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A Business Model for Circular Bioeconomy: Edible Mushroom Production and Its Alignment with the Sustainable Development Goals (SDGs)

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Abstract: Agricultural wastes (AWs) generated from farming practices pose environmental threats if not properly disposed of or recycled through biological processes. Mushroom production presents a sustainable solution by converting AWs into highly nutritious food while mitigating environmental pollution. However, there is a lack of comprehensive frameworks to assist farmers and businesses in visually understanding the essential elements of a circular bioeconomy, such as mushroom production's potential interconnections and impacts on value creation. This study theoretically elaborates on a framework using the Business Model Canvas to structure mushroom production across the following key business areas: customers, supply chains, infrastructure, and economic viability. We discuss these aspects within the context of recent studies. In addition to guiding farmers and businesses, we align mushroom production with Sustainable Development Goals (SDGs) within the supply chain, underscoring the importance of developing business models to foster the growth of circular economies and sustainability.

Keywords: agricultural wastes recycling; circular bioeconomy; mushroom cultivation; business model; Sustainable Development Goals

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1. Agricultural Wastes

Agriculture is a major contributor to the bioeconomy due to its significant biomass production, which presents an opportunity to reduce fossil fuel use and greenhouse gas emissions while creating new green markets and jobs [1]. The sector also produces agricultural wastes (AWs), which are often disposed of on farms and, most of the time, are burned, leading to various environmental damages and compromising public health [2].

AWs can be stems, leaves, straws, husks, and forest residues, among other organic materials [3]. By converting AWs into value-added products such as food, feed, bioproducts, and bioenergy, agriculture's role in the bioeconomy transition can be greatly improved [4], fostering socio-economic development and environmental stewardship. Therefore, urgent actions are required to create more resilient agricultural systems [1], as well as strategies aiming to manage, utilize, and valorize organic residues for agricultural sustainability [5].

2. Circular Bioeconomy

The circular economy can be defined as a system where materials avoid becoming waste and natural resources are regenerated. It revolves around maintaining the circula-

tion of products and materials through practices such as upkeep, reuse, refurbishment, remanufacturing, recycling, and composting. By decoupling economic activities from the depletion of finite resources, the circular economy addresses pressing global issues such as climate change, biodiversity loss, waste, and pollution [6]. The fundamental principles of the circular economy include recycling and reusing materials through the holistic and sustainable utilization of resources [7].

A bioeconomy refers to the process of producing renewable biological resources and transforming these resources and waste streams into products with added value, including food, feed, bio-based products, and bioenergy [8].

The circular bioeconomy is an intersection of circular economy and bioeconomy in which these two concepts complement each other, resulting in a sustainable framework and contributing to resolving sustainable challenges [9]. The circular bioeconomy enables rural development through the use of deep knowledge of resources, processes, technologies, and biological principles for the creation of sustainable products and services among all sectors of the economy. This approach strongly advocates for the establishment of industrial symbioses, where waste and by-products are converted into raw materials for other products. This not only reduces the volume of waste destined for landfills but also enhances their value. Consequently, it opens up new avenues for job creation within emerging bio-based value chains and helps to combat rural depopulation [10,11].

3. Edible Mushrooms

Fungi, particularly mushrooms, are vital recyclers on Earth, efficiently returning nutrients to the ecosystem by recycling AWs. They are renowned for their environmental significance and their impact on human evolution and health [12]. Fungi secrete degrading enzymes that work to break down complex materials found in the biomass into simpler compounds called "substrates" on which they grow. Mushrooms are cultivated globally [13], with a production amount of 48,335,996.08 tons in 2022 [14], on a huge variety of substrates [15] produced from AWs, such as sawdust, cottonseed, wheat straw, waste paper [16], wood chips, grasses [17], bamboo sawdust [18], eucalyptus bark, northern peroba sawdust [19], among others.

After the colonization of the substrate and under favorable conditions, the fungi produce the fruiting body, called mushrooms [20], which have high nutritional value because they contain high amounts of protein, fiber, vitamins, minerals, and bioactive compounds that are beneficial to human health [21]. The organic waste used to grow mushrooms is converted into a nutrient-rich soil amendment called spent mushroom substrate (SMS), which is abundant in organic carbon [22] and can be used in several applications, including new mushroom cycles [23].

