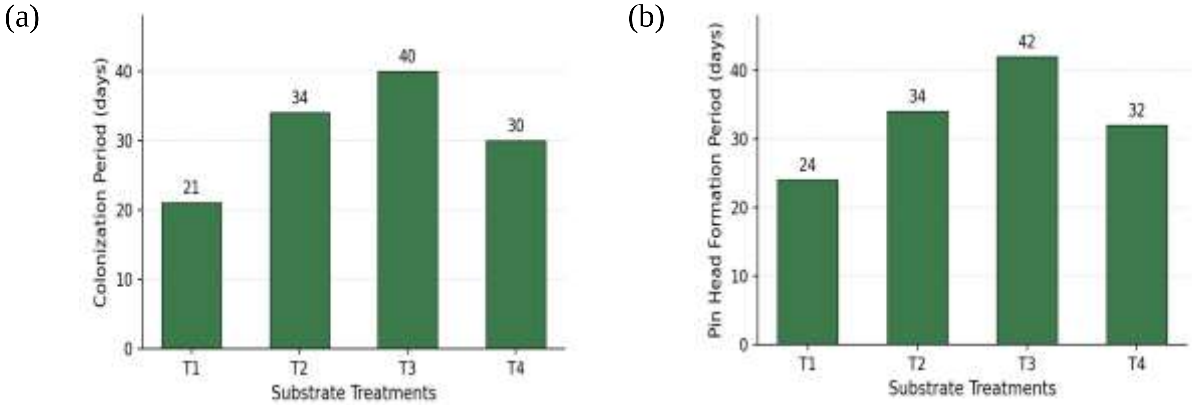
Parameter	T1	T2	T3	T4
Total organic carbon (%)	41	52	46	48
Total nitrogen (%)	1.7	0.6	1.4	1.2
C:N ratio	24:1	86:1	32:1	40:1

3.2 Mycelial Colonization and Pinhead Formation

Mycelial colonization differed markedly among treatments (Figure 4). T1 colonized most rapidly, possibly because its softer texture, lower C:N ratio, and reduced lignin content facilitated enzymatic degradation and nutrient accessibility. Conversely, although T3 had the most balanced C:N ratio, it required the longest periods for completing colonization and pinhead formation, 40 and 42 days, respectively. This result indicates that nutritional composition alone cannot explain colonization dynamics. Substrate bulk density, particle size, compaction, porosity, moisture distribution, and oxygen diffusion also regulate hyphal extension and mushroom development (Bellettini et al., 2019; Silva et al., 2024). The greater proportion of banana leaves in T3 may have produced a denser substrate structure, reducing pore spaces and gaseous exchange despite favourable nutrient availability. However, since compaction and porosity were not measured directly, this explanation should be considered a plausible mechanism requiring experimental confirmation.

T4, with a higher bagasse proportion, benefited from improved porosity and formed pinheads earlier than T2 or T3 despite a higher C:N ratio. Thus, a chemically balanced substrate may still colonize slowly when particle packing reduces oxygen transfer. Similar contrasts between nutrient enrichment and substrate structure have been reported for residue mixtures used in oyster mushroom production (Adebayo et al., 2009; Frimpong-Manso et al., 2011). These observations emphasize the importance of simultaneously optimizing both chemical and physical substrate properties during formulation.

Figure 4: Number Days for (a) Colonization and (b) Pin head Formation



3.3 Mushroom Yield and Quality

Mushroom yield is one of the most important indicators for evaluating the effectiveness of cultivation substrates because it reflects the efficiency with which fungal mycelia convert lignocellulosic biomass into edible fruiting bodies. Results revealed that, substrate composition significantly influenced biological efficiency, mushroom size, protein content, mineral composition, and overall quality of the harvested mushrooms. These findings demonstrate that optimizing substrate formulation is essential not only for maximizing production but also for improving the nutritional value of mushrooms while enhancing the subsequent utilization of spent mushroom substrate.

