Turning Trash into Treasure: Utilizing Sericultural Wastes in Mushroom Cultivation

ABSTRACT

The burgeoning sericulture industry generates substantial organic waste, posing environmental challenges. This study explores the promising avenue of utilizing these wastes for mushroom cultivation. Investigations demonstrate successful growth of diverse mushrooms, including oyster and button varieties, on substrates composed of silkworm excreta, spent mulberry leaves, and pupal cocoons. These sericulture-based substrates offer distinct advantages like readily available resources, reduced environmental footprint, and inherent nutrient content. However, knowledge gaps remain regarding the optimal substrate composition, compatibility with a wider range of mushrooms, and the feasibility of large-scale implementation. Further research is needed to address these gaps and delve into areas like regional protocols, life cycle assessments, and consumer education. This review comprehensively examines the current state of knowledge and the exciting future potential of this approach. Transforming silk leftovers into valuable resources for mushroom cultivation paves the way for a more sustainable future, promoting food security, environmental well-being, and economic opportunities.

*Keywords:*Sericultural waste, Mushroom cultivation, Sustainability, Waste management, Nutrient-rich substrates, Food security

1. INTRODUCTION

Food insecurity is a significant global challenge, especially in low- and middle-income countries with insufficient food production systems, resulting in widespread malnutrition [1]. Mushroom cultivation holds the potential to alleviate poverty and enhance the livelihoods of marginalized communities [2]. It is beneficial for human consumption, with some species being edible and others being toxic [3]. Mushroom cultivation has progressed through wood-log and non-wood-log methods, mainly driven by mushroom companies and the experiences of farmers [4]. Researchers and experts have played a key role in improving technology for existing mushroom species and exploring cultivation techniques for new ones [4]. Mushrooms, although they lack roots, do not grow without support. They depend on a crucial base known as substrate, serving as a nutritional and structural environment for their development. Selecting the appropriate substrate is essential for prosperous mushroom cultivation, impacting the yield, quality, and even the taste of the mushrooms. The substrates utilized for mushroom production in past research encompass a variety of materials such as rice straw, rice bran, wheat straw, pulp, corncobs, cocoa shell waste, cotton waste, spent grain, sawdust, maize husks, and cassava peelings [3, 5]. The additional substrates used for mushroom production include soybean straw, paddy straw, sunflower stalks, sugarcane bagasse, fruit waste, used tea leaves, bamboo leaves, and maize stalk [2, 6, 7].

At present, approximately 90% of the global mushroom production is attributed to six types of mushrooms viz., *Agaricus bisporus*, *Lentinula edodes*, *Auricularia spp*, *Pleurotus spp*, *Flammulina velutipes*, and *Volvariella volvacea*[8]. The mushroom production has grown significantly from 6,000 tons in the mid-1970s to over 60,000 tons by 2010 and to over 70,000 tons in 2018[8]. Mushrooms are currently in high demand as nutritious foods because they are low in calories, carbohydrates, fats, and sodium and they are cholesterol-free. Furthermore, mushrooms provide essential nutrients like selenium, potassium, riboflavin, niacin, vitamin D, proteins, and fiber.

The use of substrate in mushroom cultivation poses various challenges. This includes issues related to availability and cost, nutrient balance, contamination, moisture control, and sustainability. Researchers are investigating alternative substrates, such as agricultural waste and food scraps, to address these challenges. However, optimizing these options for different mushroom species presents further difficulties. Therefore, selecting and managing the appropriate substrate continues to be a complex task for mushroom cultivators, necessitating knowledge, adaptability, and ongoing innovation. Sericulture as an agro-based industry generating huge amount of waste during the operations such as pruning, rearing, reeling inthe form of branches, unconsumed leaves, litters, dead worm and pupa, cast of skin etc. Seri- waste including plant remnants, silkworm waste, pupal waste and protein by- products, must be efficiently utilized to make sericulture an attractive occupation for farmers [9]. These sericultural wastes are rich in nutrient and biodegradable in nature and can be used as a sustainable and cost-effective substrate for various mushroom species.By making use of this waste, the industry may enhance the production of healthy mushrooms while lessening the burden of disposal. Nevertheless, more investigation is required to optimize the composting process for various types of mushrooms.

