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Development of Biodegradable and Sustainable Materials using Fungal Mycelium Grown on Agricultural Residues

Pushpa H[1*], Shashidhar K[2], Maithri D.B[1], Sumalatha L[1], Shruthi A. S[1], Sriharsha D. V[2], Vishal H[1], Sathish[3], Savitha J[1]

[1]*Department of Microbiology, MS Ramaiah College of Arts, Science and Commerce-Autonomous, MSRIT Post, Mathikere, Bangalore - 560054, India.*

[2]*Department of Microbiology, Bangalore University, Jnanabharathi Campus, Bangalore - 560056, India.*

[3]*Science Farmers, #3&4, 15th Cross, Malgala Main Road, Nagarbhavi 2nd Stage, Bangalore - 560091, India.*

***Corresponding author Email**: ramesh.pushpa1@gmail.com*

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ABSTRACT

The growing environmental burden caused by synthetic and petroleum-based materials necessitates the development of sustainable alternatives. This study investigates the fabrication of biodegradable and durable composite materials using fungal mycelium grown on agricultural residues. Thirteen genera of Basidiomycota fungi producing fruiting bodies were evaluated across sixty-four agricultural substrates. Following a two-stage screening process, selected fungal strains demonstrated optimal mycelial colonization and binding capacity. Substrate compositions and growth conditions were optimized to enhance structural integrity. The resulting mycomaterials were assessed for density and compressive strength. Results indicated that combinations such as corn stalk and sawdust supported vigorous fungal growth and yielded the highest-density composites (257 kg/m³). Ganoderma-based materials also showed promising compressive strength (0.32 MPa). These findings suggest the feasibility of replacing synthetic packaging materials and particle boards with environmentally friendly fungal composites.

Keywords: Mushroom, Mycelium, Agricultural residues, Mycomaterial, Biodegradation

INTRODUCTION

There is an ongoing competition to discover novel biodegradable and sustainable materials that can significantly reduce our ecological footprint and improve the environment. This drive has led to the innovation of numerous new materials aimed at achieving the sustainability goals of our generation. One such material is a unique composite formed from fungal mycelium and low-value, non-food agricultural waste. The resulting lightweight yet robust organic material can be used for packaging fragile and delicate items, as well as for thermal insulation panels and building materials (Zimele*et al.,* 2020; Attias, *et al.,* 2020; Kofi *et al.,* 2022).

Fungi are primary decomposers and play a critical role in nutrient recycling, often forming symbiotic relationships with other species, such as the roots of various plants (mycorrhiza), by providing nutrients that support their growth. Different fungal species exhibit a range of characteristics and possess remarkable potential to invade, immobilize, and bind substrates, thereby increasing the strength of the materials they help. The scope for industrial innovation using these microorganisms is immense. Mushroom (the fruiting bodies of certain fungi, particularly in the phylum Basidiomycota and some in Ascomycota) have several notable characteristics relevant to the pharmaceutical and food industries. They possess antioxidant, anti-tumor, antiviral, anti-inflammatory, and immune-enhancing properties, in addition to being used as functional foods.

The agricultural sector is one of the main sectors generating the largest quantities of agricultural solid wastes, which are generally allowed to accumulate indiscriminately and constitute threat to food security (Verma *et al.,* 2024; Kumar & Singh, 2020). Effective management and up cycling of agricultural residues are essential strategies for mitigating greenhouse gas emissions and reducing environmental pollution. In recent years, one of the most promising innovations has been the fabrication of sustainable materials using fungi, notably mycelium of mushrooms, generally called as wood fungi. Mycelium forms a network or web-like structure on agricultural waste, creating what is commonly referred to as a mycelium brick. A mycelium brick is an organic building material formed from a combination of organic waste and the mycelium of fungi. This 100% organic material

has been progressively developed across multiple disciplines, with the architecture and construction industries recently showing interest in its potential applications (Rao *et al.,* 2024).

