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Scoping mushroom cultivation in the Northern Territory: Applying a circular economy approach

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Introduction

Mushrooms are edible fungi known for their delicious taste and nutritional benefits, and have been consumed since ancient times (Bhalerao et al., 2019). They belong to the kingdom Fungi (He et al., 2022) and main classes: Ascomycetes, which include species such as morels (*Morchella* spp.) and truffles (*Tuber borchii*), and Basidiomycetes, which encompasses hundreds of edible species like lion's mane (*Hericium erinaceous*), paddy straw (*Volvariella volvacea*), and oyster mushrooms (*Pleurotus* spp.) (Raghukumar and Raghukumar, 2017; Stajich, 2009). Fossil evidence suggests that mushrooms have been in existence for over 30 million years, predating human evolution (Bhalerao et al., 2019). In ancient Egypt, mushrooms were regarded as a symbol of immortality and reserved for royalty (Niksic et al., 2016). The Ancient Romans were familiar with both their edible and toxic properties (Grimm-Samuel, 1991). On the other hand, Chinese and European cultures recognised their medicinal and culinary applications as early as the 5th century BCE, though scientific research into mushrooms only expanded since the 19th century (Varghese et al., 2019).

Mushrooms are valued not only for their culinary versatility but also for their exceptional nutritional and medicinal benefits. They stand out as a cholesterol-free, plant-based superfood: rich in protein (18–36 % of dry weight), with all essential amino acids, as well as immune-boosting compounds such as chitin and β-glucans (Broom, 2023). In addition, they contain high vital vitamins and minerals, often exceed 10 % of the Reference Daily Intake (RDI) per 100 g (Shirur et al., 2021). Importantly, mushrooms are a natural source of Vitamin D and offer health benefits like immune support improvement, anti-cancer effects, and potential roles in managing chronic diseases like Alzheimer's and hypertension (Falch et al., 2000; Valverde et al., 2015; Zhang et al., 2007). These health benefits have contributed to the growing demand for mushrooms, creating opportunities for a sustainable and economically viable mushroom cultivation industry.

Mushroom cultivation has experienced rapid growth in recent years due to its multifaceted environmental and agricultural benefits. Mushrooms are typically cultivated on agricultural or industrial residues, which serve as substrates for their growth. Fungi decompose the complex organic compounds within these substrates into simpler nutrients, supporting fruit body development while enhancing substrate fertility. This process not only yields high-value edible mushrooms but also generates by-products such as spent mushroom substrate (SMS), which can be re-purposed as biofertilizers or compost ((Daranagama, 2023; Kosre et al., 2021) and also reduce reliance on synthetic fertilisers (Nicolcioiu et al., 2016; Udayasimha and Vijayalakshmi, 2012). Furthermore, fungi's adaptability enables mushroom cultivation on a diverse range of waste materials, from crop residues to industrial byproducts, positioning mushrooms as a scalable and sustainable solution for circular agro-industrial systems.

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From both environmental and economic perspectives, mushroom cultivation offers an innovative solution for transforming agricultural and industrial waste into valuable resources. Agro-industrial wastes, as lignocellulosic materials, provide essential nutrients supporting mushroom growth (Kumla, 2020) and common examples include manure, rice straw, wheat straw, corncobs, sawdust, rice husks, cotton husks, and sugarcane bagasse. These agricultural byproducts are often burned or randomly disposed when not properly managed, leading to environmental pollution by releasing carbon dioxide (CO_2), methane, nitrous oxide (N_2O) and other gases (Udayasimha and Vijayalakshmi, 2012; Beyer, 2023) and utilising such waste for mushroom cultivation reduces the need for complex waste disposal processes and enhances sustainability by converting waste into valuable products; closing the carbon loop, and offsetting the generation of any polluting gases (Grimm and Wösten, 2018; Prateep Na Talang et al., 2024). Furthermore, mushroom cultivation fosters local economy growth by creating new industries, utilising local resources, and generating employment opportunities (Shakil et al., 2014; Zhang et al., 2014). For example, during the infrastructure phase, local labourers and engineers can gain additional job opportunities. With ongoing raw material transport and delivery, drivers will benefit from steady work. People involved in site management and production will secure a regular source of employment. Additionally, farmers and industries supplying Agro waste will earn extra income from selling their waste for clearance, while also freeing up space for other uses. In this way, multiple layers of economic and social benefits come into play.

Recognising the gap, the absence of an established mushroom industry in the Northern Territory (NT), where most mushrooms are supplied from other states, this project seeks to address that shortfall by leveraging local opportunities. The NT's rapidly expanding cropping industry generates significant agricultural and industrial waste, which offers strong potential for use in mushroom cultivation. The cotton industry, for example, generates large quantities of by-products like gin trash, which can be repurposed as substrate for mushroom cultivation (Zikriyani et al., 2018; Amuneke et al., 2011). Growth of other crops in the NT, such as sorghum, peanuts, millet, maize, rice and pulses, produces agricultural waste that can be similarly utilised to develop a mushroom circular economy (Burke, 2022). Therefore, this review explores the potential and opportunities for utilising local agricultural waste to develop a mushroom industry in the NT. Section 2 provides a brief overview of the circular economy and its connection to mushroom cultivation. Section 3 outlines global and Australian mushroom production. Section 4 explores the prospects for mushroom cultivation in the NT region. Finally, Section 5 presents a business case for developing a mushroom-based circular economy in the NT.

Literature search strategy

A systematic literature search was conducted using major academic databases, including Google Scholar, Web of Science, PubMed, and ScienceDirect. Search terms were tailored to each thematic area of the review and included combinations of keywords such as *"mushroom cultivation Australia," "Australian mushroom industry," "mushroom varieties," "Northern Territory mushroom production," "circular economy mushroom cultivation," "cotton trash substrate," "Agro-waste mushroom cultivation,"* and *"mushroom business development."*.

Industry-specific reports were also obtained from reputable organisations such as Hort Innovation Australia and the Australian Mushroom Growers Association (AMGA). Additional searches focused on Agro-waste utilisation, examining their roles as major ingredients, minor ingredients, and supplements, as well as their availability in the Northern Territory, to evaluate their potential for substrate formulation. These searches aimed to capture both regional and global perspectives on the sustainable use of substrates. The retrieved literature was categorised into the following core thematic areas:

1. History, nutritional significance of mushrooms, and their relationship to the circular economy.
2. Peer-reviewed studies on mushroom cultivation using Agro-wastes relevant to the Northern Territory.
3. Social, economic, and environmental benefits associated with mushroom cultivation.
4. Global mushroom production trends and the status of the Australian mushroom industry.
5. Literature on business development, industry feasibility, and SWOT analysis for establishing a mushroom industry was also reviewed. A business case was developed, utilising insights from peer-reviewed studies, with a focus on the Northern Territory's opportunities, strengths, and potential challenges. This approach provides a clear framework for understanding risks and leveraging regional advantages to support sustainable mushroom industry development in the NT.

These thematic areas were afterwards synthesised into five structured sections within the review. Across all searches, more than 1,000 records were initially identified. After preliminary screening for relevance, authenticity, and alignment with the review themes, approximately 200 studies were selected for further consideration. A detailed eligibility assessment was then conducted, excluding non-relevant, duplicate, or unverifiable sources. Ultimately, 103 peer-reviewed and credible studies were included in the final review.

The inclusion criteria were to include peer-reviewed, English-language publications and verified industry documents directly relevant to the review's objectives. Non-referenced online content, blogs, and news articles were excluded unless they provided factual, industry-validated information. The final literature pool was organised according to the predefined thematic structure to ensure coherence, analytical depth, and academic clarity.

Circular economy practices and Link to mushroom cultivation

Circular economy concept

A circular economy is an economic system that eliminates or minimises waste and maximises resources in use for as long as possible by keeping materials in continuous circulation. Products, materials, and resources are reused, recycled, or composted instead of being burned, dumped, or carelessly discarded (Antikainen et al., 2018; MacArthur, 2013). The concept was initially developed in response to growing environmental concerns and the depletion of natural resources but has evolved to encompass a broad range of sustainable practices, with a focus on waste reduction and material reuse. The circular economy has expanded to include more comprehensive strategies, and its core principles aim to create a resilient, adaptable, and equitable economic system that benefits both the society and ecosystems (Velenturf & Purnell, 2021; Winans et al., 2017).