The main practical steps/segments of mushroom cultivation are the selection of the mushroom species, securing a good-quality fruiting culture, mushroom spawn production, substrate preparation, care of spawn running, and mushroom development and harvesting [20]. A flowchart was developed to summarize the general aspects of mushroom production (Figure 1).

Mushroom production is well suited to exemplify the potential synergies of the circular economy through its recycling of organic matter and nutrients via the decomposition of organic waste, production of yields high-nutritional-value food, and generation of a nutrient-rich soil SMS [22]. Mushroom companies are in the scope of circular bioeconomies regarding the main activity of the local economies into which the companies are inserted, the significant volume of waste generated (SMS), and the applicability of the SMS for the creation of new added-value products [11].

Reflections on the economic significance of the supply chain, alongside the exceptional nutritional attributes of mushrooms and their compatibility with the circular economy, make them conducive to sustainable development. Many of the 17 Sustainable Development Goals (SDGs) are associated with current and potential advantages of mushroom production and consumption, although few works have been focused on them [24].

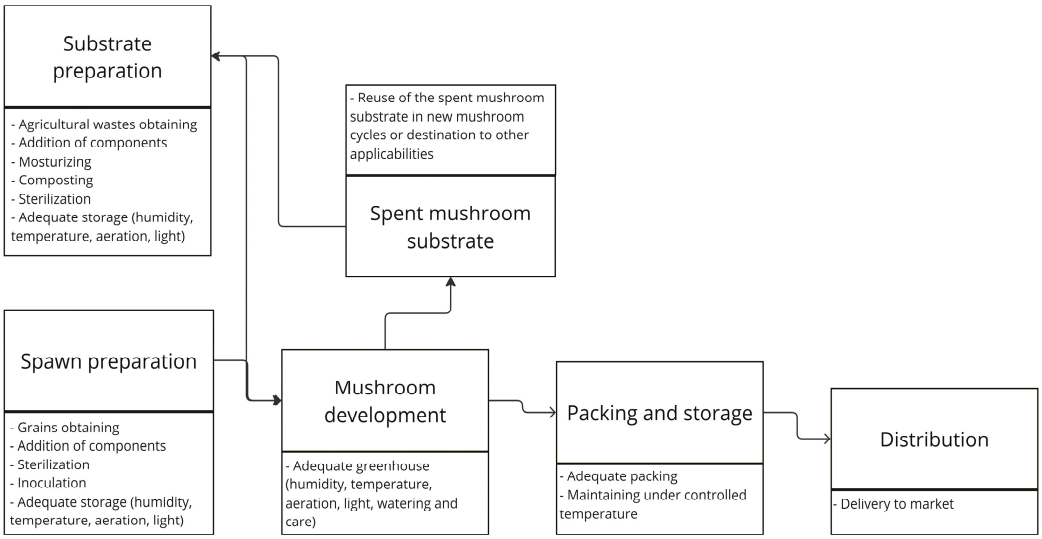

Figure 1. General aspects of mushroom production.

4. Business Model Canvas (BMC)

The Business Model Canvas (BMC) [25] is highly suitable for helping users to understand an organization's business model and is considered a conceptual instrument with widespread success in academia and among professionals due to its popularity and the support that it offers to entrepreneurs [26]. It is used as an independent variable linked to company performance and can be considered a key organizational design tool that can help to predict business success [27] and help users to visually represent the elements of a business system, the possible interconnections, and the impacts on value creation [28].

The BMC contributes to understanding how the business articulates its different components considering its elements as a whole, favoring creativity and the innovation of the business [27]. Business models are like technical drawings of the strategy to be implemented through the organizational structure, being described in nine blocks that show how the organization intends to achieve a proposal, permeating the four main areas of the business: customers, supply chains, infrastructure, and economic viability [25]. The BMC is used to articulate, challenge, and recombine tacit knowledge with implicit cognitive schemas and heuristics, proposing the implication of logic for the venture, not just an attempt to generate profits [26]. The nine blocks are briefly described according to Osterwalder and Pigneur [25] (Table 1).

Table 1. Description of BMC elements adapted from Osterwalder and Pigneur [25].

Key Elements	Description
Key partners	Identification of all partners involved in the manufacturing process of the product or provision of the service as a whole, who participate from raw material acquisition to product delivery.
Key activities	Activities that must be carried out by the organization for the customer value proposition to be achieved and for the business model to function.
Key resources	The most important assets required by the business model. Resources enable the enterprise to create and offer a value proposition, reach markets, maintain relationships with customer segments, and generate revenue. These resources can be physical, financial, intellectual, or human.
Value propositions	It corresponds not only to customer satisfaction with the product or service provided but also to differentiation or authentic characteristics that set them apart from competitors' products or services. This creates value for a specific customer segment.

