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Research Progress on the Comprehensive Utilization of Edible Fungus Residue Resources

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Abstract

The rapid development of the edible fungus industry has generated substantial amounts of spent mushroom substrate (SMS), and improper disposal of such residues has caused environmental pollution and resource wastage. This study systematically reviews resource utilization pathways for SMS in agricultural recycling, industrial energy conversion, and other fields. It analyzes the current challenges in the resource utilization of edible fungal residues and proposes recommendations for the future development of the sector, aiming to provide theoretical references for the sustainable and eco-friendly use of SMS.

Keywords

Spent mushroom substrate; resource recovery utilization; circular agriculture; sustainable development.

1. Introduction

Edible fungi represent a diverse group of fungi consumable by humans, encompassing a wide variety such as shiitake, oyster mushroom, and enoki mushroom. They hold significant importance in China's agricultural economy and are acclaimed as the "white agriculture" [1, 2]. Spent mushroom substrate (SMS), also referred to as mushroom residue or waste mushroom compost, is the residual cultivation medium remaining after the harvest of edible fungi. It is rich in mycelial residues, crude fiber, protein, and various trace elements [3, 4]. With the rapid development of China's edible mushroom industry, the total annual output has exceeded 30 million tons in recent years and continues to increase annually. The accumulation of substantial quantities of SMS not only occupies land but also leads to environmental pollution and resource wastage. Therefore, systematically synthesizing the pathways for the resource utilization of SMS and exploring efficient, green, and sustainable comprehensive utilization models are of great significance for promoting the recycling of agricultural waste, advancing the development of green agriculture, and contributing to the achievement of the "Dual Carbon" goals.

2. Problems Arising from the Accumulation of Spent Mushroom Substrate

SMS possesses a loose, porous structure and is rich in mycelial protein, polysaccharides, and other underutilized nutrients, making it a recyclable natural organic material. However, due to the current low utilization rate of SMS in China, many growers resort to methods such as incineration, discarding, or simple crushing and field-returning post-harvest. These practices, to some extent, damage the ecological environment, and the pathogens that proliferate can jeopardize the health of humans and livestock. Consequently, the scientific, standardized, high-value, and resource-oriented treatment and secondary utilization of SMS are crucial for protecting the ecological environment, reducing resource waste, and promoting the sustainable development of the edible mushroom industry [5].

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3. Pathways for the Resource Utilization of Spent Mushroom Substrate

3.1. Agricultural Recycling

3.1.1. Secondary Cultivation Techniques Using Spent Mushroom Substrate

Numerous studies have shown that the incompletely utilized cellulose, hemicellulose, and residual nutrients from mycelia in SMS can partially or fully substitute raw materials in the cultivation of other edible fungi, achieving "cultivation using waste." For instance, Zhao Shuguang et al. utilized appropriately treated SMS from *Pleurotus eryngii* to cultivate *Agaricus bisporus*, finding that this method reduced raw material costs and shortened the growth cycle [6]. Wang Chunlin et al. optimized the substrate for secondary cultivation through quantitative analysis of the nutritional components of SMS. This not only improved the physicochemical properties of the SMS but also created more suitable conditions for microbial fermentation, enhancing the utilization rate of SMS and increasing the yield and quality of edible fungi, thereby demonstrating significant economic and environmental benefits [7]. Zhang Weirui et al. investigated the effects of adding an extract from enoki mushroom SMS to solid and liquid culture media on the mycelial growth and laccase activity of *Pholiota nameko*. They found that enoki mushroom SMS is suitable for the mycelial growth of *P. nameko* and can replace a certain proportion of wood chips in its cultivation, thereby improving resource utilization efficiency and reducing the input of raw materials for edible fungus cultivation [8].

3.1.2. Application Status of Spent Mushroom Substrate as Organic Fertilizer

The production of organic fertilizer from SMS plays a significant role in soil improvement, crop yield increase, and enhancement of agricultural product quality [9]. Cheng Tuo adopted a fertilization method combining base fertilizer and topdressing to explore the effects of SMS-based organic fertilizer on the growth of passion fruit, soil physicochemical properties, and microbial community structure. The study verified that using SMS as organic fertilizer induces a series of positive changes in soil physicochemical properties, significantly regulates the fruit growth and development process, and results in a high sugar-acid ratio and superior flavor quality [10]. Zeng Zhenji et al. produced organic fertilizer by fermenting local SMS, sheep manure, and tobacco waste with microbial inoculants. The total nutrient content reached 9.34%, and it demonstrated good yield-increasing effects on crops such as pomelo, honey pomelo, navel orange, peanut, sweet potato, bitter gourd, oil tea, and tea [11]. Li Hetong et al. studied the effects of organic fertilizers produced from different ratios of chicken manure and SMS under varying composting durations on sugarcane growth, providing a reference for identifying suitable SMS-based organic fertilizer formulations for sugarcane cultivation [12].