Table 3 present the biological efficiency and quality parameters of mushrooms harvested from each treatment. Biological efficiency (BE) ranged from 51% to 60% in the first flush, all within the generally acceptable range for Oyster mushroom production (Chang and Miles, 2004). T3 achieved the highest biological efficiency (60%) and the largest cap diameter (8.0 cm), followed by T1 (55%, 7.5 cm). The result indicates that the 2:1 blend supported more effective conversion of dry substrate into fresh edible biomass, even though its colonization was slow. The banana leaves supplied nitrogen and minerals, while the smaller bagasse fraction probably preserved pore space and prevented complete collapse of the substrate during fruiting. In contrast, pure bagasse provided good structure but insufficient nitrogen, while pure leaves supported rapid growth but offered less structural stability. Recent investigations using the same residue types similarly found that mixed banana leaves and bagasse can support improved mushroom growth and lignocellulose utilization (Alves da Silva et al., 2025; Bragadeeswaran et al., 2025).

The moisture content of harvested mushrooms ranged from 88.1% to 89.4%**,** with only minor differences among treatments. Fresh oyster mushrooms typically contain between 85% and 90% water, indicating that all treatments produced mushrooms within internationally accepted quality standards. Chang and Miles, 2004; Khandakar et al., 2019 suggested that, substrate composition influenced yield and protein more strongly than fresh-tissue water content or acidity.

T3 produced the largest caps (8.0 cm) and the highest crude protein content (31.0% on a dry-weight basis), whereas T2 yielded the smallest caps (6.0 cm) with lowest protein content (24.0%). This pattern suggests that the comparatively greater nitrogen availability in T3 supported fruiting-body development and fungal protein synthesis. However, substrate structure, carbon availability, mineral composition, and environmental conditions may also have influenced these outcomes. The 31.0% protein concentration falls within the broad dry-matter range reported for cultivated oyster mushrooms, confirming that low-value agricultural residues can be biologically converted into nutrient-dense food (Hoa et al., 2015; Effiong et al., 2024). T1 recorded the highest ash content (9.0%), possibly reflecting greater mineral availability from banana leaves. Nevertheless, because ash represents total inorganic matter rather than individual elements, mineral profiling would be required to confirm which nutrients caused this increase.

Table 3: Biological Efficiency and Quality Parameters of Harvested Mushrooms

Parameter	**T1**	**T2**	**T3**	**T4**
BE first flush (%)	55	51	60	53
Cap diameter (cm)	7.5	6.0	8.0	6.5
Moisture content (%)	89.4	88.7	88.9	88.1
Ash content (%)	9.0	6.0	8.2	7.4
Crude protein (%)	28.6	24.0	31.0	26.5
Mushroom pH (%)	6.6	5.9	6.4	6.1

3.4 Biofertilizer Quality and Nutrient Recovery from Spent Mushroom Substrate

A defining feature of integrated biomass valorization is the production of multiple valuable outputs from a single biological resource. In conventional mushroom production, spent mushroom substrate (SMS) is often treated as a residual material requiring disposal. Within a circular bioeconomy, however, SMS constitutes a secondary resource that can undergo further valorization rather than representing the end of

the production chain. Oyster mushroom cultivation degrades only part of the substrate's cellulose, hemicellulose, and lignin; consequently, substantial organic matter, fungal biomass, and mineral nutrients remain after harvesting (Grimm & Wösten, 2018; Martín et al., 2023). Through controlled composting, this residual biomass can be stabilized and transformed into an organic soil amendment, thereby recovering nutrients, extending the productive life of agricultural residues, and reducing disposal requirements. In the present study, the chemical characteristics of compost produced from spent mushroom substrates were evaluated to determine their suitability as biofertilizers. The parameters assessed included pH, total nitrogen, available phosphorus, available potassium, and C:N ratio (Table 4).
Compost pH ranged from 6.7 to 7.8, a near-neutral interval suitable for many soil applications. T3 retained the highest concentrations of N (1.5%), P (0.7%) and K (2.0%), followed by T1 for most nutrients. The relatively high potassium values in banana-containing treatments are consistent with the mineral composition of banana biomass. T2 produced the lowest N and P concentrations and retained the highest compost C:N ratio (22:1), confirming slower stabilization of the carbon-rich bagasse. Ratios around 10-20:1 are commonly associated with mature or well-stabilized compost (Bernal et al., 2009), although maturity should ideally be confirmed using additional indicators such as respiration, temperature, phytotoxicity and microbial stability
The joint assessment of mushroom and compost quality is important because the highest-yielding mushroom treatment does not automatically produce the most useful residue. In this experiment, however, T3 performed best at both stages: it produced the highest BE, cap diameter and protein content and retained the greatest N, P and K concentrations in the compost. This demonstrates a cascading value pathway in which the substrate supports food production and then remains useful as an organic soil amendment. Such integration can reduce waste disposal, recover nutrients and create additional value from the same biomass stream, which is central to principles of the circular bioeconomy (Grimm and Wösten, 2018; Wan Mahari et al., 2020).