Table 1. *Cont.*

Key Elements	Description
Customer relationships	Types of relationships that the company establishes with a specific customer segment. The company should clarify the type of relationship that it will maintain with each customer, considering their particularities and needs, which can range from personal to automated relationships.
Customer segments	Definitions of the different groups of individuals or organizations that the enterprise aims to reach and serve. To better satisfy them, the company should divide customers into groups according to their distinct segments, such as common needs, behaviors, and other relevant attributes.
Channels	The organization's manner of communicating with customer segments to deliver the value proposition. Communication, distribution, and sales channels comprise the company's interface with the purchaser, representing an important role in the customer experience.
Cost structure	Encompasses all costs generated by the operation of the business model, which can vary depending on the model and its scale, and can be easily calculated based on key resources, key activities, and key partners.
Revenue streams	It represents the monetary value that the company generates from each customer segment, which can vary among purchasers. The business model may involve two types of revenue: one-time payments from the customer or continuous payments based on the delivery of the value proposition to customers.

This study aims to create a business model using the BMC tool, which outlines the key elements of a mushroom production supply chain that need to be visually understood and feasible for farmers and companies. Understanding the principal elements of the business can encourage farmers and companies to produce food in a circular bioeconomy, promoting rural development and sustainable food practices. The business model was theoretically and strictly elaborated according to the recommendations of Osterwalder and Pigneur [25] and its association with the Sustainable Development Goals (SDGs) was discussed within recent studies.

5. Business Model for Mushroom Production

The business model was filled out by looking for a sustainable and promising alternative for the reuse of AWs, involving the environmental, social, and economic contexts of an organization (Figure 2), in which a vision of customer–supplier relationships and forms of organization can be obtained, permeating the entire value chain [29].

The mushroom production chain is diversified in all its processes due to the numerous species and varieties of fungi involved, as well as because each of them has specific requirements for culture development and commercial viability. Therefore, the business model developed determines general aspects of mushroom production, considering that value chain processes are similar regardless of the species in question.

1. Key partners are identified as technical and specialized personnel involved in the implementation and monitoring of production. Trained professionals are essential to prevent the contamination of the cultivation environment by other organisms such as fungi, viruses, bacteria, nematodes, and insects. Such contamination can reduce yields and even result in total crop loss, affecting the growers' income. Effective sanitation methods for preventing these infections include the disinfection of structures, tools, walkways, picking baskets, and trays; the protection of cropping area by disinfecting workers' clothing and equipment; the disposal of trash (discarded mushrooms, spent compost) only after applying chemical disinfectants; the removal of external pollution sources, such as waste, from the growing area, before covering them with lime and keeping them away from entrances; and the isolation and treatment of contaminated zones severely to eradicate pests [30].

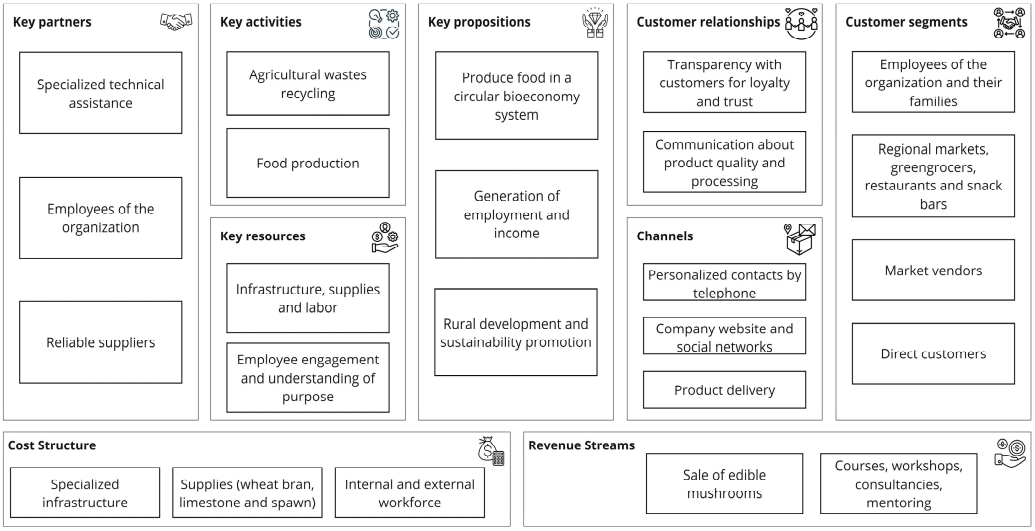

Figure 2. Business model for general aspects of mushroom production.