This paper focuses on the screening of several mycelium of fungi producing edible and non-edible mushroom in the design and construction sectors to create a bio-based material and to further understanding of the physical limits, properties, and potential of mycelium-based bio composite products.

MATERIALS AND METHODS

Collection and maintenance of mushroom culture:

Several fruit bodies of Basidiomycetous fungi were collected under the trees of Bangalore city immediately after the rainy season and stored at 4°C. Additionally, specific strains were procured from Science Farmers, Bengaluru, a leading manufacturer and exporter of a wide range of oyster mushroom and other mushroom spawn.

Preparation of mushroom culture:

The cap of each mushroom was pulled apart to expose the internal tissues. With the help of a clean sterilized scalpel, it was cut into tiny pieces and several such pieces were placed carefully on sterilized Potato Dextrose Agar (PDA) plates under sterile conditions. The plates were incubated at 25–28°C. The pure cultures were sub-cultured to PDA slants/plates, stored at 4°C until further use (Aquino *et al.,* 2022).

Stock inoculum preparation:

Jowar (*Sorghum vulgare,* belonging to the family Poaceae) seeds were washed and soaked in water overnight (8 hrs). The soaked seeds were then boiled until they were softened by 50%, and excess water was drained. The seeds were cooled to room temperature and packed in autoclavable covers, at 121°C and 15 lbs psi for 30 minutes to eliminate endophytic fungi of the seeds. Once cooled, mycelium, in the form of mycelial bits, was inoculated onto the seeds under sterile conditions. Incubation was carried out in the dark at room temperature (25–27°C) for 7–10 days.

Spawn preparation:

The above procedure (stock inoculum preparation) was typically followed except that the cooked jowar seeds were air-dried, mixed with 2% of calcium carbonate and packed in either empty glucose drip disposable bottles or in autoclavable bags and kept for sterilization. After sterilization, the bags were cooled and 10% of the inoculum from the stock was added to the seeds and mixed thoroughly. Adequate aeration was ensured by filling only 50% of the container taken for spawn preparation. The set-up was incubated in a dark room at room temperature (25–27°C) (Gayathri & Thakur, 2022).

Substrate preparation for mycocomposite material:

Substrates with higher nitrogen content, such as wheat bran, rice bran, cotton husks, corn cobs, ragi bran, rice husk, sugarcane bagasse, wheat straw, paddy straw, groundnut shell, wood chips, coconut coir, coco peat, corn stalk, pearl millet straw, cotton seed meal, soybean meal, sawdust, arecanut coir were selected for the present study. The substrates were chopped into small pieces (approximately 1–2 inches) to facilitate good mycelial growth. These chopped substrates were soaked overnight in sterile water for softening and then sterilized in an autoclave for 20 min at 15 psi. The initial moisture content was maintained between 40 and 60% based on the type of substrate selected. The sterilized substrates were cooled completely by spreading on a sterile area and used for packing (Angelova *et al.,* 2021).

Packing of mycocomposite material:

If a single substrate was taken it was packed tightly for 1–2 inches in the selected mould (plastic boxes of different sizes and shape) overlaid with a thin layer of inoculum (i.e., in the form of spawn). This procedure was repeated till ¾ of the container was filled. If a combination of two different substrates was taken, they were mixed in different proportions (50:50, 40:60, 30:70, 20:80). The packed set-up was incubated in a sterile area at 28°C. After 12–15 days the partially formed mycobricks were removed and kept in a sterile room maintained at a relative humidity (RH) of 85–95% for a further period of 15 days (Angelova *et al.,* 2021).

Use of binding agents during substrate preparation:

During substrate preparation, binding agents such as corn starch, crude wheat flour, and refined wheat flour were incorporated at selected concentrations ranging from 1% to 5% (w/w) of the total substrate weight. Following sterilization, the binding agents were added to the cooled substrate and thoroughly

mixed to ensure uniform distribution of the binder throughout the matrix. The prepared substrate was then packed into preselected molds for further incubation and mycelial colonization.