Mushroom cultivation as a circular economy Practice

In the framework of sustainable agriculture and circular economy principles, mushroom farming provides an effective method for converting lignocellulosic waste and agro-industrial by-products into nutritious, high-value, and eco-friendly food products (Kopnina et al., 2022; Winans et al., 2017). Research has shown that various agricultural wastes can be successfully utilised for mushroom cultivation. For example, wheat straw was found to increase yield in button mushroom cultivation (Munshi et al., 2010). Oyster mushrooms have been successfully grown using a wide range of materials, including sawdust, tea waste, cottonseed, wheat straw, and paper waste (Khan et al., 2011; Oyedele et al., 2018; Elyson et al., 2024), as well as corncobs, rice husk, sugarcane bagasse, and millet straw Hendrika et al., 2021; Rakib et al., 2020. Some studies also used cotton waste as a major ingredient of the

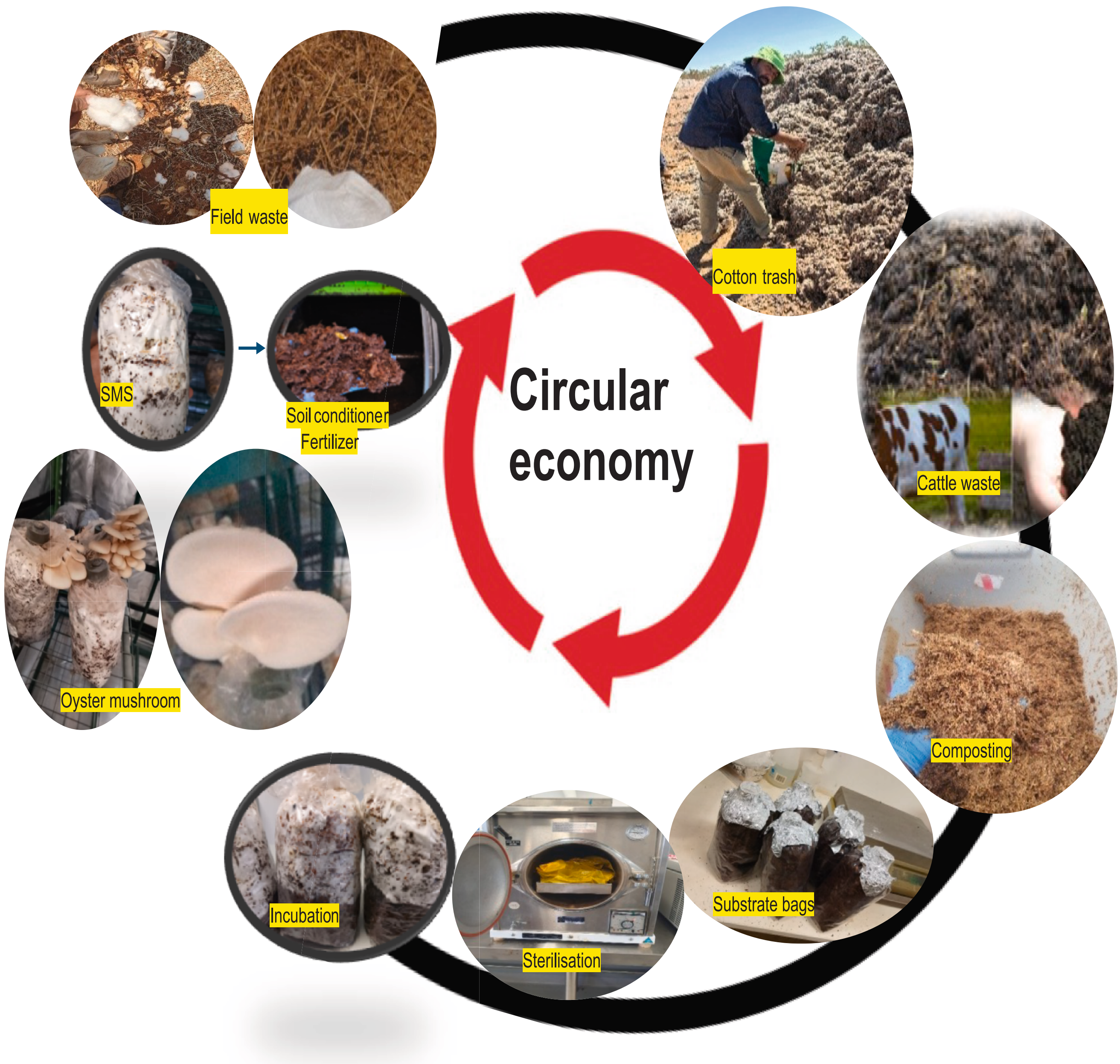

Fig. 1. Mushroom Cultivation in a Circular Economy: The NT Model.

substrate (Jahangir et al., 2015; Sardar et al., 2020), and others combined organic manure with sawdust to cultivate oyster mushrooms (Orngu et al., 2021). For straw mushroom, it was reported that pineapple leaves and palm fruit bunches could be used as substrate (Eguchi et al., 2015). Improved results were observed when cultivated on cotton waste supplemented with sodium acetate (Hou et al., 2017).

Benefits of developing mushroom industry in the circular economy framework

Mushroom cultivation brings social benefits, starting with industry development and job creation, as it requires minimal infrastructure and small investment to start production from low-cost feedstock and allows small-scale businesses to grow into larger enterprises in a short time (Oyedele et al., 2018). In addition to generating income, mushroom farming enhances food security and provides significant nutritional benefits. Rich in micronutrients, vitamin B12, and bioactive compounds, mushrooms help address dietary deficiencies and act as functional foods for managing metabolic and immune disorders (Bell et al., 2022; Das, 2021; Sharif et al., 2016). Mushroom farming also encourages the development of new skills in sustainable agriculture, giving people the chance to acquire new knowledge and confidence, which in turn supports continuing improvement in cultivation techniques to increase the profitability of the business (Balan, 2022) . Therefore, the social benefits begin with the creation of livelihood opportunities, extend to addressing food security and nutrition challenges by providing nutritious and healthy food to people, and this process supports broader community development, which in turn provides community members opportunities for education and skill development, leading to the expansion of the industry (e.g. cultivation of more mushroom varieties). Hence, the

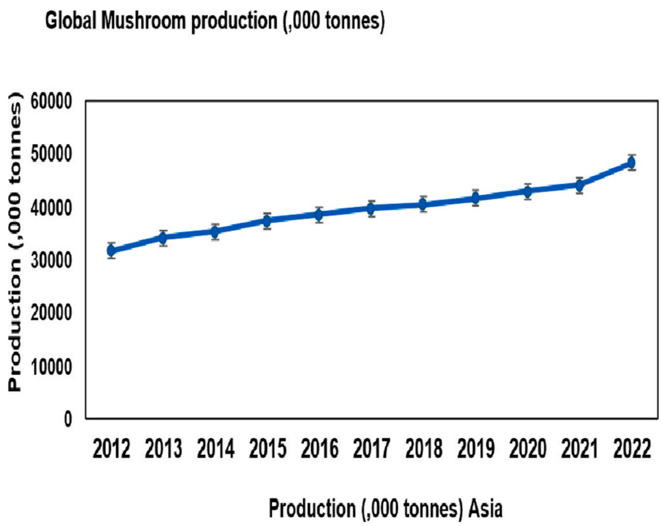

Fig. 2. Global Mushroom Production (FAOSTAT, 2023).

development of the mushroom industry can build a value chain that delivers social impact (Atlas, 2023; Das, 2021; Viriato et al., 2024).

In mushroom industry, economic benefits often merge with social benefits. As mushroom farming uses low-cost Agro-waste, adds value to waste, and produces a valuable and healthy food product, it could be a smart business choice (Cheung, 2013; Oyedele et al., 2018). This approach of utilising Agro waste helps save upfront financial inputs, lowering production costs while still offering a product that sells well in the market. Mushrooms grow quickly, which shortens the production and sales cycle to accelerate cash flow, generating fast turnover and high profit margins (Quaicoe et al., 2024; Viriato et al., 2024). In addition to selling fresh mushrooms, growers can increase income by value-adding, such as producing dried or powdered products. Moreover, from cultivation to processing, packaging, transportation and marketing, mushroom farming creates employment across many areas and helps the local economy to flourish (Grimm and Wösten, 2018).

Furthermore, socio-economic benefits and the sustainability cycle in mushroom cultivation don't end with mushroom production. The leftover material, known as spent mushroom substrate (SMS), which is no longer suitable for commercial-scale mushroom growth, has several valuable applications. In agriculture and horticulture, SMS serves as a soil amendment and organic fertiliser (Grimm and Wösten, 2018). It reduces the additional cost of synthetic fertilisers as SMS has leftover essential nutrients that can be utilised for enhancing crop yields, providing benefits to farmers and saving cost on extra fertilisers (Cunha Zied et al., 2020). It can act as a protective mulch, helping to suppress weeds and retain soil moisture. Rich in carbon, SMS can be mixed with nitrogen-rich materials, such as manure, to produce high-quality compost, while the residual fungi can function as a fast decomposer. In nurseries, a mixture of soil, SMS, and nutrient-rich supplements can be used as a growing medium for seedlings and ornamental plants, improving water retention and organic matter content (Hu et al., 2022). Additionally, SMS holds potential for energy production, either as a direct biofuel feedstock or through pyrolysis to generate energy and biochar and contribute to reducing greenhouse gas emissions (Koutrotsios et al., 2014). Through these diverse post-harvest applications of SMS, mushroom cultivation exemplifies further the principles of a circular economy.

Therefore, within the circular economy framework, mushroom cultivation stands out as a model for promoting resource efficiency and sustainable development. By transforming a wide range of agricultural waste into nutritious, high-value food, the mushroom industry significantly reduces waste while adding value to previously unutilized organic materials. In addition, the reuse of SMS further extends the sustainability cycle. This closed-loop system supports environmental conservation and contributes to economic growth, thereby making a compelling example of circular economy principles in action (Fig. 1).

Table 1
Global Mushroom Production Rankings and Figures of the top 20 countries (Cook, 2020).