2. SERICULTURAL WASTES IN COMMERCIAL MUSHROOM PRODUCTION

Mushrooms, belonging to the fungi kingdom, offer substantial nutritional benefits, with approximately 2000 edible species found globally [10]. Cultivating them requires specific conditions for optimal growth and yield. In the commercial mushroom industry, oyster mushrooms (*Pleurotus spp.*) stand out for their unique ability to colonize and break down a diverse range of lignocellulosic wastes, making them highly versatile [11].

Table 1.Cultivable species of mushroom for commercial purpose

Sl. no	Mushroom species	Common Name	Use	Distribution	Image
1	*Agaricus bisporus*	White Button	Food	North America	

2	*Agaricus subrufescens*	Almond Mushroom, Royal Sun Agaricus	Food, medicine	Brazil, China, and Japan	
3	*Agrocybe aegerita*	Black Poplar	food	Japan and Korea	
4	*Auricularia auricula*	Wood Ear, Jelly ear	Food, medicine	China	
5	*Calocybe indica*	Milky mushroom	Food	India	
6	*Cordyceps militaris*	Cordyceps	Medicine	Tibet, China, USA	
7	*Flamulina velutipes*	Enoki, Enokitake, Winter Mushroom	Food, Medicine	Japan, Asian countries	
8	*Ganoderma lucidum*	Reishi, Varnished conk	Medicine	Europe and China	
9	*Grifola frondosa*	Maitake, Sheep's Head, Ram's Head	Food, medicine	Japan, Asian countries, North America	
10	*Hypsizygus tessellatus*	Shimeji, Beech Mushrooms	Food	Japan, Asian countries	
11	*Lentinula edodes*	Shiitake	Food, medicine	worldwide	
12	*Pholiota adiposa*	Chestnut	Food	Europe	
13	*Pleurotus djamour*	Pink Oyster, Salmon Oyster	Food	Places with warmer climate	
14	*Pleurotus eryngii*	King Oyster, King Trumpets	Food	Southern Germany, Hungary, Slovakia,	

				Central Asia, Romania, China, Iran and North Africa	
15	*Pleurotus ostreatus*	Oyster	Food	Britain, Ireland, Europe, Japan, North America.	
16	*Pleurotus cintrinopileatus*	Yellow Oyster, Golden Oyster	Food	East Asia	
17	*Tremella fuciformis*	Jelly Fungus	Food, Medicine	Tropical and subtropical, Asia and North America.	
18	*Volvariella volvacea*	Paddy Straw Mushroom	Food	India, and other Asian countries	

Mushrooms, being heterotrophic organisms, rely on external nutrients for the growth of vegetative mycelium and the initiation of the reproductive stage (fructification) [12, 13]. As a result, a majority of cultivated mushrooms are saprophytic fungi or decomposers. These fungi can thrive on lignocellulosic substrates by generating various lignocellulosic enzymes that facilitate substrate degradation during their growth [12, 14].

The conventional methods of burning or landfill disposal for agro-industrial waste often led to environmental pollution, posing potential threats to human and wildlife health. An alternative approach to mitigate the negative environmental impact involves using agricultural materials as substrates for mushroom cultivation. The waste generated by industries such as agriculture, forestry, horticulture, textiles, and wood contain lignocellulosic substances suitable for mushroom growth [15]. In recent decades, extensive research has been conducted to optimize physical, chemical, and biological parameters, aiming to establish a cultivation process that effectively utilizes abundant agricultural and forestry wastes [16]. Mushrooms have emerged as highly efficient producers of food protein from otherwise considered worthless agro-wastes [17, 18].

Numerous organic residues, as indicated by Navi *et al.* in 2011, find application in mushroom cultivation, and sericulture waste emerges as a promising resource for composting when combined with mixed plant residues [19]. This waste, particularly the by-products of sericulture, has been explored by various researchers for its potential in mushroom cultivation, as highlighted by Reddy *et al.* in 2000 in oyster mushroom cultivation [20]. The effectiveness of different sericulture wastes in button mushroom cultivation was also documented by Reddy *et al.* in 2018 [21]. It can serve as substrates for mushroom cultivation due to their high availability and cost efficiency.