Initial evaluation of the mycomaterial:

The formed mycomaterials on Petri dishes or any other mould such as plastic boxes of various sizes were visually evaluated throughout the growth period. Colonization rate, formation of water droplets on the surface, permeability of water and physical strength were evaluated for each organism grown on each substrate and combination of substrates.

Final evaluation of the mycomaterial:

The resultant material was assessed for density and compressive strength, according to using densitometer and Universal Testing Machine (UTM) respectively (Aslam *et al.,* 2009).

RESULTS

Initial screening of fungi and selection of agricultural residues for mycomaterial preparation:

Species of *Pleurotus*, *Agaricus*, *Polyporus*, *Hypsizygus*, *Ganoderma*, *Coprinus*, *Trametes*, *Psilocybe*, *Lentinus*, *Volvariella*, *Conocybe*, *Lentinula*, *Hypomyces* collected in and around Bangalore in natural habitat were screened on various agricultural residues. Initial screening was carried out to assess the growth rate of each fungus on paddy straw. It was observed that the growth rate of three fungi, *Conocybe*, *Lentinula*, and *Hypomyces* were very slow even after incubating beyond 25 days and therefore not involved for further study.

In the second round of screening, in total, 10 mushroom-yielding fungi belonging to *Basidiomycota* were tested on 64 various types of agricultural residues. The selected agricultural residues are wheat bran, rice bran, cotton husks, corn cobs, ragi bran, rice husk, sugar cane bagasse, wheat straw, paddy straw, groundnut shell, wood chips, coconut coir, coco peat, corn stalk, millet straw, cotton seed meal, soybean meal, sawdust, arecanut coir, etc **(Table 1)**. The growth rate of each fungus on each substrate was assessed visually. Complete dense growth covering the entire surface of the packed substrate is considered as excellent growth and represented as ++++, good profuse growth but not covering the entire substrate was considered as good growth and represented as +++, and scarce growth denoted ++, and stunted growth is represented as +. Complete absence of growth was represented as – (**Table 1).**

Table 1: Growth* of fungi (belonging to Basidiomycota producing mushroom as its sexual fruit body) on various agriculrural wastes as solid substrate

Sl. No.	Substrate	*Pleurotus*	*Agaricus*	*Polyporus*	*Hypsizygus*	*Ganoderma*	*Coprinus*	*Trametes*	*Lentinus*	*Psilocybe*	*Volvariella*
1	Areca nut Peel	+	+	–	+	+	+	–	–	–	–
2	Banana flower pod	–	+	+	+	+	–	+	–	–	+
3	Banana stem	–	–	–	+	–	–	–	–	–	–
4	Barley seed	–	+	–	–	+	–	–	+	–	–
5	Black gram husk	+	+	–	+	–	+	+	–	–	+
6	Bengal gram husk	+ +	–	+ +	+	–	+	–	+	+	–
7	Chana bran	+	+	–	+	–	+	–	–	–	–
8	Red rice (broken)	–	–	+	+	–	–	–	+	–	–
9	Wheat (broken)	–	+	–	+	+	+ +	+	–	+	–