Manpower depends on workers both from within and external to the organization, such as expert consultants in the field. Suppliers are also key partners since mushrooms needs carbon and nitrogen sources for their development, which can be obtained from various raw materials, such as bran and limestone, and producers also need to obtain viable spawn, or the "seed", so that the substrate is well colonized [31].

2. Key activities are defined as the production of edible mushrooms through the recycling of AWs, which is a viable and promising alternative for the promotion of sustainability since the waste generated by agro-industries can be reused, preventing the burning of harvesting fields. In addition, the reuse of these wastes through mushrooms produces highly nutritious, sustainable, and low-cost food, which is in line with the SDGs as conceived by Griggs et al. [32]. The main SDG themes include newer and more comprehensive concepts of the 2030 agenda, namely prosperous lives and livelihoods, sustainable food security, sustainable water security, universal clean energy, healthy and productive ecosystems, and governance for sustainable societies.

3. Key resources are defined as the infrastructure needed to carry out mushroom cultivation, including the supplies and labor involved in mushroom production and harvesting stages. The structure must be suitable for mushroom cultivation because the fungus needs specific temperature, light, and humidity for its development [33]. Another factor defined as a key resource is employees' understanding of the purpose of the venture. If the purpose is clear and well understood, the project will be easily accepted by employees. Consequently, the employees who carry out the steps described in the business model will be engaged, which is one of the value attributes that provides self-fulfillment for those who take part it [34].

4. Key propositions are defined as food production in a circular bioeconomy system, the generation of employment and income, rural economic development, and the promotion of sustainability. Prioritizing the enhancement of biomass value over time is a fundamental aspect of the circular bioeconomy. This optimization can target economic objectives (e.g., profit), environmental goals (e.g., reducing GHG emissions), or social benefits (e.g., job creation), while ideally encompassing all three pillars of sustainability [8].

The waste generated annually through the activities of industries in the agricultural and forestry sectors has no commercial or food value in its original form. Fortunately, this waste can be converted into valuable resources through proper management, leading to a reduction in environmental pollution and economic growth through the generation of jobs and income, as well as generating highly nutritious food, a source of proteins, vitamins, minerals, and low-calorie values, without the use of pesticides [20].

Considering that many of these residues are wood-based, and that wood stores carbon throughout its life cycle, the use of these residues leads to a reduction in CO_2 emissions and, therefore, mitigates global warming [35]. Another factor contributing to the mitigation of environmental damage is farmers' perception of the threats and severity of climate change, which is the most important motivational factor in voluntary mitigation. However, adaptation depends on the availability of information related to the issues and the scope of farmers [36].

5. Customer relationships, concerning transparency with customers, along with direct and clear communication about the product and its processing, is one of the digital and personal strategies that can be used to build customer loyalty. According to Marques [37], some stages help to build customer loyalty in an organization and can be described in five steps: (1) Attract, which means that content published on social networks and via campaigns attracts the attention of potential customers; (2) Interact, which shows interactions on the various platforms between the organization and the customers, favoring relationships and bringing benefits; (3) Convert, when contacts become qualified and show intent to buy; (4) Sell, a stage that stems from the success of the conversion, whether this is direct or through digital platforms; (5) Loyalty, a stage in which there is satisfaction on the part of customers, who make recurring purchases and recommend the product to other people or organizations.

6. Customer segments are customers who are divided into groups according to their common needs and specificities. According to Osterwalder and Pigneur [25], customer groups should be separated into different segments if their needs require and justify different offers, if they have different distribution channels, if they require different types of relationships, if they have different profitability aspects, or if they are willing to pay for different aspects of the offer.

Therefore, four niches were proposed for customer segmentation: the first niche is the organization's employees and their families, who have priority in buying the mushrooms because they do not need delivery and because they have a closer relationship with the company. The second niche represents the local markets, greengrocers, restaurants, and snack bars that need an immediate supplier of the product. The third niche is represented by market vendors, which are considered a differential product in a street market. The fourth niche is personal and direct customers who seek the products directly from the company.