Within the sericulture industry, substantial quantities of waste from rearing trays are generated. Approximately 55% of the ingested leaf is digested, leaving the rest as ejected waste. It has been estimated that rearing 300 layings (with one laying equal to 400 eggs) per acre could yield about 2794 kg of litter annually [22]. This substantial waste output holds promise for efficient utilization in mushroom cultivation and biogas production, offering a means to minimize environmental pollution.

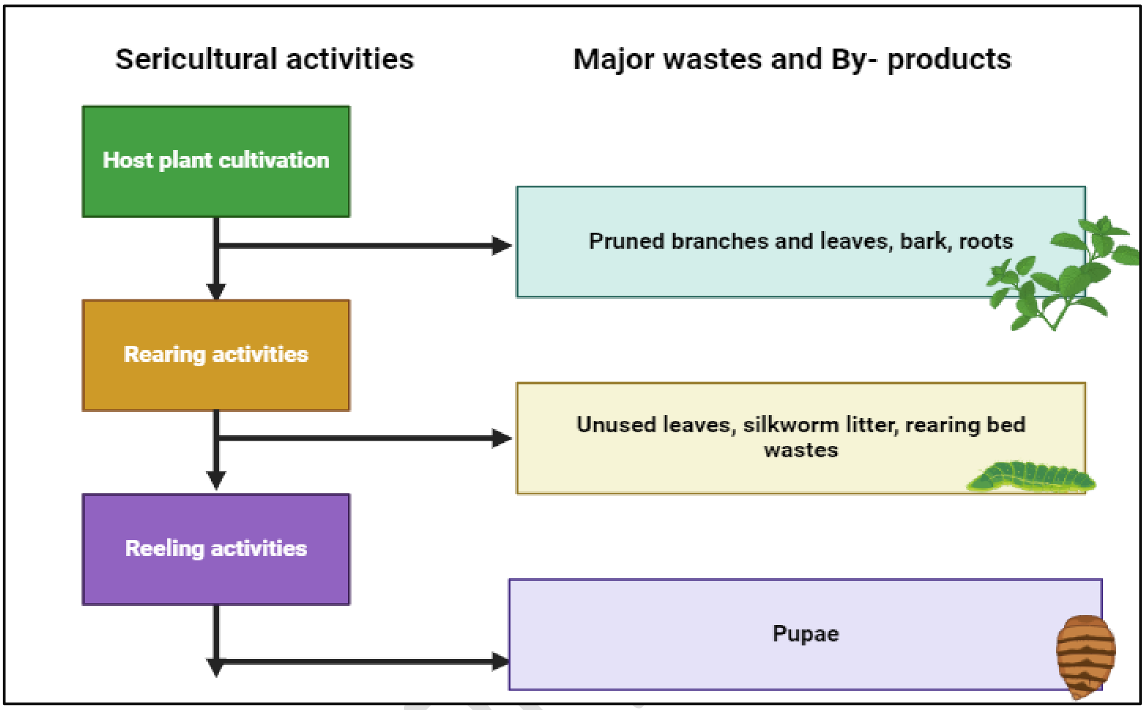

Fig. 1. Flowchart showing Waste generation from sericulture industry

3. NUTRITIONAL VALUE OF SERICULTURAL WASTES

Unlike conventional substrates like straw or sawdust, sericultural waste boasts a richer nutritional profile. Studies have documented high levels of nitrogen, cellulose, lignin, and minerals like potassium, phosphorus, and magnesium. These elements are crucial for mushroom growth and development, offering a readily available food source compared to traditional substrates often requiring supplementation. Research has explored the use of sericultural waste in cultivating various mushroom species. Oyster mushrooms (*Pleurotus spp.*), known for their versatility and rapid growth, have shown promising results when grown on substrates containing sericultural waste. Study by Reddy *et al.* (2000), successfully substituted paddy straw with silkworm stems in oyster mushroom cultivation, achieving comparable yields [20]. Similar studies by Reddy *et al.* (2018) demonstrated the effectiveness of various sericulture waste forms in cultivating button mushrooms (*Agaricus bisporus*) [21].