Table 4. Chemical Characteristics of Compost Produced After Mushroom Harvesting

Parameter	T1	T2	T3	T4
pH	7.8	6.7	7.2	6.9
Total nitrogen (%)	1.3	1.0	1.5	1.2
Available phosphorus (%)	0.6	0.4	0.7	0.5
Available potassium (%)	1.7	1.5	2.0	1.6
C:N ratio	13:1	22:1	16:1	18:1

3.5 Implications for the Circular Bioeconomy, Sustainable Agriculture and Waste Management

This study demonstrates a circular-bioeconomy pathway in which banana leaves and sugarcane bagasse are converted by *Pleurotus ostreatus* into nutritious mushrooms and subsequently into biofertilizer, extending biomass use and creating two marketable products. Evidence supports this cascade: mushroom-forming fungi transform low-value lignocellulosic wastes into food, while spent mushroom substrate remains suitable for compost and other applications (Grimm & Wösten, 2018; Martín et al., 2023). The superior 2:1 banana-leaf-to-bagasse mixture further shows that substrate optimization should target whole system performance mushroom biological efficiency plus fertilizer quality—not yield alone. The approach can reduce local dumping while producing edible protein and organic fertilizer from materials with little initial market value. Nutrient-rich spent *Pleurotus* substrate contains valuable elements, supporting its soil-amendment potential (Miśkiewicz et al., 2025). Therefore, decentralized adoption of this system can reduce residue dumping, strengthen food security, restore soil fertility, create employment, diversify enterprise income, and promote climate-resilient agriculture in Tanzania.

4. CONCLUSION AND RECOMMENDATION

This study establishes banana leaves and sugarcane bagasse as valuable resources for integrated oyster mushroom and biofertilizer production in Tanzania. Substrate characterization showed that nitrogen-rich banana leaves accelerated mycelial growth, while carbon-rich bagasse improved aeration and structural stability. Their combination therefore created favourable conditions for efficient biological conversion. Among the tested formulations, the 2:1 banana-leaf-to-bagasse ratio delivered the strongest overall performance, achieving the highest biological efficiency, greater cap diameter, improved mushroom protein content, and superior biofertilizer quality. Its spent substrate contained elevated nitrogen, phosphorus, and potassium levels, alongside a mature carbon-to-nitrogen ratio appropriate for soil application. These outcomes demonstrate that optimized blending enhances both food production and nutrient recovery across the complete processing chain. Therefore, this closed-loop approach can reduce uncontrolled residue disposal, restore soil fertility, strengthen food security, and support climate-smart agriculture. It offers municipalities, educational institutions, farming communities, and agro-processing enterprises an accessible model for sustainable waste valorization, income generation, and resource-efficient agricultural development.

The findings also support several targets within the United Nations Sustainable Development Goals (SDGs)**.** By producing edible mushroom from agricultural residues, the study contributes to SDG 2 through improved food availability. By promoting resource-efficient waste management and reducing landfill disposal, it advances SDG 3 & 11. The emphasis on agricultural waste recovery and nutrient recycling aligns closely with SDG 12 while reducing open burning and improving soil carbon contribute to SDG 13. Lastly, the use of organic biofertilizers to improve soil quality supports SDG 15 by promoting sustainable management of terrestrial ecosystems.