Rank	Country	Production (tonnes, 000)	Rank	Country	Production (tonnes, 000)
1	China	45,438	11	United Kingdom	84
2	Japan	469	12	Germany	78
3	United States	370	13	Italy	67
4	India	280	14	Ireland	65
5	Poland	256	15	Turkey	65
6	Netherlands	235	16	Indonesia	63
7	Spain	167	17	Hungary	51
8	Canada	139	18	Australia	50
9	Russia	128	19	Iran	25
10	France	101	20	Belarus	24

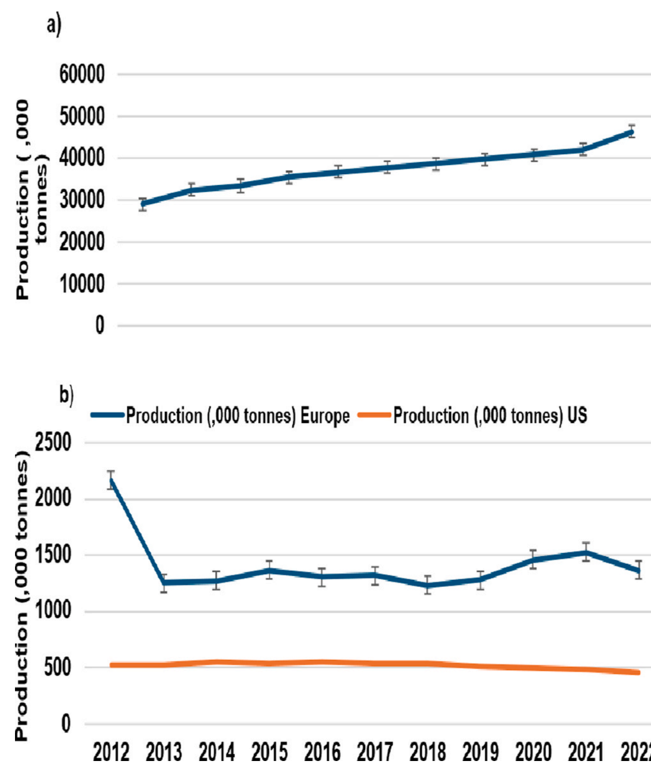

Fig. 3. Global Mushroom Production a) Asia, b) Europe and US .

Global and Australian mushroom production

Global trends

Global mushroom production has expanded significantly over the past decade (Singh et al., 2010), rising from 31.5 million tonnes in 2012 to 48 million tonnes in 2022, a 52 % increase (Fig. 2). China dominates the industry, producing 45 million tonnes (94 % of global output), followed by Japan and the United States (Table 1). Asia's mushroom sector has experienced significant growth, rising from 29 million tonnes to 46 million tonnes (Fig. 3a), largely due to China's mushroom industry expansion, where mushroom farming is now a key component of rural poverty alleviation programs. In contrast, European production declined from 2.1 million tonnes to 1.3 million tonnes, while U.S. output

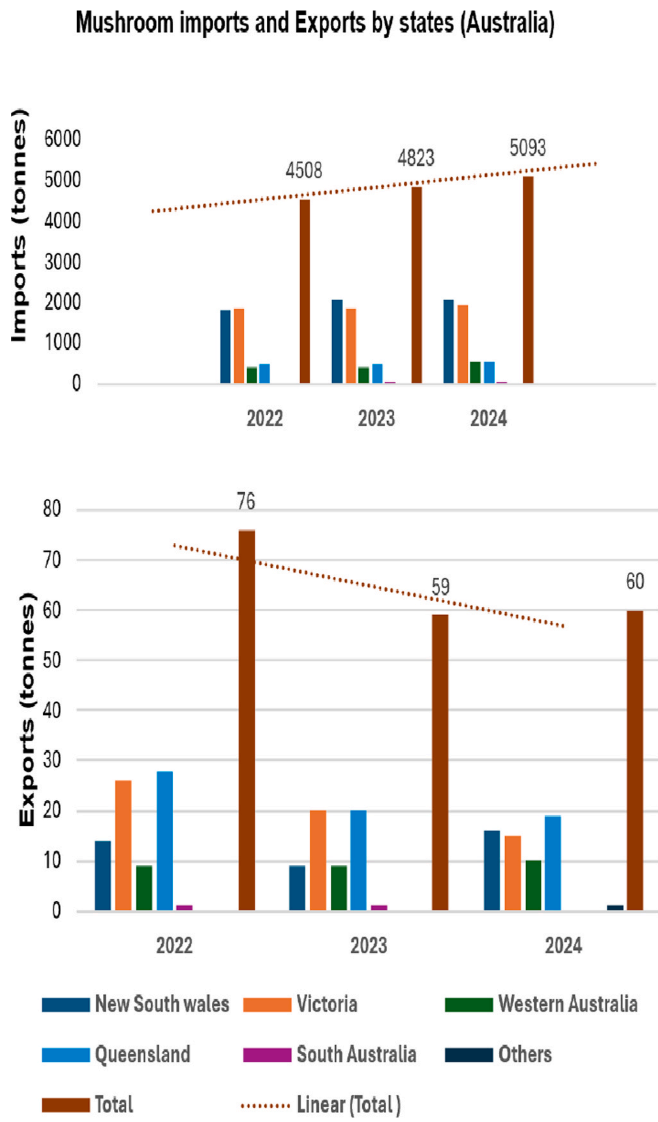

Fig. 4. Regional Mushroom imports and exports (Hort Innovation, 2020).

remained stable at around 0.5 million tonnes (Fig. 3b). These trends highlight Asia's dominance, driven by China's export-focused model, supplying mushrooms to 137 countries (Li, 2022; Singh et al., 2020).

Australian context

Australia's mushroom industry was established in 1933 and has grown into a $393 million sector (farm gate), producing 68 thousand tonnes annually (Innovation, 2023b). Mushrooms now ranks as Australia's fourth important vegetable crop, following potatoes, tomatoes and leafy greens and the sixth most valuable horticultural crop, contributing significantly to the nation's agricultural economy Godwin, 2019. While conventional button mushroom (*Agaricus bisporus*), mainly white cup and swiss brown varieties, dominate supermarket shelves, demand for gourmet species, such as shiitake, oyster, enoki, and lion's mane, is rising, driven by culinary trends and health-conscious consumers (Best, 2022). Despite this, Australia remains a net importer, with 4,823 tons of mushrooms (primarily specialty varieties) imported in 2023, and this increased to 5,094 tonnes in 2024 (Fig. 4), compared to just 60 tonnes exported in the same year (Table 2). Major suppliers include China, Korea, and Spain, while exports go mainly to Southeast Asian markets like Singapore and the Philippines (Table 2) Australian Mushroom Growers, 2023; Horticulture Innovation, 2020.

The Australian market is heavily saturated with *Agaricus bisporus*, which is cultivated on pasteurised substrates made from a wide range of agricultural and organic waste materials, including wheat and rice straw, rice husk, spent grain, wastepaper, forestry residues (such as wood chips and sawdust), poultry litter, oilseed waste, animal manure, corn stover, and sugarcane bagasse (Australian Mushroom Growers, 2023). The industry relies on approximately 25,000 tons of imported peat annually from Europe and Canada for casing, at a cost of around $300 per ton. Key industry players include Costa Group (producing 25 % of Australia's mushrooms) and Premier Mushrooms (NSW/QLD). Furthermore, South Australian Mushrooms, Majestic Mushrooms, and Regal Mushrooms collectively supply the bulk of domestic demand. Victoria leads national production (Fig. 5), followed by NSW and South Australia, with large-scale operations optimising cost efficiency to maintain competitive pricing (2020).

Northern Territory opportunities

The Northern Territory (NT) currently has no commercial mushroom production, making it entirely dependent on interstate and overseas supply chains. At the same time, the NT generates a significant amount of agricultural waste, including an estimated 2,500 to 3,000 tons of

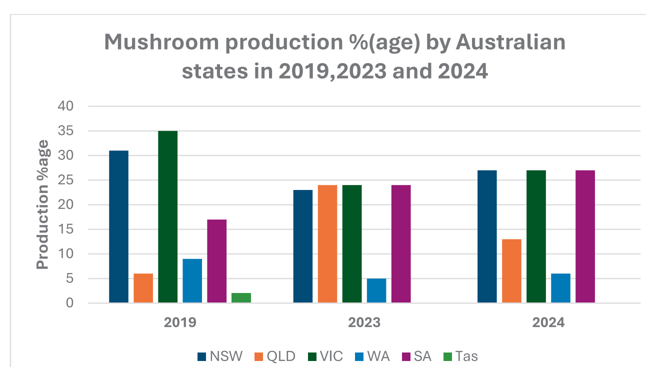

Fig. 5. Mushroom production by states in 2019, 2023 and 2024 (Hort Innovation, 2020).

Table 2
Australia's mushroom imports and exports by country (Hort Innovation, 2020-2024).

Imports by Country (tonnes)	2021	2022	2023	2024
South Korea	3457	3539	3623	3668
China	844	829	1028	1315
Croatia	9	47	12	39
Italy	80	62	72	30
Spain	19	31	86	42
Other	3	<0.5	1	<0.5
Total Imports (tonnes)	**4412**	**4508**	**4822**	**5094**

Exports by Country (tonnes)	2021	2022	2023	2024
Fiji	6	9	11	8
Brunei	22	21	15	12
Philippine	4	4	5	9
Papua New Guinea (PNG)	10	10	11	11
Singapore	4	11	3	0
Other	20	22	14	20
Total Exports (tonnes)	**66**	**77**	**59**	**60**

cotton trash annually. Laboratory trials using this cotton trash have already demonstrated its suitability for mushroom cultivation. When combined with supplementary materials such as sawdust and wheat bran to optimise substrate composition, the results indicate strong potential to establish local production. This not only positions the NT to meet its own mushroom consumption needs but also creates opportunities for developing an export market. Commonly imported varieties include button mushrooms and oyster mushrooms. So far, current trials have proven the successful cultivation of oyster mushrooms, which are highly in demand but are currently only sold in markets in packaged form, imported from interstate. However, the region's tropical climate presents opportunities for cultivating heat-tolerant species such as tropical oyster (*Pleurotus ostreatus*) varieties, straw mushroom (*Volvariella volvacea*), milky mushroom (*Calocybe indica*) and reishi mushroom (*Ganoderma lucidum*). Additionally, the NT's cattle, cotton, and other cropping industries generate agricultural waste (cotton gin trash, manure, and crop residues) that presents potential to repurpose local waste into low-cost, sustainable substrates to establish a local mushroom industry and reduce reliance on imports while creating new agribusiness opportunities (Ahmed et al., 2024; Burke, 2022; Northern Territory Government, 2023).