10	Coconut coir	+	–	–	+	–	+	–	–	–	+
11	Coconut oil cake	+ +	–	–	+	+	–	+	–	–	–
12	Carob pod	+	–	+	+ +	+ +	+	–	–	+	–
13	Coffee husk	–	–	–	–	+	–	–	–	–	–
14	Coco peat	+	+	–	–	–	+	–	–	+	–
15	**Corn cob**	+ + + +	+ +	–	+ + +	+	+ + +	+	+	+	+
16	Corn flakes	–	+	–	+	–	+	–	–	–	–
18	Corn kernel	–	–	–	–	–	+	–	–	–	–
20	Cotton seed oil cake	+ +	+	+ +	+ +	+	+	+	–	+ +	–
21	Dry copra	–	–	–	–	–	–	–	–	+	–
22	Flat bean seeds	+	–	–	–	+	–	–	+	–	–
23	Flat bean pod	–	+	–	–	–	–	–	–	–	–
24	Gram flour waste	–	–	–	+	+	–	+	+	–	+
25	Green gram husk	+	–	–	+	+	–	–	+	+	–
26	Green peas (podl)	–	–	+	–	+	–	–	+	–	+
27	Groundnut oil cake	+ +	+	+ +	+	+	–	–	–	+	+
28	Groundnut bran	–	–	–	–	–	–	–	–	–	–
29	Groundnut shell	+++	+	–	–	–	–	–	–	+	–
30	**Hemp straw**	-	+	+	++	++++	-	-	-	-	-
31	Jack fruit seeds	+	+	–	–	+	–	–	+	–	–
32	Jowar husk	+	–	+	+	+	+	–	+	–	+
33	Lemon peel	–	–	–	–	+	–	–	–	–	–
34	Linseed oil cake	+	–	–	+ +	+	–	–	+	–	+
35	Musambi peel	–	–	–	–	–	–	–	–	–	–
36	Millet straw	+	+	–	–	+	+	–	+	–	–
36	Orange peel	–	–	–	–	+	–	–	–	–	–
37	Paddy husk	–	+	–	+	–	–	+	–	–	–
38	**Paddy straw**	+ + +	+	+	+ + ++	+	+ + + +	+	–	+	–
39	Pea husk	+	_	–	+	–	–	–	–	+	–
40	Pea pod	+	+	+	+	–	–	+	+	–	–

41	Pomegranate rind	+	−	−	+	−	−	+	+	−	−
42	Potato peel *	+	+	−	−	−	−	+	−	−	−
43	Ragi bran	−	+	+	+	+	−	+	−	+	+
45	**Ragi straw**	+ + +	+	+	+ + + +	+	+ + ++	−	+	−	−
46	Rajma seed *	−	+	+	−	−	−	+	−	−	−
47	Red gram husk	+	+	−	+	−	+	−	−	−	+
48	Rice flour	−	−	−	−	−	+	−	−	−	−
49	**Rice husk**	+ + +	+	+ +	+ + +	−	+ + + +	+	+	−	+
50	Wood chips	−	−	−	−	+	−	−	−	−	−
51	Seri waste	−	−	−	−	−	−	−	−	−	−
52	Sesame oil cake	+	+	−	+	+	+	+	−	−	−
54	Sorghum bran	+	+	−	+	−	−	+	+	−	−
56	Soybean meal	+ +	+	+	+ +	−	+	−	+	−	+
57	**Sugarcane bagassae**	+ + +	+	+ +	+ + + +	−	+ + ++	+	+ +	-	+
58	Sunflower oil cake	+ +	+	+	+ +	−	+	−	−	+	−
59	Sweet potato	−	−	+	+	+	+	−	+	−	+
60	Tamarind pod	+	+	−	−	+	−	−	−	+	−
61	Tapioca	−	−	+	−	−	+	−	−	−	−
62	Tea waste	−	−	−	−	−	−	−	−	−	−
63	Urad dhal husk	−	+	−	+	−	−	+	−	+	−
64	**Wheat bran**	+ + +	+ +	+	+ + + +	+	+ + + +	−	+	−	+

Substrate combinations:

Two fungal species belonging to the genera *Ganoderma* and *Pleurotus* were selected based on preliminary screening results (**Table 1**) and cultivated on various substrate combinations. The use of blended substrates aimed to enhance water-holding capacity, improve substrate structure and porosity, and achieve an optimal carbon-to-nitrogen (C:N) ratio, thereby promoting superior substrate performance and fungal growth, ultimately contributing to the structural integrity of the resultant mycomaterial.