Table 2. Nutritional composition of sericultural wastes

Sl. no	Nutrients	Sericulture litter	Unused mulberry wastes
1	Cellulose (%)	18.6	52.0

2	Hemicellulose (%)	17.3	15.7
3	Lignin (%)	19.4	20.0
4	Carbon (%)	40.1	43.34
5	Nitrogen (%)	2.90	1.82
6	Phosphorus (mg/100g)	940	920
7	Potassium (mg/100g)	3636	1800
8	C:N ratio	15.42	22.93

Source:Sharma et al., 1999 [23]

4. UTILIZATION OF SERICULTURAL WASTES IN MUSHROOM CULTIVATION

Sericultural wastes, particularly silkworm leaf litter, silkworm excreta, and spent silk pupae residues, contain essential nutrients that serve as an excellent substrate for mushroom cultivation, supporting the growth and development of mushroom mycelium. Sharma and Madan, (1992) investigated using silkworm waste to cultivate oyster mushrooms (*Pleurotus sajor-caju*), analysing its nutritional value and comparing yields on different substrates [24]. Yield comparisons and biological efficiency calculations revealed that the maximum fruit body yield occurred during the first flush across all replicates. Paddy straw (T_1) exhibited the highest biological efficiency, while combining silkworm waste with castor leaves (1:1) resulted in zero (T_6), potentially due to the presence of a toxic protein ricin in castor leaves. While some small mushrooms grew on pure silkworm waste, they observed that the substrate became overly compact, hindering further growth. Mixing silkworm waste with other substrates in equal parts also reduced yield due to compactness. The authors propose using smaller amounts of silkworm waste (1:4 or less) to capitalize on its nitrogen content and potentially eliminate the need for additional nitrogen sources.

Table 3. Average production and bio-efficiency of*Pleurotus sajor-caju* on different wastes

Treatments	Average Yield (gm.)			N (%)		Bio-efficiency (%)
	1st flush	2nd flush	3rd flush	R	S	
T_1	350	100	62	0.68	1.54	102
T_2	13	10	-	3.4	3.8	5
T_3	150	30	25	1.32	2.30	41
T_4	135	26	10	1.81	3.0	34
T_5	300	70	40	1.9	2.91	82
T_6	Nil	Nil	Nil	2.30	3.16	Nil
T_7	30	15	Nil	2.12	2.94	9

R = raw substrate, S = spent residue, N= Nitrogen

Source: Sharma and Madan, (1992)

In subsequent investigations, Patrabansh and Madan, (1997) tested three biomasses (*Populus deltoides*, *Eupatorium adenophorum*, and sericulture waste) alone and mixed with paddy straw for oyster mushroom (*Pleurotus sajor-caju*) cultivation [11]. It was noted that the spawn run exhibited excellent performance in substrates of *P. deltoides* and *E. adenophorum*, whether alone (T_1 and T_4) or in combination with paddy straw (T_2, T_3, T_5 and T_6). However, the sericulture waste alone

(T_7) showed less remarkable performance, though it improved notably when mixed with paddy straw (T_8 and T_9). When used individually, *E. adenophorum* displayed the highest biological efficiency (T_4) followed closely by *P. deltoides* (T_1), while sericulture waste showed the lowest (T_7). Previous studies by Madan *et al.,* (1989) [25] and Sharma and Madan (1992) [24] also reported very low biological efficiency (4-5%) of *P. sajor-caju* when cultivated on sericulture waste alone. However, significantly higher efficiency (98%) was achieved when mixed with paddy straw at a higher ratio (1:4), similar to the outcome of the present study with a ratio of 1:2 (T_9). According to the researchers this improvement might be due to using a mixture of twigs, leaves, and litter, oven-drying for pasteurization, or the substrate's softness. Notably, there was a discernible increase in nitrogen content in the substrates after *P. sajor-caju* cultivation in sericulture waste, (T_7, T_8 and T_9) corroborating findings from previous research by Sharma and Madan (1992) [24].