3.1.3. Use of Spent Mushroom Substrate as a Cultivation Medium for Plants

SMS can inhibit plant diseases, promote plant growth, and offer considerable economic benefits, making it an ideal cultivation substrate for horticultural plants and other crops [13]. Huang Shuiying et al. prepared a seedling substrate with loose, porous structure and relatively uniform particle size by low-temperature baking coupled with high-temperature pyrolysis of oyster mushroom SMS. This substrate promoted faster germination speed and stronger growth vitality in sorghum and pak choi [14], demonstrating greater feasibility and broader application prospects compared to commercial substrates. Guo Jingyu et al. investigated the effects of different types and treatment methods of SMS on the mycelial growth and yield of *Stropharia rugosoannulata*. They found that SMS from *Pholiota microspora*, which has a high fat content, could replace traditional cultivation substrates for *S. rugosoannulata* production after sterilization, providing a basis for SMS reuse and low-cost cultivation, thereby promoting the sustainable development of the *S. rugosoannulata* industry [15]. Luo Hailing studied the effects of different application rates of SMS from *Pleurotus* spp. cultivated on grass substrate added to soil on the growth of 'Laimu No.1' seedlings. The conclusion was that adding this SMS

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to soil benefited seedling growth, with the most significant effect observed at an application rate of 75.0 $g \cdot kg^{-1}$ [16].

3.1.4. Application of Spent Mushroom Substrate in Ecological Remediation

While researching the screening of SMS with high laccase content and its dye decolorization effect, Liu Zilu et al. pointed out that SMS from industrial-scale *Pleurotus eryngii* cultivation possesses high laccase activity and can be used for the decolorization and detoxification of dye wastewater containing substances like malachite green and reactive brilliant blue [17]. Additionally, returning SMS to fields can improve the physicochemical properties of saline-alkali soil and enhance soil fertility. Research has found that applying SMS in combination with aluminum sulfate significantly improves nutrient status in paddy fields on saline-alkali land, leading to marked increases in organic matter, available phosphorus, and alkali-hydrolyzable nitrogen content. The combined application of amendments and SMS optimizes soil properties in newly reclaimed saline-alkali paddy fields, increasing soil cation exchange capacity (CEC), available potassium, and soil organic carbon (SOC) content, while reducing soil acidification and exchangeable sodium percentage (ESP) [18]. Thus, SMS serves as an efficient and environmentally friendly ecological remediation material for addressing water pollution and ameliorating saline-alkali cropland.

3.1.5. Feed Application of Spent Mushroom Substrate and its Use in Animal Husbandry

SMS holds broad development prospects in animal feed applications due to its high nutritional and medicinal value. Through appropriate processing, it can be developed into feed for various livestock and poultry, improving their production performance and enhancing immune and antioxidant capacities. Certain types of SMS can also improve digestive system function, modulate gut microbiota structure, and enhance nutrient digestibility, demonstrating high application value in the breeding industry [19]. Long Yong, utilizing representative SMS types from Guizhou (such as from *Hypsizygus marmoreus* and *Flammulina velutipes*) and Chinese herbal medicine residues, developed a fattening FTMR (Full Total Mixed Ration) formula for black goats based on these unconventional feed resources. This provides a valuable reference for addressing issues such as shortage of feed ingredients, high rearing costs, and low economic returns in China's meat goat industry under intensive housing systems [20]. Duan Yulan et al., based on research into the nutritional requirements of beef cattle and processing technologies for concentrated feed supplements in large-scale beef cattle farming, contributed to the development of the beef cattle industry, improvement of domestic beef self-sufficiency, and reduction of import dependence through research on the development of composite biological feed from SMS and efficient, healthy breeding techniques [21].

3.2. Industrial and Other Applications of Spent Mushroom Substrate

In the industrial sector, SMS can be utilized for energy production through processes such as compression molding to prepare biomass solid fuels [22] or anaerobic digestion to produce biogas [23]. The residual mycelia in SMS are rich in bioactive components like polysaccharides, flavonoids, and enzymes, which can be extracted for use in developing functional products in pharmaceuticals, cosmetics, and other industries [24]. Concurrently, SMS can be composited with other materials to produce environmentally friendly products like lightweight building materials and packaging materials [25], thereby expanding its application scenarios in green industrial production.

In other application areas, SMS can be used as bedding in fermentation beds to improve animal housing environments; as a substrate for vermicomposting to facilitate organic matter conversion; for producing bio-based chemicals like ethanol; as a partial substitute for pulp raw materials in the paper industry; and as a passivation material for remediating pesticide-contaminated soils [26-27].