The study assessed four formulations, first-flush biological efficiency, and chemical biofertilizer properties under controlled conditions at one location. Missing replicate data, complete ANOVA results, composting dynamics, microbial quality, pathogen safety, crop responses, and economic assessment limit broader recommendations. Long-term field trials should measure crop productivity, soil biodiversity, nutrient cycling, and carbon sequestration. Economic feasibility, life-cycle impacts, greenhouse-gas emissions, and resource efficiency also require evaluation. Molecular analysis and stakeholder-supported pilot demonstrations should validate composting mechanisms, scalability, profitability, safety, and environmental performance before widespread adoption. Also future researches should test diverse Tanzanian residues, including maize stalks, rice straw, cassava peels, coconut husks, coffee husks, and sisal waste.

AKNOWLEDGEMENT

I express my sincere acknowledgement to Water Institute for providing Laboratory facilities and technical support throughout this study. I am also grateful to vendors at Mabibo market and Ubungo sugarcane juice processors for providing the agricultural residues used in this study.

REFERENCES

1. Adebayo G.J., Omolara B.N., Toyin A.E., “Evaluation of yield of oyster mushroom (Pleurotus pulmonarius) grown on cotton waste and cassava peel”, African Journal of Biotechnology, 2009, 8 (2), 215–218.
2. Alves da Silva M., Pereira J.R., Santos L.F., “Blended agricultural residues for oyster mushroom cultivation and biodegradation efficiency”, Journal of Agricultural Waste Management, 2025, 14 (1), 33–45.
3. Alves da Silva S., Zárate-Salazar J.R., Pereira Monteiro R.E., de Medeiros R.L., de Souza H.A.N., Dias B.O., Pereira F.O., “Assessment of the productive and biodegradative non-enzymatic performance of Pleurotus mushrooms grown on agricultural wastes of sugarcane bagasse and banana leaves”, World Journal of Microbiology and Biotechnology, 2025, 41, 157.
4. Ayeleru O.O., Dlova S., Akinribide O.J., Ntuli F., Kupolati W.K., Marina P.F., Olubambi P.A., “Challenges of circular economy implementation in Africa”, Sustainability, 2022, 14 (3), 1145.
5. Babu S., Rathore S.S., Singh R., Kumar S., Singh V.K., Yadav S.K., Yadav V., Raj R., Yadav D., Shekhawat K., Wani O.A., “Exploring agricultural waste biomass for energy, food and feed production and pollution mitigation: A review”, Bioresource Technology, 2022, 360, 127566.
6. Baitu G.P., Idress K.A.D., Gadalla O.A.A., Öztekin Y.B., “Mapping biomass energy potential from agricultural residues in Tanzania”, In 15th International Congress on Agricultural Mechanization and Energy in Agriculture (458, 84–93). Springer, 2024.
7. Bellettini M.B., Fiorda F.A., Maieves H.A., Teixeira G.L., Ávila S., Hornung P.S., Júnior A.M., Ribani R.H., “Factors affecting mushroom Pleurotus spp. cultivation”, Brazilian Archives of Biology and Technology, 2019, 62, e19180335.
8. Bernal M.P., Alburquerque J.A., Moral R., “Composting of animal manures and chemical criteria for compost maturity assessment”, Bioresource Technology, 2009, 100 (22), 5444–5453.
9. Bitew T.D., Mandefro S.A., “Substrate optimization for cultivation of Pleurotus ostreatus on lignocellulosic wastes (coffee, sawdust, and sugarcane bagasse) in Mizan–Tepi University, Ethiopia”, Journal of Applied Biology and Biotechnology, 2018, 6 (4), 14–20.
10. Bragadeeswaran S., Kumar R., Balasubramanian P., “Nutritional evaluation of oyster mushrooms cultivated on blended banana leaves and sugarcane bagasse substrates”, Asian Journal of Agricultural Research, 2025, 19 (2), 122–130.
11. Bragadeeswaran T., Pravi P.R., Varsnica B., Shree G.V., “Cultivation of oyster mushroom using sugarcane bagasse and dried banana leaves”, AIP Conference Proceedings, 2025, 3267, 020026.
12. Carvalho C.S.M., Aguiar L.V.B., Sales-Campos C., Minhoni M.T.A., Andrade M.C.N., “Applicability of the use of waste from different banana cultivars for the cultivation of the oyster mushroom”, Brazilian Journal of Microbiology, 2012, 43 (2), 819–826.
13. Casteliano G.A., et al., “Alkalinization and moist-heat treatments of substrates for cultivation of edible mushrooms in pupunha and cocoa residues”, African Journal of Agricultural Research, 2022.
14. Chang S.T., Miles P.G., “Mushrooms: Cultivation, nutritional value, medicinal effect, and environmental impact (2nd ed.)”, CRC Press, 2004.
15. De Bonis M., Sambo P., Zanin G., Cardarelli M., Nicoletto C., “Spent Pleurotus substrate as organic fertilizer to improve yield and soil fertility: The case of baby leaf lettuce production”, Journal of the Science of Food and Agriculture, 2025, 105 (11), 5874–5886.