Among the tested combinations, a mixture of paddy straw and hemp straw in a 2:1 ratio supported dense mycelial colonization by *Ganoderma* and *Pleurotus* species (**Table 2**). Likewise, a combination of corn stalk and sawdust proved to be an effective substrate for the growth of these two fungi. In contrast, *Trametes* species did not exhibit vigorous growth on any of the substrate combinations evaluated in this study. Overall, the findings suggest that hemp straw, sawdust, corn cobs, and corn stalk when combined with paddy straw in appropriate proportions represent promising substrates for the cultivation of *Ganoderma* and *Pleurotus* species for mycomaterial production. Our findings were earlier reported by Kofi *et al.* (2022) who observed that

hemp is a suitable substrate for the formation of mycomaterial.

Table 2: Growth* of selected fungi on various substrate (agri residues) combinations

Sl. no	Substrate	Ratio	Organisms	Growth
1	Paddy straw + ragi straw	1:1	*Ganoderma* sp.	++
3	Ragi straw + corn stalk	1:2	*Pleurotus* sp.	++
4	Paddy straw + cornstalk	2:1	*Pleurotus* sp.	--
5	Ragi straw + corn stalk	2:1	*Ganoderma* sp.	--
6	Paddy straw + corn stalk	1:2	*Ganoderma* sp.	++
7	Paddy straw + hemp	1:2	*Ganoderma* sp.	+++
8	Corn stalk + saw dust	1:1	*Ganoderma* sp.	+++
9	Ragi straw + hemp + saw dust	2:2:1	*Pleurotus* sp.	--
11	Corn stalk+ hemp + saw dust	1:2:1	*Ganoderma* sp.	+++
12	Corn cob + paddy straw + corn stalk	1:2:3	*Pleurotus* sp.	+++
13	Saw dust + ragi straw + arecanut husk	2:2:1	*Ganoderma* sp.	++
14	Paddy straw + hemp	2:1	*Pleurotus* sp.	+++
15	Paddy straw + hemp + corn stalk	2:1:1	*Ganoderma* sp.	++

Binding agents and contamination:

The primary objective of incorporating binding agents such as corn starch, crude wheat flour, and refined wheat flour into the substrate was to evaluate their influence on enhancing fungal growth, improving substrate cohesion, and thereby potentially increasing the density and compressive strength of the resulting mycomaterial. These materials were selected for their known ability to act as nutrient-rich additives that may stimulate mycelial proliferation and interfacial bonding.

However, in the present study, the addition of these binding agents led to adverse effects, as the enriched substrates became more susceptible to contamination by airborne fungal spores, which outcompeted or inhibited the growth of the selected fungi. As a result, fungal colonization typically characterized by prolific mycelial growth was significantly hindered in several replicates (data not shown). Rice husk ash when used as a binding material is reported to increase the growth and strength of the material formed (Ganta *et al.,* 2022).

Initial evaluation of the mycomaterial:

Fungal colonization of the substrates was observed over time, during which the fungi actively digested the nutrient material and developed a network of interconnected mycelial cells, resulting in the formation of compact composite materials. Under stereomicroscopic observation, specialized hyphae, specifically skeletal and binding hyphae characteristic of mushroom-forming fungi, were identified, suggesting their potential role in enhancing the mechanical strength of the resulting mycomaterials. During the growth phase, nearly all fungal strains produced either colorless or honey-colored droplets on the surface of the developing mycomaterial, irrespective of the substrate used. This guttation phenomenon indicated active metabolic processes and fungal growth.