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4. Challenges and Problems in the Resource Utilization of Spent Mushroom Substrate

4.1. Weak Awareness of Agricultural Recycling

Currently, the edible mushroom industry primarily focuses on economic benefits. Producers, local governments, and farmers generally lack a systematic understanding of the resource attributes of SMS. Large quantities of SMS are indiscriminately discarded, incinerated, or simply returned to fields, leading not only to resource waste but also causing environmental pollution and fostering pests and diseases. Within the circular agriculture chain, SMS, as a key link in the "agricultural waste – edible fungus cultivation – SMS reuse" cycle, has not yet formed a closed loop. Public awareness and social participation urgently need enhancement.

4.2. Technical Bottlenecks and Lack of Standardization

The physicochemical properties of SMS are significantly influenced by cultivation substrates, fungal strains, harvest flushes, and regional variations, resulting in considerable compositional fluctuations that hinder the development of large-scale, high-value utilization technologies. Presently, applications of SMS in areas such as feed, organic fertilizer, and substrate use are still at the laboratory or pilot scale, lacking efficient and low-cost common processing technologies. Furthermore, China has not yet established a unified system of standards for the classification, collection, pretreatment, and product quality of SMS, leading to unstable product quality and low market acceptance.

4.3. Poor Industry Chain Integration and Low Marketization

SMS generation is decentralized, resulting in high costs for collection, transportation, and storage, and a lack of large-scale collection, storage, and transportation systems. Downstream utilization enterprises are typically small in scale and geographically dispersed, failing to establish stable supply-demand cooperation mechanisms with upstream growers. Processed SMS products often have low added value, market channels are underdeveloped, and consumer acceptance of SMS-derived products is limited. Consequently, a complete and efficient market-driven industrial chain has not been formed, constraining the sustainable development of the SMS resource utilization industry.

5. Development Prospects and Outlook

To address the current challenges, future efforts in the resource utilization of spent mushroom substrate should advance towards systematization, standardization, and high-value development, as elaborated below:

5.1. Strengthening Top-Level Design and Policy Guidance

It is recommended to integrate SMS resource utilization into agricultural green development plans. Through fiscal subsidies, tax incentives, technology promotion, and other measures, enterprises, cooperatives, and farmers should be encouraged to participate in the collection, storage, and primary processing of SMS. Efforts should be made to promote a collaborative mechanism involving "government guidance, enterprise leadership, and farmer participation," improve regional collection networks, and reduce circulation costs.

5.2. Enhancing Technological Innovation and Standard System Construction

Increased investment in research and development is essential, focusing on key technological breakthroughs such as rapid fermentation, component separation, and bioactive compound extraction from SMS, to develop high-value-added products like functional feeds, biochar, and composite materials. Simultaneously, acceleration in establishing national standards and

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industry specifications for SMS classification, harmless treatment, and product quality is crucial to promote standardized and quality-oriented industrial development.

5.3. Promoting Whole Industry Chain Integration and Market Cultivation

Support deep integration of "industry-university-research-application," encourage leading enterprises to drive progress, and build an integrated industrial chain encompassing "mushroom production – SMS recycling – processing and utilization – product application." Strengthen market cultivation and publicity to enhance the market recognition and competitiveness of SMS-based products like organic fertilizers and cultivation substrates, and expand their application scenarios in areas such as soil remediation, ecological agriculture, and green materials.

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References

[1] Kong Wei, Yuan Ruiqi, Kong Weiwei, et al. Overview of the History, Current Status, and Research Progress in Edible Fungus Strain Preservation. Edible Fungi of China, 2015, 34(05): 1-5.

[2] Zhang Hao, Zhang Huanshi, Wang Meng, et al. Research Progress on Edible Fungus Cultivation Techniques in China. Northern Horticulture, 2014, 5: 175-179.

[3] Peng Luoping. Reutilization of Edible Fungus Residue and Exploration of Future Utilization Directions. Industrial Microbiology, 2023, 53(3): 40-42.

[4] Wang Weixia, Zhang Zhiqi, Li Shuge, et al. Research Progress on the Resource Utilization of Edible Fungus Residue. Modern Horticulture, 2023, 46(13): 59-61.

[5] Zhang Yuan, Han Gensuo, Zhang Wenchao, et al. Comprehensive Utilization Pathways and Application Recommendations for Edible Fungus Residue. Northwest Horticulture, 2025, (09): 1-2.

[6] Zhao Shuguang, Meng Hua, Shi Liang, et al. Industrialized High-Efficiency Cultivation Techniques for Agaricus bisporus Using Pleurotus eryngii Residue as Substrate. Anhui Agricultural Science Bulletin, 2018, 24(18): 20-21.

[7] Wang Chunlin, Jia Guojun, Zhao Chendong. Key Techniques and Process Optimization for Secondary Cultivation Using Edible Fungus Residue. Contemporary Agricultural Machinery, 2025, (10): 58-59.