Prospects for mushroom cultivation in the NT region

Overview

The Northern Territory, Australia's third-largest federal division, spans 1.35 million km2 but has a small population of approximately 250,500 people, mostly residing in Darwin and a few spread across remote regions (Australian Bureau of Statistics, 2021). Despite its vast land area, agriculture in the NT remained underdeveloped until recent years. The cattle industry, the region's largest primary sector, occupies around 60 % of the land . However, agriculture is now experiencing significant growth. For instance, cotton cultivation has expanded from 8,000 to 15,000 ha following the establishment of a new cotton gin in Katherine in 2023 (Ahmed et al., 2024; Fitzgerald, 2023) and this development is encouraging further cultivation. Similar growth is evident in grain and cereal production, generating additional organic waste that could serve as a substrate for mushroom cultivation (Orngu et al., 2021; Sardar et al., 2020) to promote and initiate the mushroom industry in the NT from these locally available wastes.

Availability of Agro waste as mushroom substrate feedstock

Researchers worldwide have studied a wide range of Agro-waste materials to convert them into high-value edible mushrooms, and this review aims to assess the applicability of such wastes in the NT. Commonly studied materials in literature include different types of agricultural waste such as wheat straw, grain residues, sesame and millet crop waste, paddy straw, peanut crop waste, and hay (Aslam et al., 2022; Besufekad et al., 2020). Food and fibre industrial wastes, such as cotton gin trash and fibre rejects, sugarcane bagasse, rice bran, soy meal, forestry wastes including sawdust, wood shavings, paper waste, and cardboard, and animal industry wastes, including cow manure and poultry manure. These wastes have been widely investigated as mushroom substrates (Orngu et al., 2021; Raymond et al., 2013) and many of them are available in the NT.

Researchers have experimented with different ratios and compositions of these materials to optimise mushroom yield and quality. Among these, some materials are used as primary ingredients, such as cotton gin trash, sawdust, and hay (all available in the NT), which typically make up 60 to 80 % of the substrate. Therefore, they are best sourced locally to minimise transportation costs. While others serve as minor components or supplements, such as wheat bran, millet crop waste, or cattle manure, they help balance the carbon-to-nitrogen (C: N) ratio of the substrate, provide additional nutrients to improve Biological Efficiency (BE%),

Table 3
Substrate Materials: Their Functions and Availability in the NT.

ingredient	Substrate component	Material source and Availability in NT (Y/N)	C: N	Function of material	Reference
Major ingredient	Sawdust	Wood, sawmilling industry (Y)	200–500:1	Provides high carbon content and moisture retention	(Bhattacharjya et al., 2014; OA (Orngu et al., 2021); Oseni et al., 2012)
	Cotton waste	Plant waste/cropping field (Y)	30–40:1	Nutrient-rich substrate provides cellulose, moisture, and aeration	(Chang, 1974; Jahangir et al., 2015; (Khan et al., 2017)
	Cotton trash	Ginning product (Y)	50–100:1	Nutrient-rich	(Agba et al., 2021; (Hou et al., 2017); Olana & Keneni, 2020)
Minor supplement	Poultry litter	Animal waste (Y)	10–20:1	Enhances nitrogen content, supports mycelium development	(Jasinghe & Perera, 2006; Noble & Gaze, 1994; Pokhrel, 2016)
	Cow dung	Animal waste (Y)	20:1	Enhances nitrogen content and mycelium development	(Nuruddin et al., 2010; OA (Orngu et al., 2021)
	Rice bran	Rice milling (N)	12:1	Balances carbon and nitrogen, nutrient-rich	(Owaid et al., 2015; Radzi et al., 2021)
	Wheat bran	Wheat milling, Feedlot stores, Local grocery shops (Y)	12:1	Nutrient-rich balances carbon and nitrogen	(Dundar et al., 2008; (Khan et al., 2017); Oseni et al., 2012; Rahman et al., 2012; Zhang et al., 2002; Zhou et al., 2018)
	Sesame cropping waste	Cropping fields, Feedlot stores (Y)	20–30:1	Adds carbon and nitrogen, provides nutrients (calcium, magnesium, phosphorus, micronutrients)	(Ikujenlola & Ogunba, 2018)
	Millet cropping waste	Cropping fields, Feedlot stores (Y)	20–30:1	Source of carbon, nitrogen, phosphorus, micronutrients, and organic matter	(Olana & Keneni, 2020; Zhang et al., 2002)
	Paper/Cardboard Waste	From local schools, offices, businesses, and warehouses (Y)	200–400:1	High source of carbon, moisture retention	(Getachew et al., 2019); Kopiński & Kwiatkowska-Marks, 2012)
	Soybean meal/ Maxi soy	A byproduct of soybean oil extraction, Feedlot stores, and Bunnings (Y)	8:1	Source of protein and nitrogen, higher mycelial development, higher biological efficiency	(Chutimanukul et al., 2023; Estrada & Royse, 2007; Garg, 2014)
Additives	Lime ($CaCO_3$)	Limestone/dolomitic rock, Local stores (Y)	Nill	Raises pH, source of calcium, suppresses pathogens, and keeps optimum pH for mycelium	(Chukwu et al., 2022; (Hendrika et al., 2021); Khan et al., 2013)
	Gypsum ($CaSO_4 \cdot 2H_2O$)	Natural mining, Local feedlot and agriculture product supplier (Y)	Nill	pH stabilizer, provides structure and nutrients for for mycelium development	(Gerrits, 1977); Li et al., 2022; Misz et al., 2024)

enhance substrate texture and water retention, and support mycelium development. The ratio of minor components varies from 20 to 30 %, depending on the major ingredient being used, as the selection of minor ingredients must precisely balance the C:N ratio and the nutrients in the substrate, aiming to achieve efficient mushroom cultivation results. In the NT, minor components can be sourced from emerging crops, some of which are used as rotational crops, such as millet, sorghum, sesame, and occasionally peanut. In addition, materials already integrated into existing agricultural, livestock, and industrial supply chains, such as cow manure (as fertiliser), wheat bran, rice bran (as cattle/horse feed), and paper waste or cardboard (as industrial or consumer waste), can also be utilised. Additives such as lime and gypsum help regulate pH, suppress pathogens, enhance substrate structure and balance nutrients (Akinyele and Adetuyi, 2005; Hendrika et al., 2021; Kumla, 2020; Osunde et al., 2019). Given their low usage, even if such additives needed to be imported from interstate or overseas, they have a limited impact on overall production cost. A summary of the major ingredients, minor ingredients, and supplements is provided in Table 3, considering ingredient availability for potential industry development in the NT.

Socio-economic potential

Mushroom cultivation offers significant socio-economic potential, particularly in regions seeking sustainable, small-scale agricultural development, such as the NT. Previous studies highlight that edible mushrooms not only are a good source of nutrition but also create significant employment opportunities and a profitability potential (Grimm et al., 2021). According to the Australian Mushroom Growers Association (AMGA), 2023, The sector employs around 4000 people and has an economic multiplier of 5, highlighting its broad impact on local economies. The average production costs, including cultivation, packaging, and transportation, are approximately $5.06/kg, while retail prices range from AUD 11.50 to AUD 27.32/kg (Chudleigh, 2011; Cooke, 2024; Wamucii, 2024), indicating great profit margin. Developing a mushroom industry could particularly benefit Indigenous communities in the NT, where small-scale agricultural projects are increasingly sought to create employment and improve food security (Springer, 2015; Cooke, 2024). Many Indigenous populations face limited access to nutritious food, which negatively impacts their health (Gracey & King, 2009). Mushrooms, being low in calories and rich in protein, can help address dietary gaps while supporting weight management and muscle health. Therefore, the industry presents considerable profit potential and can make a positive contribution to the NT's socio-economic landscape. Establishing a local industry would also make this nutritious food more accessible and affordable to remote and Indigenous communities.

Based on the above discussion, the NT meets several key criteria for mushroom cultivation: (1) availability of agricultural waste for substrates, (2) clear market gap and opportunities to develop a sustainable mushroom industry, and (3) communities that would benefit economically and nutritionally. Although several key criteria support the development of a mushroom industry in the NT, there are also significant challenges and limitations that must be addressed simultaneously. These include selecting species suited to local environmental conditions and consumer demand, ensuring a reliable supply of agricultural waste for mushroom substrate, establishing feasible infrastructure such as storage facilities and contamination-free laboratories for regular spawn production, and providing adequate facilities suitable for all cultivation process needs. Additional challenges involve building professional expertise across the production process, from initial composting through to harvesting, along with the ability to manage bacterial and fungal issues effectively. Developing and sustaining a skilled workforce also remains a critical requirement. The next step is to design a viable business model supported by a sustainable and locally adopted production system. Further details on these challenges are discussed in the following chapter.