Table 4. Total Yield, Nitrogen content and bio-efficiency of*Pleurotus sajor-caju* on *Populus deltoides, Eupatorium adenophorum,* and sericulture waste

Treatments	**Total Yield (g)**	**Nitrogen content in the substrate**		**Bio-efficiency (%)**
		Before cultivation (%)	**After cultivation (%)**	
T_1	298.72±7.50	1.47	1.82	74.68
T_2	350.82±17.30	0.92	1.92	87.71
T_3	409.91±41.30	0.83	1.91	102.47
T_4	306.60±10.50	1.82	2.87	76.65
T_5	325.35±9,70	1.52	2.84	91.34
T_6	409.92±0.10	1.30	2.90	102.48
T_7	84.77±2.40	2.75	3.06	29.85
T_8	317.55±13.20	2.09	3.07	79.39
T_9	393.75±8.60	1.75	2.95	98.44
T_{10}	487.07±13.70	0.44	2.09	121.77

Source: Patrabansh and Madan, (1997)

Building on the previous work, Reddy *et al.* (2018) explored using silkworm waste viz. silkworm leaf litter, silkworm excreta, and spent silk pupae residues for the production of button mushroom (*Agaricus bisporus* Lange) [21]. The research focused on evaluating various compost recipes, utilizing different combinations of silkworm residues and paddy straw, for the production of button mushrooms. Reddy *et al.* (2018) found that composted silkworm residue exhibited increased microbial counts (bacteria, fungi, and actinomycetes) until the 21st day [21]. However, they observed that the cellulose and lignin contents significantly decreased during composting and post-mushroom production. Maximum yield and bio-efficiency of button mushrooms were observed in paddy straw, yet they concluded that paddy straw can be substituted with silkworm leaf litter, silkworm excreta, and spent silk pupae as the mushrooms grown on paddy straw plus silkworm residues displayed superior protein and fat contents.