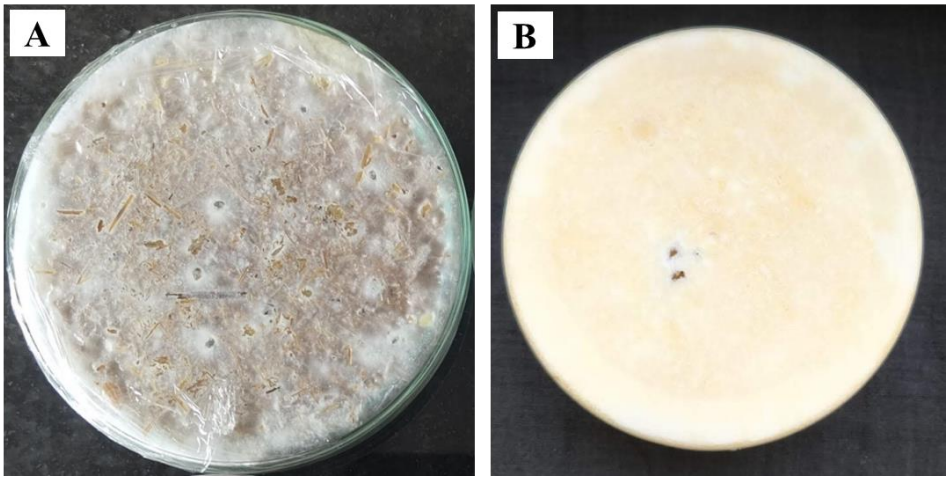


Figure 1: Initial (A) and Final (B) growth of *Ganoderma* sp. on corn stalk + sawdust (1:1) to form mycomaterial.



Figure 2: Mycomaterial after the growth of *Ganoderma* sp. grown on corn stalk + hemp + sawdust (1:2:1).

Multiple sets of mycelial blocks were cast, and upon full colonization, the blocks were demoulded and subjected to oven drying. After drying, each block was inspected for robustness and compactness (**Figure 3A & 3B**). The mycelial development of *Ganoderma* sp. resulted in a uniformly dense and compact structure, with complete surface colonization of the substrate, indicating vigorous growth and strong substrate-binding potential. Based on these qualitative assessments, selected samples were evaluated for compressive strength and density.

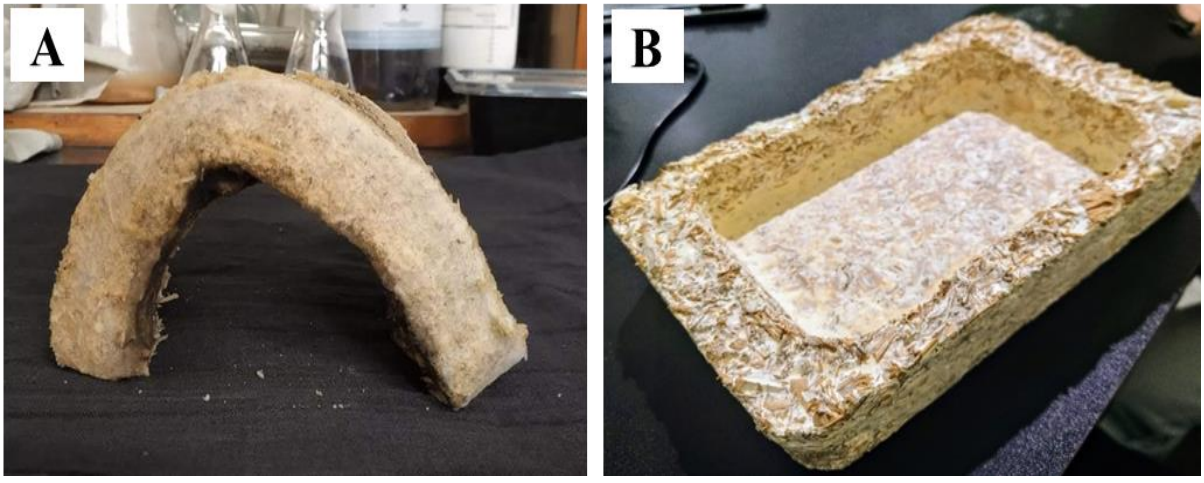


Figure 3: Mycomaterial moulded to various shapes (Growth by *Pleurotus* sp. on ragi straw + corn stalk (1:2)).