Developing a business case for the mushroom circular economy in the NT

To establish a sustainable business model that delivers long-term socio-economic and environmental benefits, it is essential to understand the mushroom industry and specifically, the prospects to develop the industry considering the fundamental elements of the business model in the context of the NT (Viriato et al., 2024).

Key aspects for mushroom production

a) **Species choice**: For mushroom cultivation, it is essential to choose species that are well-suited to both the consistently available substrate and the local environmental conditions. In the NT, a cattle-dominant region where cattle manure and forage are abundant, along with forestry waste like sawdust, and significant amounts of cotton crop residue and cotton gin waste, oyster mushroom, shiitake, button mushroom and paddy straw mushrooms can be considered (Kumla, 2020; Suwannarach et al., 2022) . Furthermore, the NT's tropical climate provides favourable conditions for cultivating heat-tolerant species, such as straw mushrooms, oyster mushrooms (high-temperature species and cultivars), milky mushrooms, and shiitake (Thakur, 2014). Adaptation to high ambient temperatures promotes the rapid growth of these species, reducing the need for cooling and lowering energy inputs, thereby improving the sustainability of production.
b) **Spawn sourcing and preparation**: Sourcing spawn materials sustainably can be challenging and may involve a range of issues like logistics, safe transportation, keeping quality and maintaining it contamination-free, storage and economic factors during consistent demand (Springer, 2015). Therefore, after selecting the appropriate mushroom species, it is crucial to obtain spawn from reliable and reputable suppliers or to establish a dedicated facility for consistent and high-quality spawn production. The process of mother culture and spawn preparation requires strict maintenance of sterile conditions to prevent contamination and ensure the viability of the spawn, so proper training is crucial. However, in the NT, access to training and education on mother culture and spawn preparation is currently limited. To address this gap, collaboration with interstate or overseas mushroom producers could help develop local expertise. Establishing a local facility with trained staff will enhance the industry's productivity by identifying and tackling issues before they arise.
c) **Waste sourcing, storage and substrate preparation**: Sourcing agricultural waste in the NT demands building a broad network of suppliers across industries such as cotton, cattle, and forestry to ensure a consistent and scalable substrate supply. Given the NT's seasonal variability and geographic remoteness, it is essential to establish long-term partnerships and logistics solutions to manage supply fluctuations and secure a stable supply. Once the agricultural waste is received, it must be properly stored to maintain its quality. For instance, with the current capacity of the cotton gin, approximately 2,500 to 3,000 tons of cotton trash can be collected each season. In addition, a few tons of supplementary substrate ingredients, such as sawdust from local milling industries, can be sourced, along with smaller quantities of other crop residues, to optimise the substrate formulation. Furthermore, a limited amount of cattle waste from local farms can be incorporated to enhance nitrogen levels in the substrate. Therefore, ensuring proper storage facilities and adequate space allocation is essential to maintain substrate quality and support consistent mushroom production (Krishnappa et al., 2022; Rahatkar and Rathod, 2021) . In the NT, an undercover storage space can keep feedstock dry, reducing the chance of moulding and associated contamination. Preparing the waste into a suitable substrate requires appropriate infrastructure to carry out all essential steps, including grinding, mixing, soaking, sterilisation, and bagging. Additionally, dedicated incubation rooms

are needed for mycelium development, followed by fruiting chambers for mushroom growth. These chambers must be properly equipped to monitor and control critical environmental factors, such as humidity, temperature, light, and airflow, to maintain optimal growing conditions, especially during the NT's hot and humid wet season.

d) **Shelf-S life, logistics and distribution**: Due to the perishable nature of mushrooms and the long transport distance from the NT to major markets, it is essential to select species/ varieties with longer shelf life and optimise growing conditions to ensure that product quality is maintained throughout the supply chain. These factors are closely linked to logistics and distribution, as the success of marketing channels depends heavily on the ability to deliver fresh produce to market. Proper packaging and the use of well-equipped transportation systems with controlled temperature and humidity are critical to preserving mushroom quality during transit. Without efficient post-harvest handling and distribution infrastructure, mushrooms are highly susceptible to spoilage, resulting in reduced market value and increased losses (Oliveira et al., 2012).

Key elements of a mushroom production business model

a) Feasibility **assessment and Infrastructure Planning**: Analysing local and external demand and supply for specific mushroom species is a key step in developing a viable business. It is essential to conduct a thorough cost-benefit analysis for planning the necessary infrastructure and materials, such as the type of mushroom and its spawn, substrate materials, sterilisation equipment, rental space, utilities, and initial production sheds that can later be upgraded with automated environmental control systems, especially where manual handling is limited. Estimating all fixed and variable costs alongside conservative revenue projections is critical for evaluating business feasibility. This initial analysis helps determine the appropriate scale of operations and identify the break-even point, providing a foundation for gradual business expansion (Alcalde-Calonge et al., 2022; Osterwalder, 2010; Viriato et al., 2024). In the NT, infrastructure and equipment costs are generally higher than in major cities, and the supply chain often involves longer lead times due to geographic isolation. These regional conditions should be fully factored into the business planning process. However, businesses can access Commonwealth and NT government initiatives such as Northern Australia Development Program, Business Innovation Program and Business Growth Program to help offset these disadvantages.

b) **Supply chain for raw materials**: Once the production plans are secured, establishing relationships with suppliers to ensure a steady supply of raw materials, such as agricultural waste, is essential (Sharma, 2015). In the NT, this includes sourcing the availability of residue/ waste from locally grown crops like cotton, millet, sesame, hay and industry, such as cotton gin trash. However, transporting these materials to mushroom cultivation sites can be challenging due to the NT's vast distances and logistical constraints. Therefore, optimising supply chain efficiency by balancing transportation costs with consistent access to substrate materials, spawn, and markets will be critical for sustainable production (Viriato et al., 2024). Furthermore, a rapid turnover of waste materials is important when considering storing waste, as the NT's hot and humid climate can cause undesirable premature composting or contamination.

c) **Professional understanding of local conditions and effective partnerships:** Employing local experts familiar with climatic variations, market conditions, and regional opportunities is imperative. Collaboration with the Australian Mushroom Growers Association and/or other local professionals can support the adoption of new

Table 4
Mushroom Production Business Model: Northern Territory (NT) Context.

Key Factor	Key Aspects	Opportunities	Challenges
Species Choice	Selecting species suited to the local substrate & climate. Heat-tolerant species: Oyster, Shiitake, Button, Paddy Straw, Milky mushrooms.	• Abundant local waste (cotton, cattle, forestry). • Tropical climate promotes rapid growth.• Reduces energy needs for cooling.	• Requires careful selection to match specific substrate types and seasonal conditions.
Spawn Supply	Sourcing high-quality, contamination-free spawn from reliable suppliers or establishing a local facility. Requires sterile techniques and training.	• Local spawn facility provides income and industry control.• Collaboration with experts builds local knowledge.	• Limited local training and expertise. • Logistical and economic challenges in consistent sourcing.• High risk of contamination without proper skills.
Waste Sourcing & Substrate Preparation	Building a broad supplier network for consistent substrate supply (cotton gin trash, sawdust, cattle waste). Requires storage and processing infrastructure.	• Utilises low-cost, abundant agricultural by-products.• add value to the waste streams.	• Seasonal variability and geographic remoteness. • High infrastructure cost for grinding, mixing, sterilisation.• Hot, humid climate risks premature composting/moulding.
Shelf-life & Distribution	Selecting species with longer shelf-life. Critical need for proper packaging and temperature-controlled transport.	• Access to major markets with high-quality produce.	• High perishability of mushrooms. • Long transport distances to markets increase spoilage risk.• Requires significant investment in cold chain logistics.
Feasibility & Infrastructure	Conducting cost-benefit analysis, demand assessment, and planning for infrastructure (sheds, equipment). Scale operations based on break-even analysis.	• Government grants and programs can offset high costs (e.g., Northern Australia Development Program).• Potential for gradual expansion and automation.	• Higher infrastructure and equipment costs than in major cities.• Long supply chain lead times due to geographic isolation.
Supply Chain & Partnerships	Establishing reliable raw material supply chains. Partnering with local experts and industry bodies (e.g., Australian Mushroom Growers Association).	• Local expertise helps navigate unique environmental/social conditions.• Partnerships support technology adoption and problem-solving.	• Vast distances and logistics increase transport costs. • Past failures due to poor understanding of local conditions.• Managing contamination/ disease requires expert knowledge.
Production & Environment	Maintaining optimal species-specific conditions (temp, humidity, pH). Knowledge of all growth stages from spawning to harvest.	• Tropical climate is ideal for heat-tolerant species.• Using solar energy can offset high energy costs.	• Requires precise environmental control, especially during the hot, humid wet season.• Need for knowledge in all pre-harvest activities.
Workforce Development	Investing in training programs and workshops. Engaging Indigenous communities and using expert exchange programs.	• Builds long-term socio-economic resilience.• Expands the local talent pool and supports business scalability.	• Scarcity of labour and difficulty retaining skilled professionals in the NT.