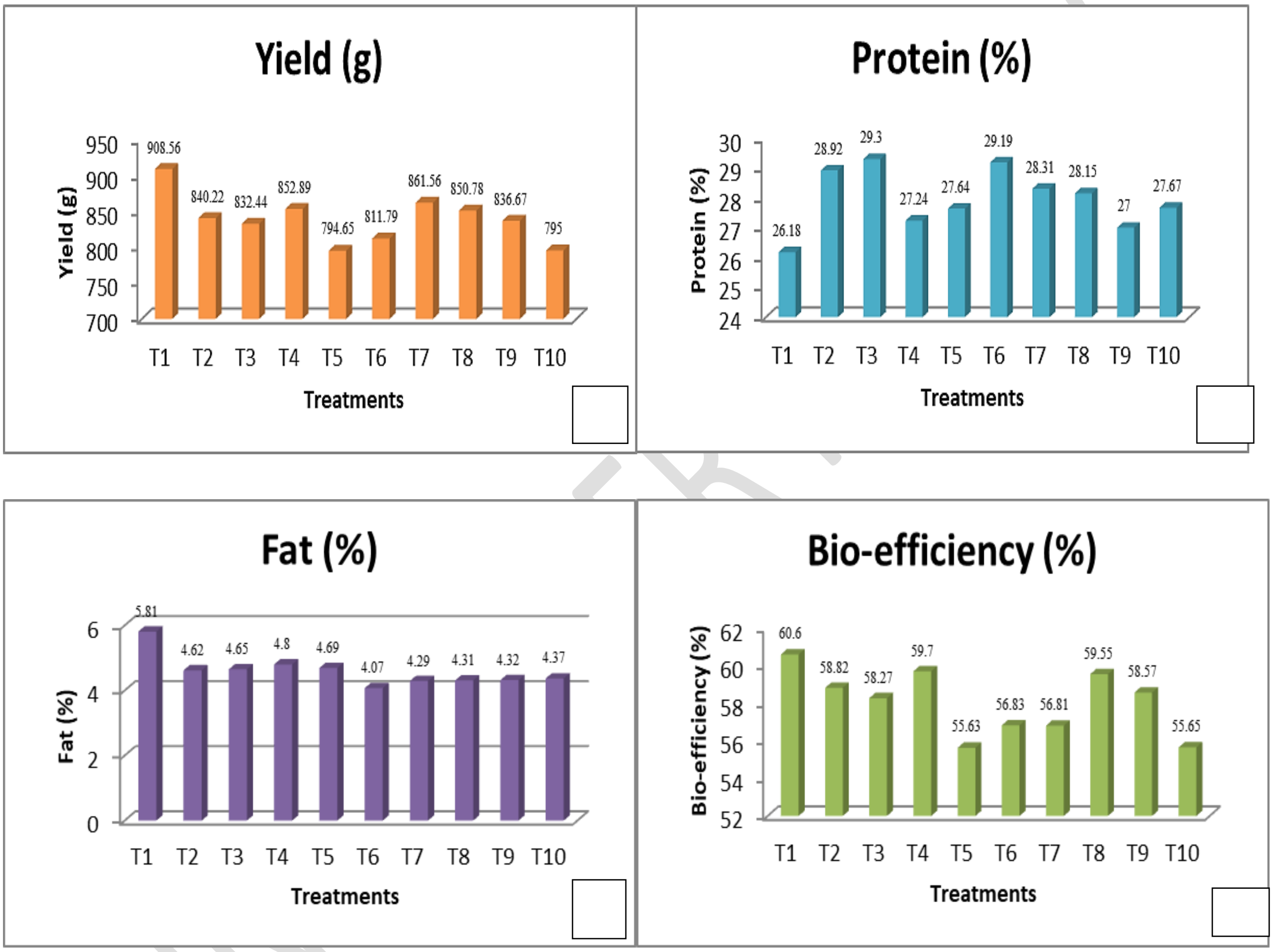

Fig. 2. a. Yield and biochemical compositions (b. protein, c. Fat, d. Bio-efficiency) of Button mushroom as influenced by various silkworm-based substrates

5. ENVIRONMENTAL AND ECONOMIC CONSIDERATIONS:

Repurposing sericultural wastes for mushroom cultivation offers notable environmental advantages, facilitating waste reduction and sustainable resource utilization. Through the utilization of by-products such as silkworm excreta, spent mulberry leaves, and pupal cocoons as substrates for mushroom growth, we mitigate the environmental impact typically associated with sericulture practices while simultaneously extracting value from otherwise discarded materials. Redirecting sericulture wastes away from landfills effectively diminishes greenhouse gas emissions linked to decomposition processes. This strategy aligns harmoniously with the principles of a circular economy, emphasizing the reuse and recycling of resources to curtail waste production and optimize resource efficiency. Additionally, the nutrient-rich composition of sericultural waste is advantageous, as it contains essential elements like nitrogen, phosphorus, and potassium vital for supporting robust mushroom growth. This natural abundance of nutrients obviates the necessity for chemical fertilizers, thereby reducing the risk of pollution and conserving natural resources. Furthermore, cultivating mushrooms on sericultural wastes enriches soil health by introducing organic matter and nutrients, bolstering ecosystem resilience.