16. De Medeiros R.L., Andrade G.M., Crispim R.B., dos Santos Silva N.N., Alves da Silva S., de Souza H.A.N., Zárate-Salazar J.R., de Medeiros F.D., Dantas C.E.A., Viera V.B., e Silva A.L., Tavares J.F., Pereira F.O., "Nutritional and antioxidant potential of Pleurotus djamor produced on agronomic wastes of banana leaves and sugarcane bagasse", Brazilian Journal of Microbiology, 2024, 55 (2), 1117–1129.
17. Debrah J.K., Teye G.K., Dinis M.A.P., "Barriers and challenges to waste management hindering the circular economy in sub-Saharan Africa", Urban Science, 2022, 6, 57.
18. Dehariya P., "Sustainable mushroom cultivation using agricultural waste materials", International Journal of Environmental Sciences, 2013, 3 (5), 145–152.
19. Dias Nunes M., da Luz J.M.R., Paes S.A., Ribeiro J.J.O., Silva M.C.S., Kasuya M.C.M., "Nitrogen supplementation on the productivity and chemical composition of oyster mushroom", Journal of Food Research, 2012, 1 (2), 113–119.
20. Effiong M.E., et al., "Assessing the nutritional quality of Pleurotus ostreatus cultivated on different substrates", 2024.
21. Frimpong-Manso J., Obodai M., Dzomeku M., Apertorgbor M.M., "Influence of rice husk on biological efficiency and nutrient content of Pleurotus ostreatus", International Food Research Journal, 2011, 18, 249–254.
22. Gebru H., et al., "Growth and yield performance of Pleurotus ostreatus cultivated on different agricultural residues and substrate mixtures", Mycobiology, 2024.
23. Gottinger A., Ladu L., Quitzow R., "Studying the transition towards a circular bioeconomy—A systematic literature review on transition studies and existing barriers", Sustainability, 2020, 12 (21), 8990.
24. Grimm D., Wösten H.A.B., "Mushroom cultivation in the circular economy", Applied Microbiology and Biotechnology, 2018, 102 (18), 7795–7803.
25. Hoa H.T., Wang C.L., Wang C.H., "The effects of different substrates on the growth, yield, and nutritional composition of two oyster mushrooms", Mycobiology, 2015, 43 (4), 423–434.
26. Huwel N., Mrema J., Kavishe M., "Effects of mixed banana leaves and sugarcane bagasse substrates on oyster mushroom cultivation", Tanzania Journal of Agricultural Sciences, 2020, 19 (2), 55–63.
27. Joseph C.O., Makwinja F., "Effects of substrate–supplement interactions on yield performance of oyster mushroom (Pleurotus ostreatus)", Tanzania Journal of Science, 2026, 52 (1), Article 6.
28. Kardung M., et al., "Development of the circular bioeconomy: Drivers and indicators", Sustainability, 2021, 13 (1), 413.
29. Kaza S., Yao L., Bhada-Tata P., Van Woerden F., "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050", World Bank, Washington, DC, 2018.
30. Khan M.W., et al., "Effect of different levels of lime and pH on mycelial growth and production efficiency of oyster mushroom", Pakistan Journal of Botany, 2013, 45 (1), 297–302.
31. Khanna M., Nhamo G., Chikodzi D., "Agricultural waste management and circular bioeconomy opportunities in Sub-Saharan Africa", Resources, Conservation and Recycling, 2024, 201, 107245.
32. Kumla J., et al., "Cultivation of mushrooms and their lignocellulolytic enzyme production through the utilization of agro-industrial waste", Molecules, 2020, 25 (12), 2811.
33. Lin S.Y., Holden N.M., Thongdara R., Silalertruksa T., Gheewala S.H., Prapaspongsa T., "Circular economy models of sugarcane biorefinery towards carbon neutrality and environmental sustainability", Sustainable Production and Consumption, 2025, 59, 305–324.