technologies to improve production efficiency. Professional partnerships can also help address challenges such as maintaining proper substrate-to-waste ratios, optimising C: N ratio, ensuring nutrient balance, and managing contamination and diseases (including controlling bacterial diseases such as bacterial yellowing, brown blotch, soft rot, and stipe necrosis, as well as fungal diseases like dry bubble, green mould, brown spots, and cobweb) (Choi et al., 2003; Jarial et al., 2024; Nongthombam et al., 2021). In the NT, engaging local expertise is particularly critical, as past business failures by interstate and overseas investors were often due to a poor understanding of the region's unique environmental and social conditions (Filippov, 2025).

d) **Production** aspects: Once the infrastructure is established and the key substrates are selected, it is important to maintain optimal environmental conditions, particularly substrate temperature, relative humidity, and pH, according to the requirements of each species. For instance, oyster mushrooms, especially pink and warm-weather varieties, thrive at temperatures between 24–28 °C. Milky mushrooms (*C.indica*) perform best at 28–30 °C (Subbiah and Balan, 2015), while reishi mushrooms (*G. lucidum*) grow well within a range of 25–30 °C (Van der Berg, 2018), making all suitable for tropical climates. Similarly, straw mushrooms (*V. volvacea*) grow optimally at 28–30 °C with around 85 % humidity and yield the best results when the substrate pH is maintained between 6.5 and 7 (Akcay et al., 2023; Uddin et al., 2011). Additionally, essential knowledge of pre-harvest activities is required, including several stages starting from spawn preparation, followed by substrate inoculation, the colonisation period, and finally, fruiting and harvesting. Lastly, when aiming to save costs and space in regions like the NT with year-round sunshine, it's worth considering investing in small container sheds designed to serve as incubation chambers and growth facilities, equipped with solar panels. Using solar-battery systems can help offset energy costs and reduce overall expenses (Rukhiran et al., 2023).

e) **Suitability of species against the availability of waste:** Selecting mushroom species that are commercially viable and compatible with locally available substrates is crucial for sustainable cultivation and marketability. Particularly in tropical regions like the NT, where high temperatures and humidity prevail for most of the year (Australian Bureau of Statistics, 2021). Ideal candidates are those capable of thriving on a range of agro-industrial by-products while requiring minimal inputs, thereby enabling low-cost production. Oyster mushrooms are especially adaptable and are popular among customers, capable of growing on materials such as hay, cotton waste, rice husks, sawdust and paper waste, particularly when supplemented with wheat or rice bran and gypsum (Getachew et al., 2019; Khan et al., 2017). Similarly, straw mushrooms (*V. volvacea*) are well-suited to tropical climates, making them a promising option for the NT (Ahlawat et al., 2011). Importantly, both species can be initially cultivated on a small scale using locally abundant waste from the cotton and cattle industries, offering a low-risk approach to evaluate their performance, with the potential for expansion if early trials prove successful.

f) Workforce **Development**: The economic prosperity of a region is increasingly linked to the skills and capabilities of its workforce. To build a sustainable and successful business, it is essential to invest in the overall development of talent through well-structured training programs and workshops. In the NT, labour scarcity and the challenge of retaining skilled professionals have been persistent barriers to the growth of many industries. Expanding the talent pool through stronger workforce development systems, combined with training programs that engage Indigenous communities and support regional employment, not only promotes individual professional growth but also strengthens business scalability and long-term socio-economic resilience (Garmise, 2009). Initiatives that bring in experienced professionals to train aspiring mushroom cultivators through short-term visits and exchange programs can help fill the knowledge gap. This exchange not only disseminates valuable knowledge but also generates economic benefits for the region by enhancing local capacity building. Table 4 provides a concise overview of the mushroom production business model.

Conclusion

Mushroom cultivation holds global significance, and this review summarises key knowledge of the mushroom industry globally and in Australia while highlighting the Northern Territory's potential for future industry development. Recycling cotton, cattle and other local agricultural wastes for mushroom cultivation presents a sustainable, "waste-to-wealth" model for industry development. Environmentally, this approach enhances resource efficiency, minimises agricultural waste, and promotes circular economy principles. Economically, it creates new revenue streams and promotes cross-industry partnerships. Socially, it can generate employment opportunities and enhance community support, especially for Indigenous people, contributing to the NT's broader sustainable development goals. The success of mushroom businesses in the NT will rely on locally suitable species and varieties, efficient substrate sourcing, spawn and feedstock handling, climate-resilient infrastructure, and strong workforce development. Business models should consider local conditions, including the hot, humid, and variable climate, as well as higher logistics and infrastructure costs. Utilising government support available for regional innovation is crucial to ensure long-term industry viability. The biggest challenges, however, remain geographic isolation and remoteness, which significantly affect supply chains, market access, and production scalability.

Limitations and future work

This analysis is subject to some limitations, as it is based on literature and desktop review, with limited empirical data on production, market demand, and consumer preferences. The findings should therefore be considered as general guidance, with on-the-ground studies required for validation. Future work will focus on developing locally adapted substrate recipes, conducting detailed nutrient analyses, and undertaking comprehensive economic modelling. Additionally, surveys on mushroom consumption and purchasing habits in the NT will be essential to strengthen market understanding.

CRediT authorship contribution statement

Waseem Ahmed: Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Yujuan Li:** Writing – review & editing, Supervision. **Edward Mwando:** Writing – review & editing, Supervision. **Kamaljit Sangha:** Writing – review & editing, Supervision. **Tham Dong:** Supervision. **Cheng-Yuan Xu:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Bhalerao, V., Gaikwad, A., Deokar, C., Raghuwanshi, K., 2019. The mystical world of mushrooms. Advancing Frontiers in Mycology & Mycotechnology: Basic and Applied Aspects of Fungi 3–48. https://doi.org/10.1007/978-981-13-9349-5_1.

Raghukumar, S., Raghukumar, S., 2017. In: "fungi: Characteristics and Classification," *Fungi in Coastal and Oceanic Marine Ecosystems:*. Marine fungi, pp. 1–15. https://doi.org/10.1007/978-3-319-54304-8_1.

Stajich, J.E., et al., 2009. The fungi. Current Biology 19 (18), R840–R845. https://doi.org/10.1016/j.cub.2009.07.004.

Niksic, M., Klaus, A., Argyropoulos, D., 2016. "Safety of foods based on mushrooms," in *Regulating Safety of Traditional and Ethnic Foods*. Elsevier 421–439.

Grimm-Samuel, V., 1991. On the mushroom that deified the Emperor Claudius. The Classical Quarterly 41 (1), 178–182. https://doi.org/10.1017/S0009838800003657.

Van der Berg, C., 2018. Industrial and medicinal application of Reishi and Lion's Mane mushrooms [Master's thesis. University of the Free State]. University of the Free State Repository.

Varghese, R., Dalvi, Y.B., Lamrood, P.Y., Shinde, B.P., Nair, C., 2019. Historical and current perspectives on therapeutic potential of higher basidiomycetes: an overview. 3 Biotech 9, 1–15. https://doi.org/10.1007/s13205-019-1886-2.

Broom, F., 2023. Mushroom sales are shooting up as people look to reduce meat consumption and boost their health. ABC Rural. https://www.abc.net.au/news/rural/2023-05-15/mushrooms-increasingly-in-demand-as-meat-alternative/102325544.

Shirur, M., Barh, A., Annepu, S.K., 2021. In: "sustainable Production of Edible and Medicinal Mushrooms: Implications on Mushroom Consumption," *Climate Change and Resilient Food Systems:*. Issues, Challenges, and Way Forward, pp. 315–346.

Valverde, M.E., Hernández-Pérez, T., Paredes-López, O., 2015. Edible mushrooms: improving human health and promoting quality life. International Journal of Microbiology 2015 (1), 376387. https://doi.org/10.1155/2015/376387.

Zhang, M., Cui, S.W., Cheung, P.C., Wang, Q., 2007. Antitumor polysaccharides from mushrooms: a review on their isolation process, structural characteristics and antitumor activity. Trends in Food Science & Technology 18 (1), 4–19. https://doi.org/10.1016/j.tifs.2006.07.013.

Elyson, S., Jonathan, C., Kudakwashe, C., Loice, C.. Evaluation of wheatstraw, sawdust, banana fronds, maize cobs and cotton hulls substrate combinations for Pleurotus ostreatus cultivation. https://doi.org/10.21203/rs.3.rs-4831136/v1.

Falch, B.H., Espevik, T., Ryan, L., Stokke, B.T., 2000. The cytokine stimulating activity of (1→ 3)-β-D-glucans is dependent on the triple helix conformation. Carbohydrate Research 329 (3), 587–596. https://doi.org/10.1016/S0008-6215(00)00222-6.

Kosre, A., Koreti, D., Mahish, P.K., Chandrawanshi, N.K., 2021. Current perspective of sustainable utilization of agro waste and biotransformation of energy in mushroom. *Energy: crises, challenges and solutions*, pp. 274–302.

Nicolcioiu, M.B., Popa, G., Matei, F., 2016. Mushroom mycelia cultivation on different agricultural waste substrates. Scientific Bulletin. Series f. Biotechnologies 20, 148–153.

Udayasimha, L., Vijayalakshmi, Y., 2012. Sustainable waste management by growing mushroom (Pleurotus florida) on anaerobically digested waste and agro residues. Int. J. Eng. Res. Technol 1 (5).

Kumla, J., et al., 2020. Cultivation of mushrooms and their lignocellulolytic enzyme production through the utilization of agro-industrial waste. Molecules 25 (12), 2811. https://doi.org/10.3390/molecules25122811.

Hort Innovation. (2020–2024). Horticulture Innovation Australia Limited. https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/mt21006/.