Density results:

An attempt was made to determine the density and compressive strength of the formed mycomaterial in order to evaluate the suitability of the material for packing purposes. Density of a material is the mass per unit volume (kg/m³), which plays a crucial role in determining the thermal insulation properties, biodegradability, and load-bearing capacity of the material. Mycomaterials generally exhibit low bulk densities in the range of 60–250 kg/m³ depending on the substrate, fungal strain, and compaction during molding and drying processes. In our study, a species of *Ganoderma* showed the highest density of 257 kg/m³ when grown with a combination of cornstalk and sawdust in 1:1 proportion (**Table 3**). Other combinations as illustrated showed good density between the range of 140–202 kg/m³ by the species of *Pleurotus*.

Table 3: Density of formed mycomaterial on various combination of substrates

Sl. No	Substrate	Ratio	Organism	Density (kg/m^3)
1.	Paddy straw + Corn stalk	1:2	*Ganoderma sp*	155.00
2.	Paddy straw + Hemp	1:2	*Ganoderma sp.*	169.00
3.	Corn stalk + Saw dust	1:1	*Ganoderma sp.*	257.00
4.	Corn stalk + Hemp + Saw dust	1:2:1	*Ganoderma sp.*	202.00
5.	Saw dust + Ragi straw + Arecanut husk	2:2:1	*Ganoderma sp.*	151.00
6.	Paddy straw + Hemp	2:1	*Pleurotus sp.*	193.00
7.	Ragi straw + Corn stalk	1:2	*Pleurotus sp.*	142.00
8.	Corn cob + Paddy straw + Corn stalk	1:2:3	*Pleurotus sp.*	51.40

Compressive strength:

A species of *Ganoderma*, which exhibited the highest density among strains tested (**Table 3**), was selected for compressive strength evaluation. Compressive strength, defined as the maximum compressive stress a material can endure before failure, is crucial for materials designed to withstand compressive loads, particularly in construction and manufacturing.

Mycomaterials, especially those made with *Ganoderma*, typically exhibit compressive strengths ranging from 0.3 to 1.9 MPa, and under optimized conditions (e.g., heat pressing), values can reach up to 4.4 MPa (Zhang *et al.*, 2024; Appelhans *et al.*, 2022). In our study, *Ganoderma* grown on a corn stalk:sawdust mix (1:1) produced a mycomaterial with moderate compressive strength (0.32 MPa), falling within the reported range.

Optimizing density and compressive strength is essential for tailoring mycomposites for applications such as sustainable packaging, thermal/acoustic insulation, and non-structural architectural elements. While mechanical performance remains modest compared to traditional building materials, attributes like biodegradability**,** low embodied energy**,** and application-specific customization make *Ganoderma*-based mycomposites a compelling option in green engineering.

Table 4: Compressive strength of formed mycomaterial grown with *Ganoderma* sp.

Sl. No.	Substrates	Ratio	Organism	Compressive strength (MPa)
1.	Corn stalk + Saw dust	1:1	*Ganoderma sp.*	0.32

DISCUSSION

The majority of commonly used materials such as glass, plastic, and steel, which are frequently employed for insulation, packaging, and other purposes, pose serious and long-lasting threats to biodiversity. These materials can persist in the environment for decades or even centuries, continuing to adversely affect ecosystems. Marine wildlife is particularly vulnerable. Turtles, for instance, often mistake plastic bags for jellyfish, one of their main food sources. Similarly, seabirds like albatrosses confuse small plastic pellets for fish eggs or red plastic for squid. Ingesting plastic, often along with other debris, they feed it to their chicks, which can ultimately result in the death of

the offspring. This behavior contributes to the population decline of such species, pushing them toward extinction. According to estimates from the United Nations Environment Programme (UNEP), plastic debris causes the death of over one million seabirds and at least 100,000 marine mammals every year (David *et al.,* 2009).

Given the ecological consequences of synthetic materials, there is an urgent need to adopt sustainable, biodegradable alternatives derived from renewable resources.