[8] Zhang Weirui, Liu Shengrong, Zhou Xiuzhao, et al. Effects of Flammulina velutipes Residue Extract on Mycelial Growth and Laccase Activity of Pholiota nameko. Modern Agricultural Science and Technology, 2024, (06): 33-36.

[9] Leng Peng, Liu Zhaobu, Li Xiqiang, et al. Research Progress on Production of Microbial Organic Fertilizer from Edible Fungus Residue. Hubei Agricultural Sciences, 2021, 60(S1): 17-19.

[10] Cheng Tuo. Effects of Edible Fungus Residue Organic Fertilizer on Soil and Fruit Quality in Passion Fruit Cultivation. Guizhou University, 2025.

[11] Zhenji Zeng, Chen Yixiang, Ling Hongtong, et al. Study on the Production of Organic Fertilizer from Edible Fungus Spent Substrate. Edible Fungi of China, 2015, 34(02): 56-59.

[12] Li Hetong, Wei Rongyao, Nong Yanfeng, et al. Effects of Edible Fungus Residue Organic Fertilizer on the Growth of Sugarcane. Anhui Agricultural Science Bulletin, 2023, 29(22): 44-49.

[13] Qi Jun, Liu Sumei, Xu Hui, et al. Application of Edible Fungus Spent Substrate in Horticultural Cultivation Media. In: Chinese Mycological Society, Edible Fungi Branch of Chinese Society for Horticultural Science. Abstract Collection of the 9th National Edible Fungi Academic Symposium. China Edible Fungi Association; Beijing Forestry University, 2010: 39.

[14] Huang Shuiying, Wang Zhanghong. Preparation and Seedling Raising Effects of Seedling Substrate Based on Pleurotus ostreatus Residue. Agriculture and Technology, 2025, 45(16): 35-39.

ISSN: 2710-0588

[15] Guo Jingyu, Wang Yanchun, Ao Ni, et al. Effects of Different Fungus Residues and Treatment Methods on Mycelial Growth and Yield of Stropharia rugosoannulata. Edible Fungi, 2025, 47(03): 89-93.

[16] Luo Hailing. Effects of Adding Juncao Pleurotus ostreatus Spent Substrate to Soil on the Growth of Laimu No. 1 Seedlings. Fujian Agricultural Science and Technology, 2025, 56(01): 44-47.

[17] Liu Zilu, Sun Yue, Zhang Guoqing, et al. Screening of Edible Fungus Residues with High Laccase Content and Their Dye Decolorization Effect. Chinese Journal of Applied and Environmental Biology, 2019, 25(06): 1457-1463.

[18] Xu Zijie, Wang Jing, Cao Zijian, et al. Current Status and Research Progress in the Resource Utilization of Edible Fungus Spent Substrate. Edible and Medicinal Fungi, 2021, 29(06): 496-500.

[19] Yang Hongmei, Wang Yu. Research Progress on the Application of Edible Fungus Residue in Animal Feed. Chinese Herbivore Science, 2018, 38(05): 48-50+67.

[20] Long Yong. Study on the High-Efficiency Feed Utilization of Edible Fungus Residue and Traditional Chinese Medicine Residue in Black Goats. Guizhou University, 2023.

[21] Duan Yulan. Development of Compound Biofeed from Edible Fungus Residue for Beef Cattle and Research on High-Efficiency Healthy Breeding Technology. Suining Xinxin Ruihe Agriculture Co., Ltd., Sichuan Province, 2022-08-10.

[22] Zhang Xian. Preparation, Characterization, and Adsorption Properties of Hydrothermal Fungus Residue Biochar. Zhejiang University of Science and Technology, 2019.

[23] Gao Xionghui. Anaerobic Digestion Treatment of Auricularia cornea var. liroleuca Residue and Lignin Recovery. Chinese Academy of Agricultural Sciences, 2021.

[24] Mao Ning. Isolation and Application of Microorganisms for Fermentation of Edible Fungus Residue. Food Research and Development, 2020, 41(18): 228.

[25] He Yongxiang. Research and Demonstration of Integrated Technology for Edible Fungi in Hezhou City. Hezhou Academy of Agricultural Sciences, Guangxi Zhuang Autonomous Region, 2020-07-27.

[26] Wang Xianxin. Screening of Highly Efficient Cellulose- and Lignin-Degrading Microbial Consortia and Their Application in Fungus Residue Fermentation. Qingdao University of Technology, 2024.

[27] Huang Xiusheng. Research and Application of Resource Utilization Models and Key Technologies for Edible Fungus Waste. Institute of Agricultural Ecology, Fujian Academy of Agricultural Sciences, Fujian Province, 2017-11-21.