7. Channels are extremely important for communication, relationships, and delivering value to customers, which will be carried out through the organization's social networks and by transporting mushrooms to customers. This interaction network must have clear and well-defined objectives, using the right platforms and tools so that there is a high probability of good results, as well as a high capacity to adapt to changes and use new techniques [37]. In a case study conducted in Italy within the European context to evaluate the edible mushroom supply chain, it was found that online sales are a promising channel, as most of the identified mushroom producers sell their products through this medium [24].

8. Cost structure concerns that fact that although mushroom cultivation is considered low-cost, the cost structure includes specific greenhouses that must provide specific temperature, humidity, and lighting for cultivation [31], as well as the supplies needed to produce the substrate [38]. Internal and external labor are also included in the cost structure, with external employees, consultants, and people specializing in mushroom cultivation for the initial implementation of the project and subsequent follow-up when necessary, along with internal employees for the maintenance of the cultivation.

9. Revenue streams are sources of income defined as the sale of products by the organization, which could become a self-sustaining enterprise. In addition, educational workshops, courses, consultancies, and mentoring that can be carried out at the organization for students, farmers, and the community are also sources of income and, at the same time, train people interested in sustainable and low-cost farming techniques, promoting environmental education.

Environmental education plays a fundamental role in understanding sustainability since promoting awareness is based on education, making these two factors inseparable in the educational context [39]. Educational interventions that focus on local, tangible, and actionable aspects and can be monitored by individual behavior are the most successful in providing climate change education for ecological development. The main adaptation methods for mitigating environmental damage can be broadly classified into resource conservation technologies, cropping system technologies, and political or socio-economic interventions [36].

6. Sustainable Development Goals (SDGs)

Seen that mushroom production can be in the scope of a circular bioeconomy, the developed BMC could be useful for the association of this practice with a few SDGs. The SDGs strive to encourage organizations worldwide to operationalize and integrate sustainability, addressing both present and future stakeholder needs and fostering sustainable development for society as a whole [40].

SDG 01: No poverty. The aim of SDG 01 is to end poverty in all forms, everywhere. Mushroom cultivation can be associated with SDG 01 because it is considered a typical recycle-economy, as well as sustainable agriculture and forestry, being an example of rural economic development and poverty alleviation [33]. Nowadays, mushroom cultivation ranks among the most lucrative enterprises globally, with mushrooms being a significant cash crop in horticulture [41].

SDG 02: Zero hunger. The aim of SDG 02 is to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture. Target 2.4 aims to establish sustainable food production systems and resilient agricultural practices, which enhance productivity while preserving ecosystems and building capacity to adapt to climate change by 2030. There is an association between the improvement in agricultural productivity and the incomes of small-scale mushroom producers, and mushroom production benefits the environment due to it using agricultural wastes as substrates for mushroom production, avoiding these wastes being burned in the atmosphere [20].

Mushroom cultivation offers versatility across agricultural systems, with applications ranging from compost use to direct mushroom production. Countries may integrate it into climate and sustainable development strategies while prioritizing it in circular food chains for food security and public health benefits. Small-scale farmers stand to gain significantly, needing minimal resources to start cultivation, thereby enhancing income and food availability [42].

SDG 08: Decent work and economic growth. The aim of SDG 08 is to promote sustained, inclusive, and sustainable economic growth; full and productive employment; and decent work for all. The global mushroom industry's multi-dimensional nature plays a crucial role in addressing the critical food shortages facing humanity. Its production, which has a positive impact on reducing environmental pollution, highlights its significance. Mushroom production and distribution can act as catalysts for fostering equitable economic growth in society [20].

Transitioning from conventional industrial practices to sustainable models is imperative due to finite resources and detrimental environmental impacts. Within this framework, fostering a biobased economy emerges as a pivotal responsibility [43].

SDG 09: Industry, innovation, and infrastructure. The aim of SDG 09 is to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. Focusing on Target 9.4, which aims to improve infrastructure and update industries to be sustainable, focusing on efficient resource use and the widespread adoption of clean technologies and environmentally friendly industrial processes by 2030, mushroom production can be considered a clean technology industry. The cultivation of many species of mushrooms entails employing low-cost technological processes [41], which can be variable depending on personal preference, the availability of substrates, and the amount of resources available [20].

