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The circular economy in the mushroom production chain of Mantiqueira mountains

Karen Missaki Yao Okabe[1]; Jeniffer de Nadae[1].

[1] Institute of Production and Management Engineering, Federal University of Itajubá, Itajubá-MG, Brazil.

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Abstract

This study analyzes circular economy practices within the edible mushroom production chain through a case study of a producer in Serra da Mantiqueira, Brazil. The research identifies specific circular economy practices currently implemented by the producer and examines challenges related to enhancing sustainability. Although operating on a small scale, the producer has prioritized sustainability and circular economy principles since the business's inception, resulting in the implementation of numerous circular practices across the production chain.

Keywords

Sustainability; Production chain; Edible mushrooms.

Introduction

In recent years, the edible mushroom market has experienced significant growth. According to the Food and Agriculture Organization (FAO, 2024a), from 2012 to 2024 the production of mushrooms and truffles in the world increased by more than 34%, which reveals the greater prominence of the market over the years. In 2022, the top 10 producers were concentrated in Asia, Europe and North America, with the largest producer being China, with a production of more than 45 million metric tons, followed by Japan producing around 470,000 metric tons of mushrooms (FAO, 2024b).

In Brazil, the production of edible mushrooms has increased over the years and is more concentrated in the South and Southeast regions of the country, with the largest producer and consumer being the state of São Paulo (Capra & Tonin, 2019). The increase in consumption of these foods is driven not only by the intensification of Asian cultural influence in countries, but also by the growing demand for sustainable, healthy and more affordable food (Schneider, 2023). In this way, it is necessary to search for foods that are nutritional sources produced in a more conscious and sustainable way.

The reuse and recycling of waste are essential practices for environmental sustainability; however, one study says that the national rate of recycling and composting of solid urban waste is 11% (Cempre, 2010 apud Marchi, 2011). On the global stage, the circular economy has emerged as a solution to the current environmental challenges, seeking a more conscious and efficient use of resources (Maluf, 2024). According to the Ellen MacArthur Foundation (2015), the Circular Economy consists of a framework of systemic solutions created to tackle global challenges such as climate change, biodiversity loss, waste and pollution. In this way, it reduces the extraction of raw materials from nature, reducing waste along the chain and thus generating more value in the product cycle through better management and process optimization. Potting et al. (2017) proposes ten possible strategies for circularity classified into three categories: smarter product manufacturing and use (R0 to R2); extending the useful life of products or their parts (R3 to R7) and useful applications of materials (R8 and R9), with R0 representing greater circularity, while R9 represents greater linearity. Given the complexity of the transition process from the linear economy to the circular economy, specific models and frameworks can support organizations, according to De Almeida et al. (2021). Within the food industry, the transition is mainly focused on food waste, since it accounts for a significant portion of waste generation, but cannot always be considered waste, but rather possible raw materials that can be incorporated into other processes (Rajković et al., 2020).

Although other strategies, approaches, and tools may be needed to fully support the transition (Bocken et al., 2016), the great importance of adopting a circular economy model within the food sector is based on the new market opportunities it brings, such as: carbon credits, processing byproducts from various food production chains, reducing food waste, creating new sources of income, improving brand reputation, conserving natural resources and encouraging innovation (de Almeida, 2021; Saha, 2023). In addition, Sehnem (2019) points to other environmental, economic, operational and social benefits such

*Corresponding author
E-mail address: missakiyao@unifei.edu.br (K. M. Y. Okabe.)

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as recycling and reverse logistics, which in addition to adding value within the production chain, create jobs and develop the community. The sustainable practices that incorporate the principles of the circular economy into food production can be identified: Paths to Regeneration, Circular Choices, From Discard to Value, Packaging that Circulates, Sustainable Logistics, Green Energy, Responsible Water Management, Efficient Solid Waste Management, Collaboration and Training, Digital Innovation in Agriculture, and Sustainable Biotechnology.

Brazil has potential to be exploited for better use of resources combined with innovation, in order to contribute to cost reduction and sustainability in the process. In turn, the Serra da Mantiqueira offers a favorable environment when it comes to the circular economy, encouraging economic models that seek to optimize resources and minimize waste. Today, it is manifested intensely when it comes to sustainable tourism, gastronomic tourism and ecological restoration, aimed at biodiversity conservation, sustainable practices and support for local producers (Souza et al., 2023; Sanguinetto, 2012). The Serra da Mantiqueira, located in southeastern Brazil and stretching across the states of São Paulo, Minas Gerais and Rio de Janeiro, is particularly suitable for mushroom production due to a combination of environmental factors. With a mountain range that is home to a variety of ecosystems, including forests and woodlands, the region is rich in water resources, and its altitude, which varies between 1700 and 2400 meters, are ideal and essential conditions for the growth and development of mushrooms (Instituto Semeia, 2023; Antunes, 2020).

Therefore, the Serra da Mantiqueira offers a favorable environment for mushroom production, both in terms of climate and available natural resources. This study focused on the Serra da Mantiqueira region, specifically the area in the city of Santo Antônio do Pinhal-SP. The aim of this research was to analyze circular economy practices in the edible mushroom chain through a case study of a local producer.