Beyer, D. M. (2023). Impact of the mushroom industry on the environment. Penn State Extension. https://extension.psu.edu/impact-of-the-mushroom-industry-on-the-environment.

Shakil, M.H., Tasnia, M., Munim, Z.H., Mehedi, M.H.K., 2014. Mushroom as a mechanism to alleviate poverty, unemployment and malnutrition. Asian Bus Rev 4 (9), 31–34.

Zhang, Y., Geng, W., Shen, Y., Wang, Y., Dai, Y.-C., 2014. Edible mushroom cultivation for food security and rural development in China: bio-innovation, technological dissemination and marketing. Sustainability 6 (5), 2961–2973.

Zikriyani, H., Saskiawan, I., Mangunwardoyo, W., 2018. Utilization of agricultural waste for cultivation of paddy straw mushrooms (Volvariella volvacea (Bull.) Singer, 1951). International Journal of Agricultural Technology 14 (5), 805–814.

Amuneke, E., Dike, K., & Ogbulie, J. (2011). Cultivation of Pleurotus ostreatus: An edible mushroom from agro base waste products.

Besufekad, Y., Tadesse, T., Abebe, M., 2020. Selection of appropriate substrate for production of oyster mushroom (Pleurotus ostreatus). Journal of Yeast and Fungal Research 11 (1), 15–25.

Burke, P. (2022, November 28, 2022). *Growing the Economy* https://ntfarmers.org.au/growing-the-economy/#:~:text=News%2C%20Press%20Release%2C%20Updates,'.

Antikainen, R., Lazarevic, D., Seppälä, J., 2018. Circular economy: Origins and future orientations. Factor X: Challenges, implementation strategies and examples for a sustainable use of natural resources, pp. 115–129.

MacArthur, E., 2013. Towards the circular economy. Journal of Industrial Ecology 2 (1), 23–44.

Velenturf, A.P., Purnell, P., 2021. Principles for a sustainable circular economy. Sustainable Production and Consumption 27, 1437–1457. https://doi.org/10.1016/j.spc.2021.02.018.

Viriato, V., Carvalho, S.A.D.d., Santoro, B.d.L., Bonfim, F.P.G., 2024. A Business Model for Circular Bioeconomy: Edible Mushroom Production and Its Alignment with the Sustainable Development Goals (SDGs). Recycling 9 (4), 68. https://doi.org/10.3390/recycling9040068.

Wamucii, S., 2024. Australia mushrooms & truffles prices. https://www.selinawamucii.com/insights/prices/australia/mushrooms/.

Winans, K., Kendall, A., Deng, H., 2017. The history and current applications of the circular economy concept. Renewable and Sustainable Energy Reviews 68, 825–833.

Kopnina, H., Boatta, F., Baranowski, M., de Graad, F., 2022. Examining the feasibility of circular economy in the food industry. Separating Aspirations from Reality, The Impossibilities of the Circular Economy.

Oyedele, O., Adeosun, M., Koyenikan, O., 2018. Low cost production of mushroom using agricultural waste in a controlled environment for economic advancement. Int J Waste Resource 8 (1), 1–5.

Munshi, N.A., Dar, G.H., Ghani, M., Kauser, S., Mughal, N., 2010. Button mushroom cultivation. Communication and Publication Centre SKUAST-K 1, 1–33. https://doi.org/10.33545/26174693.2024.v8.i2Se.600.

Jahangir, M.M., Samin, G., Khan, N.A., Rehman, A., Aslam, Z., Amjad, M., Ziaf, K., Qadri, R.W., Khan, I., Atiq, M., 2015. Performance of oyster mushroom (Pleurotus ostreatus) grown on cotton waste and sorghum straw based growing substrates. Pakistan Journal of Phytopathology 27 (1), 77–81.

Khan, M.W., Ali, M., Farooq, M., 2011. Growth response of oyster mushroom (PleurotusOstreatus) by using different methods of spawning raised on cotton waste. Pak. J. Phytopathol 23 (2), 156–158.

Rakib, M.R.M., Lee, A.M.L., Tan, S.Y., 2020. Corn husk as lignocellulosic agricultural waste for the cultivation of Pleurotus florida mushroom. BioResources 15 (4), 7980.

Sardar, A., Satankar, V., Jagajanantha, P., Mageshwaran, V., 2020. Effect of substrates (cotton stalks and cotton seed hulls) on growth, yield and nutritional composition of two oyster mushrooms (Pleurotus ostreatus and Pleurotus florida). J. Cotton Res. Dev 34 (1), 135–145.

Orngu, O., Nwaoha, I., Unagwu, B., Etim, V., 2021. Oyster mushroom (Pleurotus ostreatus) cultivation using sawdust and different organic manures. Asian Food Science Journal 20, 67–74. https://doi.org/10.9734/AFSJ/2021/v20i530299.

He, M.-Q., Zhao, R.-L., Liu, D.-M., Denchev, T.T., Begerow, D., Yurkov, A., Kemler, M., Millanes, A.M., Wedin, M., McTaggart, A.R., 2022. Species diversity of Basidiomycota. Fungal diversity 114 (1), 281–325.

Hendrika, A., Soffan, A., Althaf, M., Amanda, S., Fani, R., Tampubolon, P., Lestari, R., 2021. Application and composition of sawdust, grass straw, rice husk, and rice bran for white oyster mushroom (Pleurotus ostreatus Jacq.) growth media using hydrated lime sterilization. AIP Conference Proceedings.

Hou, L., Li, Y., Chen, M., Li, Z., 2017. Improved fruiting of the straw mushroom (Volvariella volvacea) on cotton waste supplemented with sodium acetate. Applied Microbiology and Biotechnology 101, 8533–8541. https://doi.org/10.1007/s00253-017-8476-1.

Daranagama, D.A., 2023. From Decomposers to Superheroes": Unleashing the Hidden Powers of Fungi to Save Our Planet. Journal of Desk Research Review and Analysis 1 (1).

Das, A.K., et al., 2021. Edible mushrooms as functional ingredients for development of healthier and more sustainable muscle foods: a flexitarian approach. Molecules 26 (9), 2463. https://doi.org/10.3390/molecules26092463.

Sharif, S., Mustafa, G., Munir, H., Weaver, C.M., Jamil, Y., Shahid, M., 2016. Proximate composition and micronutrient mineral profile of wild Ganoderma lucidum and four commercial exotic mushrooms by ICP-OES and LIBS. Journal of Food and Nutrition Research 4 (11), 703–708. https://doi.org/10.12691/jfnr-4-11-1.

Eguchi, F., Kalaw, S. P., Dulay, R. M. R., Miyasawa, N., Yoshimoto, H., Seyama, T., & Reyes, R. G. (2015). Nutrient composition and functional activity of different stages in the fruiting body development of Philippine paddy straw mushroom, Volvariella volvacea (Bull.: Fr.) Sing. *Advances in Environmental Biology*, *9*(22 S3), 54-66.

Bell, V., Silva, C., Guina, J., Fernandes, T., 2022. Mushrooms as future generation healthy foods. Frontiers in Nutrition 9, 1050099. https://doi.org/10.3389/fnut.2022.1050099.

Atlas, Scientific., 2023. The ultimate guide to small-scale mushroom farming. Atlas Scientific Environmental Robotics. https://atlas-scientific.com/blog/small-scale-mushroom-farming/.

Australian Bureau of Statistics, 2021. Australian Statistical Geography Standard (ASGS): Local government areas. Australian Government. https://www.abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs.

Australian Mushroom Growers, Association.. Mushroom annual investment plan. https://australianmushroomgrowers.com.au.

Balan, V., et al., 2022. Challenges and opportunities in producing high-quality edible mushrooms from lignocellulosic biomass in a small scale. Applied Microbiology and Biotechnology 106 (4), 1355–1374. https://doi.org/10.1007/s00253-021-11749-2.

Cheung, P.C., 2013. Mini-review on edible mushrooms as source of dietary fiber: Preparation and health benefits. Food Science and Human Wellness 2 (3–4), 162–166. https://doi.org/10.1016/j.fshw.2013.08.001.

Prateep Na Talang, R., Na Sorn, W., Polruang, S., Sirivithayapakorn, S., 2024. Alternative crop residue management practices to mitigate the environmental and economic impacts of open burning of agricultural residues. Scientific Reports 14 (1), 14372. https://doi.org/10.1038/s41598-024-65389-3R.

Quaicoe, O., Asiseh, F., Aloka, A.S., 2024. Enhancing year-round profitability for small-scale ranchers: An economic analysis of integrated cattle and mushroom production system. Sustainability 16 (13), 5320. https://doi.org/10.3390/su16135320.

Grimm, D., Wösten, H.A., 2018. Mushroom cultivation in the circular economy. Applied microbiology and biotechnology 102, 7795–7803. https://doi.org/10.1007/s00253-018-9226-8.

Chudleigh, P., 2011. *An Economic Analysis of HAL Investment in the Communication and.* Extension.

Cunha Zied, D., Sánchez, J.E., Noble, R., Pardo-Giménez, A., 2020. Use of spent mushroom substrate in new mushroom crops to promote the transition towards a circular economy. Agronomy 10 (9), 1239.

Hu, W., Di, Q., Liang, T., Liu, J., Zhang, J., 2022. Effects of spent mushroom substrate biochar on growth of oyster mushroom (Pleurotus ostreatus). Environmental Technology & Innovation 28, 102729. https://doi.org/10.1016/j.eti.2022.102729.