After the mushroom cultivation cycle concludes, the leftover substrate becomes a lignocellulosic by-product known as the spent mushroom substrate (SMS). This material can be used as a biofertilizer and soil enhancer for biofuel or feed production or recycled as a substrate to initiate another mushroom cultivation cycle [24]. The SMS also shows significant potential within the circular economy framework, aiming to minimize waste and enhance resource efficiency, contributing to the sustainable and green development of the global mushroom industry [44].

SDG 12: Responsible consumption and production. The aim of SDG 12 is to ensure sustainable consumption and production patterns. Target 12.5 aims to promote, by 2030, substantially reduced waste generation through prevention, reduction, recycling, and reuse; mushroom production is a typical crop correspondent.

Population growth, climate change, and the exhaustion of non-renewable resources such as phosphate and fossil fuels present significant hurdles to the worldwide agricultural network, posing grave threats to food security, particularly in densely populated and underdeveloped regions. Addressing these challenges holds promise through enhanced utilization and recycling methods applied to non-consumable biomass [42]. Mushroom cultivation differs from other conventional crops because they grow on low-value-added by-products like trees, sawdust, thinning, branches, and many others. These materials are valorized, serving as cultivation resources for mushrooms and associated with sustainable forest management [45].

The BMC for edible mushroom production can be associated with the SDGs (Figure 3) as it permeates the environmental, economic, and social pillars of sustainability. The symbols are from the BMC, to which aspect of sustainability they belong.

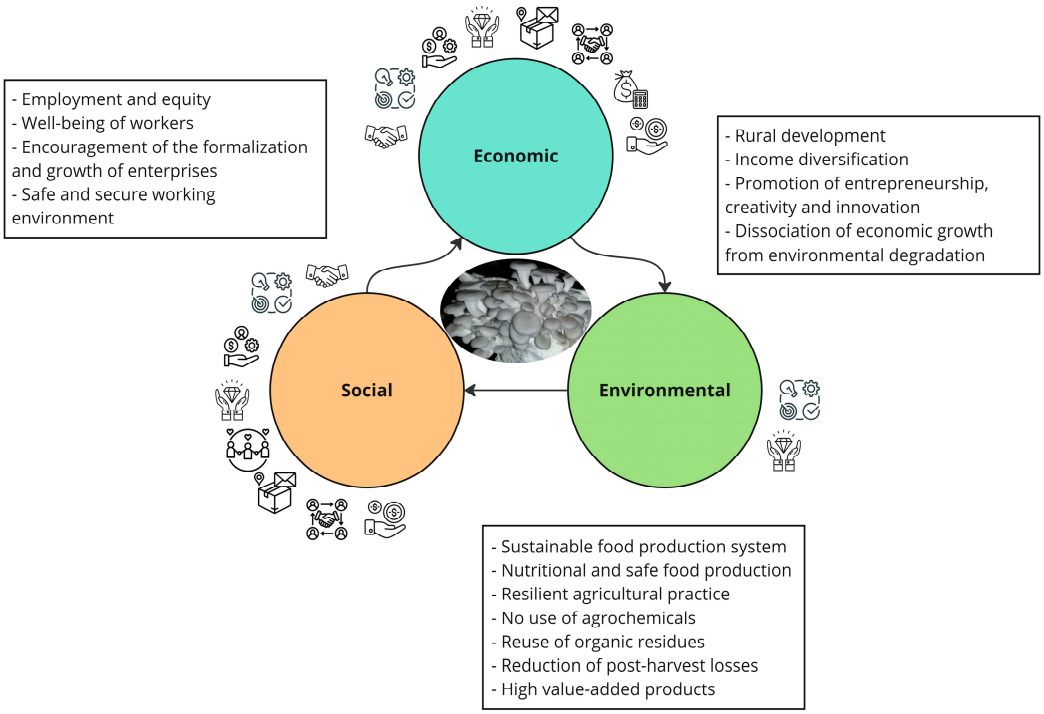

Figure 3. Sustainability aspects of mushroom production in alignment with the SDGs.

7. Discussion

Circular economy business models can be categorized into two main groups: those that promote reuse and prolong product lifespan through repair, remanufacturing, upgrades, and retrofits and those that transform used goods into fresh resources through material recycling. Individuals of various ages and abilities play a central role in these models. Ownership transitions to stewardship, with consumers evolving into active users and creators [46].