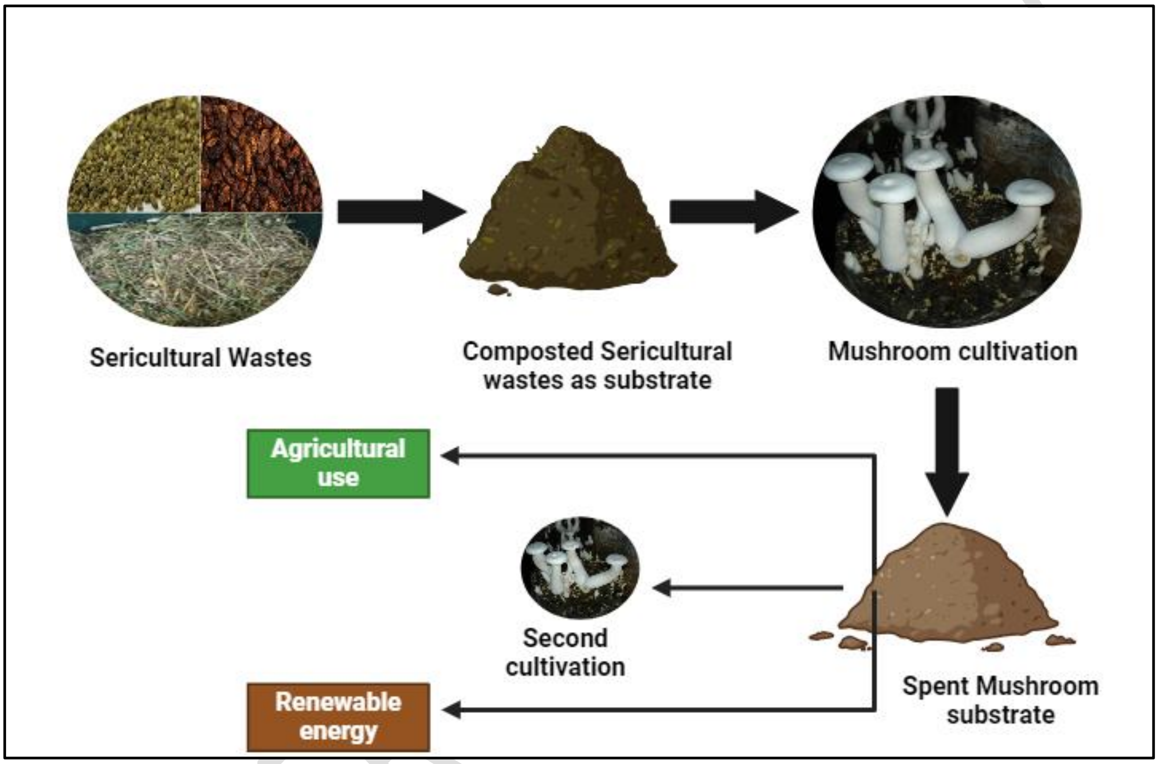

Fig. 3. Recycling Sericultural wastes for Mushroom cultivation

Integrating sericultural wastes into mushroom cultivation practices not only holds promising environmental benefits but also demonstrates considerable economic feasibility and commercial potential. By utilizing these waste materials as substrates for mushroom cultivation, farmers can significantly reduce their production costs associated with purchasing conventional substrates or chemical fertilizers. Sericultural wastes are often readily available at or near silk production facilities, thus minimizing transportation costs and logistical complexities. Moreover, the cultivation of mushrooms on sericultural wastes can generate additional revenue streams for silk producers, effectively diversifying their income sources. Furthermore, mushrooms cultivated on sericultural wastes may also command premium prices in niche markets due to their environmentally friendly production methods and potentially enhanced nutritional profiles. Overall, integrating sericultural wastes into mushroom cultivation practices presents a compelling economic case, offering a viable and sustainable avenue for both waste management and agricultural income generation.

6. FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES:

Although promising for sustainable agriculture and waste management, mushroom cultivation using sericulture waste requires further research. Optimizing substrate composition by determining ideal ratios of silkworm components and exploring additional ingredients to enhance quality and yield is crucial. It is evident that sericulture waste, particularly silkworm litter abundant in nitrogen, could function as a viable organic waste source for various edible mushroom varieties, but research is needed to address issues like compactness in oyster mushroom cultivation. Further exploration, innovation, and adoption of mushroom cultivation using sericultural wastes hold significant implications for agriculture, waste management, and sustainability. This approach contributes to the circular economy by valorising agricultural residues and organic wastes, thereby closing nutrient loops and reducing reliance on conventional fertilizers. Additionally, integrating mushroom cultivation with sericulture practices provides synergistic benefits, such as enhanced soil fertility, pest management, and income diversification for farmers. Overall, ongoing research and development in this field have the potential to transform waste streams into valuable resources, foster sustainable agricultural systems, and alleviate environmental pressures.

7. CONCLUSION:

In conclusion, the comprehensive review of the utilization of sericultural wastes in mushroom cultivation underscores the promising potential of this practice for sustainable agriculture and waste management. While the existing research highlights successful applications of sericultural wastes as substrates for mushroom cultivation, it also reveals substantial knowledge gaps and areas for future exploration. The review emphasizes the need for further research to optimize substrate composition, address compactness issues, and determine the ideal ratios of sericultural wastes and other agricultural residues for maximizing mushroom yield.

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