34. Martín C., et al., “Spent substrate from mushroom cultivation: exploitation potential toward various applications and value-added products”, 2023.
35. Mhando J.A., Mwakatobe A.R., Mrema J.P., “Utilization of banana leaves as substrate for oyster mushroom cultivation”, African Journal of Agricultural Research, 2020, 15 (7), 1015–1023.
36. Miśkiewicz K., et al., “Agri-food wastes as substrates for oyster mushroom cultivation and their agricultural potential”, Scientific Reports, 2025.
37. Mtui G.Y.S., “Evaluation of sugarcane bagasse and banana leaves as substrates for oyster mushroom cultivation”, Tanzania Journal of Science, 2020, 46 (4), 765–774.
38. Mujtaba M., et al., “Lignocellulosic biomass from agricultural waste to the circular economy: A review with focus on biofuels, biocomposites and bioplastics”, Journal of Cleaner Production, 2023, 402, 136815.
39. National Environment Management Council., “National state of the environment report for Tanzania”, NEMC, 2021.
40. Nurfitri N., Mangunwardoyo W., Saskiawan I., “Lignocellulolytic enzyme activity patterns of three white oyster mushroom strains during mycelial growth and fruiting-body development”, Journal of Physics: Conference Series, 2021, 1725, 012056.
41. Rao M.M., Botsa S.M., Rao T.P., Goddu S.R., Vijayasanthi C., “A comprehensive review on agricultural waste production and onsite management with circular economy opportunities”, Discover Sustainability, 2024, 5, 288.
42. Richard E.N., et al., “Two-stage banana leaves waste utilization towards mushroom production and biogas generation”, Biomass Conversion and Biorefinery, 2020.
43. Sagawa T., Yokoyama S., Imou K., “Bagasse cogeneration in Tanzania: Utilization of fibrous sugarcane waste”, International Energy Journal, 2008, 9, 175–180.
44. Sileshi G.W., et al., “Consolidating global residue data from agriculture, fisheries, forestry and related industries”, Earth System Science Data, 2025, 17, 369–391.
45. Silva M., et al., “Pre- and postharvest strategies for Pleurotus ostreatus: A review”, Journal of Fungi, 2024, 10, 342.
46. Tan E.C.D., Lamers P., “Circular bioeconomy concepts—A perspective”, Frontiers in Sustainability, 2021, 2, 701509.
47. University College London., “Solid waste management and urban sanitation in Dar es Salaam”, UCL Press, 2017.
48. Venkatesh G., “Circular bio-economy—Paradigm for the future: Systematic review of scientific journal publications from 2015 to 2021”, Circular Economy and Sustainability, 2022, 2, 231–279.
49. Wan Mahari W.A., Peng W., Nam W.L., Yang H., Lee X.Y., Lee Y.K., Liew R.K., Ma N.L., “A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry”, Journal of Hazardous Materials, 2020, 400, 123156.
50. Wiesnerová L., Hřebečková T., Jablonský I., Koudela M., “Effect of different water contents in the substrate on cultivation of Pleurotus ostreatus”, Folia Horticulturae, 2023, 35 (1), 25–31.
51. World Bank., “Africa's waste management outlook: Addressing open burning and greenhouse gas emissions”, World Bank, 2022.