The literature widely acknowledges the significance of business models for overall corporate performance and, more specifically, for corporate sustainability. Meanwhile, research in sustainable entrepreneurship is beginning to examine how these models contribute to the broader sustainability-related transformation of markets and society [47]. Business model innovation can be a crucial driver for the transformation needed to achieve the Sustainable Development Goals (SDGs). At the same time, the SDGs can help organizations to identify and explore opportunities for business model innovation [48].

Business models can play a crucial role in achieving the transformation needed to accomplish the SDGs, while simultaneously supporting companies in their search for new market opportunities and new ways to create, deliver, and capture value for stakeholders [48]. A case study conducted with small and medium-sized enterprises confirmed that the BMC framework helps to firms excel in their markets by providing a robust strategic management and planning tool for achieving their goals and objectives. By leveraging the theory of organizational creativity, these enterprises can seamlessly integrate solutions into their business models, including the BMC framework, to enhance their business success [49].

The generation of AWs is increasing due to the growing demands of the population, which leads to an urgent need to define appropriate strategies and management for the use and recovery of this waste, ensuring agricultural sustainability, food, and health security [5]. Mushroom farming represents a significant application of the circular economy, offering numerous opportunities to close material and energy loops [22].

The agri-food sector is not yet fully integrated into the bioeconomy landscape, and business models are recommended to promote this integration, creating an environment where all parts of a business are involved [29]. Producing edible mushrooms using agricultural waste offers a sustainable solution. Mushrooms utilize waste as a nutritional source, producing protein-rich food and medicinal products while reducing atmospheric pollutants [20]. Thriving in the mushroom market segment will predominantly hinge on entrepreneurs' capacity to discern the forces, tools, and methodologies that shape it, alongside their adeptness at amalgamating scientific expertise with market insights [24]. Better integration between mushroom production and the food production chain could contribute to food security and human health through the food produced, to the environment through carbon sequestration, and to soil fertility through the spent compost originated, which can reduce the use of antibiotics and pesticides in the soil through its application [42]. While mushroom production and consumption have been on the rise [13], there has also been a global increase in campaigns to dissuade consumers from consuming animal products, especially meat, as reducing meat consumption has become an important sustainability goal [50]. As one of the most commercially important crops, mushroom cultivation constitutes a recycling economy, contributing not only to rural economic development but also to poverty reduction [33]. Mushroom cultivation is rapidly expanding on agricultural farms in China due to its high production value and job creation for locals, ranking among the top five sectors—behind grains, vegetables, fruits, and edible oils—and surpassing sugar, cotton, and tobacco in market flow [51].

However, implementing sustainable practices for agricultural residues is still limited, as it requires new perspectives on the relationship between customer and supplier, new business models, and new forms of organization, permeating the links of value chains [29]. Companies that contribute to advancing the SDGs are likely to enhance engagement with customers, employees, and stakeholders; bolster their license to operate; increase resilience against future legislative costs or requirements; and mitigate legal, reputational, and other business risks [48].

In addition, recycling plays a crucial role in advancing the concept of a circular economy, a novel sustainability model capable of mitigating environmental impacts while fostering fresh business prospects [7]. Promoting business models grounded in complete ownership and liability, with indefinite duration, has the potential to revolutionize a na-

tion's competitiveness [46]. Further efforts could be made concerning strategies to promote not only the acceptance but also the adoption and diffusion of circular economies [52].

8. Conclusions

This study proposes a new framework through the BMC tool to structure the key elements of mushroom production in a feasible and outlined manner so that farmers and companies can understand the principal aspects and be encouraged and inspired to produce food in a recycling economy business system. This study also connected the BMC with the SDGs to help organizations to drive the transformation needed to achieve these goals, while simultaneously supporting companies in exploring new market opportunities and discovering innovative ways to create, deliver, and capture value for stakeholders. However, specific business models should be created for each mushroom species and treated individually, so that the specificities of each cultivation are considered along with marketing aspects.

The research has some limitations, including its conceptual nature, which provides a broad overview without specific details relevant to the mushroom sector, and its reliance solely on secondary data for empirical analysis. To address these issues, future research should focus on creating detailed case studies using the proposed approach to collect primary data and enhance their practical applications. It is expected that future researchers and implementers will build upon this approach to tackle these challenges. Additionally, this study's goal is to encourage researchers to share insights on developing new business models for other sustainable crop practices, thereby advancing sustainability and supporting the rural sector.

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