Materials and methods

The interview with the producer was designed to assess good circular economy practices in the edible mushroom production chain. The interview script comprised 38 open-ended questions, divided into sections: general aspects to understand the functioning of the edible mushroom production chain, sustainability practices within the production process, and specific aspects of circular economy initiatives observed. This structure allowed for a thorough exploration of the practices adopted in mushroom production, as well as the generation and management of waste throughout the production process. The interview took place in June of 2024, during two visits to a local producer in Santo Antônio do Pinhal-SP. The producer, who has been cultivating Shimeji and Shiitake mushrooms for over eight years, pursued studies and training in mushroom cultivation following a career change, transforming this field into his passion. The producer guided us through the production site, sharing his story and responding to the interview questions.

Results and discussion

The studied company specializes in producing Shiitake and Shimeji mushrooms for the local market and is currently trialing the cultivation of Lion's Mane mushrooms. The motivation for entering mushroom production stemmed from three key characteristics of this crop: its efficient use of space - production in greenhouses and on vertical shelves allows for high yields in limited areas; its potential for clean production without pesticides; and its utilization of agricultural waste in the production process. During the interview, the producer described the production process, highlighting that compost is sourced from nearby suppliers to ensure quality and optimize transportation logistics. The compost bags are organized by production batch, allowing for quality control. Inside a controlled-environment facility, the bags are placed on vertical shelves to maximize production efficiency. Each compost bag is estimated to yield approximately 20% of its weight in mushrooms, with production efficiency ranging between 10% and 25%, which is carefully monitored to ensure optimal conditions. Fresh mushrooms have a refrigerated shelf life of 10 days, therefore it is important to have a clear and structured process for harvesting, packaging, and distributing to guarantee a fresh and high-quality product for the consumer. The producer reports an annual production capacity of approximately 4.5 tons of mushrooms utilizing a 70 m² facility.

For packaging, the market typically requires Styrofoam trays for smaller quantities and plastic bags for larger orders. The producer has experimented with sustainable alternatives, such as cardboard trays, though these were not accepted by the market. However, he has since adopted reusable plastic containers for restaurant deliveries, reducing plastic use. Distribution to intermediaries (e.g., markets and greengrocers) and consumers is carried out using a natural gas vehicle (NGV) to minimize emissions, a practical choice given the long distance from the central market. When the mushroom-producing compost reaches the end of its lifecycle, it is repurposed as nutrient-rich fertilizer within the local vegetable-growing community. Additionally, large substrate bags are reused as waste bags. Based on the interview and literature review, Table 1 summarizes the results and relationships within the R9 circular economy framework as applied to the edible mushroom production chain. Despite being a small-scale producer, the company has prioritized sustainability and circular economy principles from its inception. Consequently, most practices expected within a circular economy framework are currently being implemented for this production chain.

Conclusions

The case study method proved effective, enabling a detailed and contextualized analysis of sustainability practices in a small-scale mushroom production chain. This study identifies areas for potential improvement, particularly in water management and packaging sustainability. Although the producer currently uses a semi-artificial well, rainwater harvesting could further enhance the operation's sustainability. Additionally, transitioning from plastic to alternative packaging solutions that support refrigeration, and storage could increase consumer acceptance and reduce environmental impact. Educating consumers on reusing plastic packaging or correctly disposing of Styrofoam can also contribute to a more circular production chain. Local producers may benefit from exploring new technologies and innovations to ensure product quality and serve as a model of sustainability within the market. Future studies could expand on these findings by examining a broader range of mushroom producers to develop a more comprehensive understanding of circular economy practices in this sector.

Table 1. Relationship between the Circular Economy and the edible mushroom production chain.

Circular Economy aspects	Description	Interview
Refuse (R0)	Avoid the use of non-renewable and toxic materials from the outset	The producer does not use chemical pesticides in his production, seeking alternative bio-inputs if necessary
Rethink (R1)	Redesign processes to maximize efficiency and minimize waste	Producer implements sustainable cultivation techniques, but faces challenges in some aspects to make the process more sustainable
Reduce (R2)	Reduce consumption of natural resources and energy	Efficient use of water and energy through a semi- artesian well and solar panels, but there are limitations in reducing plastic packaging
Reuse (R3)	Reuse products and components whenever possible	Reuse growing substrates for compost and manure, large bags of substrate as garbage bags
Repair (R4)	Repair products to extend their useful life	Cultivation equipment undergoes constant preventive maintenance and was built by the producer (humidifier, fan)
Renovate (R5)	Renovate old products for continuous use	Adaptation and construction of equipment used in production
Remanufacturing (R6)	Remanufacturing products to restore their functionality	Products that have not been marketed are used to produce antipasto or mushroom quibbles, these are not marketed
Redefine (R7)	Redirect materials to new uses	Used substrates are redirected to compost and manure
Recycling (R8)	Recycling materials to create new products	Recycling organic waste into compost and manure, but recycling plastics is still a challenge
Recover (R9)	Recover energy from waste through processes such as incineration	Energy recovery is not practiced due to a lack of infrastructure.

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