Fungi are, in general, considered the primary decomposers, playing a critical role in nutrient recycling. They grow in all major ecosystems, from the polar regions to the deep seas, yet tend to be largely overlooked. Mushrooms are the reproductive structures or fruiting bodies of fungi belonging to the sub-division *Basidiomycota* of the fungal kingdom. Their indispensable role in recycling organic matter, especially in forests, has long been known. The vegetative structure, i.e., mycelium, is considered the earth's natural network—exceeding the computational powers of our most advanced supercomputers (Paul Stamets, 2005). The mycelial network of mushrooms is composed of interweaving, continuously branching cell chains. Different species of fungi display diverse characteristics and have tremendous potential to invade, immobilize, and bind substrates, thereby increasing the strength of the materials formed. Industrial innovation using such microbes (fungi) is immense.

India generates a significant amount of agricultural waste, with an estimated 500 million tons (Mt) of crop residues annually. A substantial portion of this waste is utilized for purposes like livestock feed and energy production. However, a considerable surplus remains—around 140 Mt—of which 92 Mt is burned each year. This burning contributes heavily to air pollution, particularly in states like Punjab, Haryana, and Uttar Pradesh (Rao *et al.*, 2024).

Therefore, sustainable materials made from fungal mycelium and agricultural waste offer an environmentally friendly alternative. These materials decompose readily when discarded and, if ingested by wildlife, pose no threat despite lacking nutritional value. Their biodegradability significantly reduces their environmental footprint. They use only 12% of the energy required to manufacture conventional plastic packaging and result in up to 90% lower carbon emissions, largely due to the use of renewable resources and lower energy consumption involved in the process (Rejeesh, 2022).

The growth efficiency of fungi significantly depends on the physical properties of the substrates they colonize. This study investigates the growth response of selected fungal species on various agricultural residues and combinations of substrates in fixed proportions. The mycelial composites reflect mycelial growth parameters—such as temperature, humidity, and nutrient availability which can be modified to optimize their qualities. This flexibility enables the creation of unique characteristics suited to a variety of applications.

Preliminary findings from our study offer insight into the development of sustainable mycomaterials, which can be shaped and adapted for various packaging applications. The environmental parameters standardized in our study shed light on designing or creating materials with unique qualities suitable for a wide range of applications, especially in manufacturing furniture, insulation panels, myco-boards (as replacements for MDF), kayaking boats, bricks, packaging materials, and even fashion goods. These mycomaterials exhibit significant properties such as fire resistance, water resistance, lightweight, low cost, and good insulation. Once no longer useful, mycomaterials being fully natural and biodegradable can be disposed of in compost bins or directly applied to soil. They decompose within 30–90 days, enriching the environment by returning nutrients to the soil.

Beyond environmental benefits, this innovation offers economic opportunities, particularly for rural communities. By converting agricultural waste, previously a burden on landfills, into valuable raw materials, farmers and local producers can gain an additional source of income.

CONCLUSIONS

Mycelium-based packaging materials offer a sustainable alternative to conventional petroleum-based packaging such as polystyrene (expanded polystyrene foam). Polystyrene is derived from non-renewable fossil fuels, is non-biodegradable, and persists in the environment for centuries, contributing to microplastic pollution and marine biodiversity loss. It is highly flammable and releases toxic fumes when burned. In contrast, mycelium materials are produced from fungal

biomass, primarily species belonging to Basidiomycota, grown on agricultural residues such as straw and husk. They are lightweight, possess good insulation and shock-absorbing properties, and are naturally fire-resistant without requiring chemical additives.

Environmentally, polystyrene accumulates in landfills and oceans, causing harm to wildlife, as highlighted by reports from the United Nations Environment Programme. In contrast, mycelium materials are fully biodegradable and decompose within 30–90 days, enriching the soil. Additionally, mycelium technology utilizes agricultural waste, helping reduce stubble burning and providing economic opportunities for rural communities.

Overall, mycelium-based packaging represents an eco-friendly, low-carbon, and circular alternative to conventional polystyrene packaging materials.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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