Koutrotsios, G., Mountzouris, K.C., Chatzipavlidis, I., Zervakis, G.I., 2014. Bioconversion of lignocellulosic residues by Agrocybe cylindracea and Pleurotus ostreatus mushroom fungi–assessment of their effect on the final product and spent substrate properties. Food Chemistry 161, 127–135. https://doi.org/10.1016/j.foodchem.2014.03.121.

M. Singh, S. Kamal, and V. P. Sharma, "Status and trends in world mushroom production-III-World Production of different mushroom species in 21st century," *Mushroom Research,* vol. 29, no. 2, 2020, doi: DOI:10.36036/MR.29.2.2020.113703.

Li, C., Xu, S., 2022. Edible mushroom industry in China: current state and perspectives. Applied Microbiology and Biotechnology 106 (11), 3949–3955. https://doi.org/10.1007/s00253-022-11985-0.

Horticulture Innovation Australia. (2020, 2023, 2024). Australian horticulture statistics handbook [Online]. https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/australian-horticulture-statistics-handbook.

Best, P. (2022). ***Financial review*** https://www.afr.com/life-and-luxury/food-and-wine/why-australia-s-chefs-are-going-wild-for-exotic-mushrooms-20220823-p5bc6l.

Hort Innovation. (2020). Recycled organics as an alternative to peat in mushroom casing trials. Australian Mushrooms Journal, (2). https://agora.australianmushrooms.com.au/wp-content/uploads/2020/06/JOURNAL-2020-EDITION-2-FINAL.pdf.

Ahmed, W., Xu, C., Mwando, E., 2024. Utilizing cotton waste to grow mushrooms [Newsletter]. Agriculture and Biosecurity Newsletter. https://daf.nt.gov.au/publications/agriculture/newsletters/agriculture-and-biosecurity/agriculture-and-biosecurity-newsletter-february-2024.

Northern Territory Government (2023), Field crops. https://industry.nt.gov.au/publications/primary-industry-publications/publications-search.

Fitzgerald, R., 2023. May 24). NT agribusiness strategy eyes new cropping, cotton gins in aim to grow sector to $2 billion. ABC News. https://www.abc.net.au/news/2023-05-24/nt-agribusiness-strategy-2030-crops-land-clearing-cotton-gins/102382600.

Aslam, S., Khan, N.A., Hassan, M.H., 2022. Use of peanut (Arachis hypogaea) shells waste along with different agricultural wastes for the cultivation of Pleurotus pulmonarius. Agricultural Sciences Journal 4 (1), 63–70. https://doi.org/10.56520/asj.v4i1.130.

Raymond, P., Mshandete, A.M., Kivaisi, A.K., 2013. Cultivation of oyster mushroom (Pleurotus HK-37) on solid sisal waste fractions supplemented with cow dung manure. Journal of Biology and Life Science 4 (1), 273–286. https://doi.org/10.5296/jbls.v4i1.2975.

Orngu, O., Mbaeyi-Nwaoha, I., Unagwu, B., Etim, V., 2021. Oyster mushroom (Pleurotus ostreatus) cultivation using sawdust and different organic manures. Asian Food Science Journal 20 (5), 67–74. https://doi.org/10.9734/AFSJ/2021/v20i530299.

Akinyele, B., Adetuyi, F., 2005. Effect of agrowastes, pH and temperature variation on the growth of *Volvariella volvacea*. African Journal of Biotechnology 4 (12).

Osunde, M.O., Olayinka, A., Fashina, C.D., Torimiro, N., 2019. Effect of Carbon-Nitrogen ratios of lignocellulosic substrates on the yield of mushroom (Pleurotus pulmonarius). Open Access Library Journal 6 (10), 1–8.

Gerrits, J., 1977. The significance of gypsum applied to mushroom compost, in particular in relation to the ammonia content. Netherlands Journal of Agricultural Science 25 (4), 288–302.

Godwin, S.. NSW Farmers: Growing the best. NSW Farmers' Association. https://www.nswfarmers.org.au/NSWFA/NSWFA/Posts/The_Farmer/Innovation/Australian_mushroom_growers_the_crop_taking_off.aspxS.

Gracey, M., King, M., 2009. Indigenous health part 1: Determinants and disease patterns. The Lancet 374 (9683), 65–75. https://doi.org/10.1016/S0140-6736(09)60914-4.

Suwannarach, N., Kumla, J., Zhao, Y., Kakumyan, P., 2022. Impact of cultivation substrate and microbial community on improving mushroom productivity: a review. Biology 11 (4), 569.

Cooke, J. (2024). *Under Cover Vegetable Growing in Australia - Market Research Report (2014-2029)* https://www.ibisworld.com/australia/industry/under-cover-vegetable-growing/2055/.

Thakur, M. (2014). Present status and future prospects of tropical mushroom cultivation in India: a review.

Springer, N.P., et al., 2015. Sustainable sourcing of global agricultural raw materials: Assessing gaps in key impact and vulnerability issues and indicators. PLoS One 10 (6), e0128752.

Krishnappa, M., Kantharaja, R., Puneeth, M., 2022. "Mushroom Cultivation using Agricultural Wastes," in *Sustainable utilization of Fungi in Agriculture and Industry*. Bentham Science Publishers 134–148.

Rahatkar, T.A., Rathod, M.G., 2021. Arrangement and necessary infrastructure for oyster mushroom cultivation. Research Insights of Life Science Students 3, 717–719.

Singh, P., Langowski, H.C., Wani, A.A., Saengerlaub, S., 2010. Recent advances in extending the shelf life of fresh Agaricus mushrooms: a review. Journal of the Science of Food and Agriculture 90 (9), 1393–1402.

Oliveira, F., Sousa-Gallagher, M., Mahajan, P., Teixeira, J., 2012. Development of shelf-life kinetic model for modified atmosphere packaging of fresh sliced mushrooms. Journal of Food Engineering 111 (2), 466–473.

Osterwalder, A., 2010. Business model generation: a handbook for visionaries, game changers, and challengers, ed: John Wiley & Sons.

Alcalde-Calonge, A., Sáez-Martínez, F.J., Ruiz-Palomino, P., 2022. Evolution of research on circular economy and related trends and topics. a thirteen-year review. Ecological Informatics 70, 101716. https://doi.org/10.1016/j.ecoinf.2022.101716.

Sharma, K., 2015. Mushroom: Cultivation and processing. International Journal of Food Processing Technology 5, 9–12. https://doi.org/10.15379/2408-9826.2018.05.02.02.

Nongthombam, J., Kumar, A., Ladli, B., Madhushekhar, M., Patidar, S., 2021. A review on study of growth and cultivation of oyster mushroom. Plant Cell Biotechnology and Molecular Biology 22 (5–6), 55–65.

Choi, I.-Y., Joung, G.-T., Ryu, J., Choi, J.-S., Choi, Y.-G., 2003. Physiological characteristics of green mold (Trichoderma spp.) isolated from oyster mushroom (Pleurotus spp.). Mycobiology 31 (3), 139–144.

Jarial, R., Jarial, K., Bhatia, J., 2024. Comprehensive review on oyster mushroom species (Agaricomycetes): Morphology, nutrition, cultivation and future aspects. Heliyon 10 (5).

Filippov, N., 2025. 9 Key Reasons Why Small Businesses Fail in Australia. https://annamoney.au/blog/guides/why-do-small-businesses-fail-in-australia/.

Subbiah, K.A., Balan, V., 2015. A comprehensive review of tropical milky white mushroom (Calocybe indica P&C). Mycobiology 43 (3), 184–194. https://doi.org/10.5941/MYCO.2015.43.3.184.

Akcay, C., Ceylan, F., Arslan, R., 2023. Production of oyster mushroom (Pleurotus ostreatus) from some waste lignocellulosic materials and FTIR characterization of structural changes. Scientific Reports 13 (1), 12897. https://doi.org/10.1038/s41598-023-40200-x.

Uddin, M., Yesmin, S., Khan, M., Tania, M., Moonmoon, M., Ahmed, S., 2011. Production of oyster mushrooms in different seasonal conditions of Bangladesh. Journal of Scientific Research 3 (1), 161–167. https://doi.org/10.3329/jsr.v3i1.6130.

Rukhiran, M., Sutanthavibul, C., Boonsong, S., Netinant, P., 2023. IoT-based mushroom cultivation system with solar renewable energy integration: Assessing the sustainable impact of the yield and quality. Sustainability 15 (18), 13968. https://doi.org/10.3390/su151813968.

Getachew, A., Keneni, A., Chawaka, M., 2019. Production of oyster mushroom (Pleurotus ostreatus) on substrate composed from wheat straw, waste paper and cotton seed waste. International Journal of Microbiology and Biotechnology 4 (2), 38–44.

Khan, N.A., Amjad, A., Binyamin, R., Rehman, A., Hafeez, O.B.A., 2017. Role of various supplementary materials with cotton waste substrate for production of Pleurotus ostreatus an oyster mushroom. Pakistan Journal of Botany 49 (5), 1911–1915.

Ahlawat, O., Singh, R., Kumar, S., 2011. Evaluation of Volvariella volvacea strains for yield and diseases/insect-pests resistance using composted substrate of paddy straw and cotton mill wastes. Indian Journal of Microbiology 51 (2), 200–205.

Garmise, S., 2009. Building a workforce development system as an economic development strategy: Lessons from US programs. Local Economy 24 (3), 211–223. https://doi.org/10.1080/02690940802645497.