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Mycelium-Biomass Composites: Sustainable Processing, Applications, and Opportunities for Circular Economy Transitions in Ecuador

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DEDICATORIA

Dedico este logro a Dios, quien me ha iluminado con su espíritu de sabiduría en todo este trayecto.

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RESUMEN

Los Materiales Basados en Micelio (MBMs) son biomateriales innovadores desarrollados a partir del micelio, la red filamentosa (hifas) que constituye la estructura vegetativa de los hongos. Gracias a su capacidad de crecer sobre una amplia variedad de sustratos lignocelulósicos, el micelio permite la producción de materiales biodegradables y sostenibles, con propiedades mecánicas y térmicas competitivas frente a los materiales convencionales. Este estudio examina el estado de la investigación sobre los compuestos de micelio-lignocelulósicos como sustitutos de materiales tradicionales, con especial atención a su desarrollo e implementación en el contexto ecuatoriano. Así, los géneros de hongos más estudiados incluyen *Pleurotus, Ganoderma* y *Trametes*, destacándose las especies *P. ostreatus, G. lucidum* y *T. versicolor,* las cuales se cultivan comúnmente sobre sustratos de residuos agroforestales. Los MBMs se aplican en diversos sectores, destacando su uso en biocompuestos para embalajes, construcción, paneles de aislamiento y textiles. El proceso de producción generalmente implica la preparación del sustrato mediante técnicas como limpieza, trituración, esterilización o pasteurización, seguida de la inoculación, la colonización mediante fermentación en estado sólido y el crecimiento controlado en moldes para dar forma al producto final. Los tratamientos posteriores pueden incluir secado y, en algunos casos, prensado térmico para mejorar la resistencia mecánica y la estabilidad dimensional. El interés en los MBMs se debe a la necesidad urgente de sustituir plásticos y espumas sintéticas por alternativas renovables, compostables y de bajo impacto ambiental. Como un campo emergente, el desarrollo de MBMs contribuye al avance de la biofabricación y respalda los principios de la economía circular. En Ecuador, la investigación sobre MBMs aún se encuentra en una etapa inicial; sin embargo, la abundante disponibilidad de residuos agrícolas representa un gran potencial para explorar nuevos sustratos y aplicaciones innovadoras.

Palabras clave: Alternativas biodegradables, alternativas ecológicas, biofabricación fúngica, biomateriales circulares, biomateriales fúngicos ecuatorianos, residuos agroindustriales.

ABSTRACT

Mycelium-Based Materials (MBMs) are innovative biomaterials developed from mycelium, the filamentous network (hyphae) that forms the vegetative structure of fungi. Owing to its ability to grow on a wide range of lignocellulosic substrates, mycelium enables the production of biodegradable and sustainable materials with mechanical and thermal properties that are competitive with those of conventional materials. This study examines the state of research on mycelium-lignocellulosic composites as substitutes for conventional materials, with a particular focus on their development and implementation in the Ecuadorian context. Thus, the most extensively studied fungal genera include *Pleurotus, Ganoderma*, and *Trametes,* particularly the species *P. ostreatus, G. lucidum*, and *T. versicolor*, which are commonly cultivated on agroforestry waste substrates. MBMs are applied in a variety of sectors, with notable uses in biocomposites for packaging, construction, insulation panels, and textiles. The production process typically involves substrate preparation through techniques such as cleaning, grinding, sterilization, or pasteurization, followed by inoculation, colonization through solid-state fermentation, and controlled growth in molds to shape the final product. Subsequent treatments may include drying and, in some cases, thermal pressing to enhance mechanical strength and dimensional stability. Interest in MBMs is driven by the urgent need to replace plastics and synthetic foams with renewable, compostable, and low-impact alternatives. As an emerging field, MBM development contributes to the advancement of biofabrication and supports the principles of the circular economy. In Ecuador, research on MBMs is still at an early stage; however, the abundant availability of agricultural residues presents significant potential for exploring novel substrates and innovative applications

Key words: Agroindustrial residues, biodegradable alternatives, circular biomaterials, Ecuadorian fungal biomaterials, fungal biofabrication, green alternatives.

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INTRODUCTION

Most industrial materials, like those used in construction and packaging, are nonrecyclable and harmful to the environment, consuming resources and causing pollution throughout their lifecycle. They contribute eight to 10 percent of global CO_2 emissions and prompt plastic bans in many countries [1], [2]. Rapid population growth has intensified the demand for the building materials industry, leading to persistent shortages, and to meet rising housing needs, there is a sharp increase in the production of materials such as bricks, cement, steel, aluminum and wood [3]. The production of materials like steel and concrete demands high energy consumption and causes pollution, which is measured through embodied carbon, limiting their widespread use [4]. Another common example is packaging, which serves a key function by protecting products, ensuring their safety, and sharing important information, making it indispensable in commerce today [5]. The environmental harm caused by fossil derived plastics is becoming more evident due to resource depletion, greenhouse gas emissions, and their non-biodegradable nature, with a large portion of this waste resulting from plastic packaging [6]. Nevertheless, conventional plastics are increasingly being replaced by alternative materials considered more sustainable wherever technically possible [7].

In the development of sustainable materials, clean processes play a crucial role in transforming raw materials into valuable resources through technological innovation [8]. The growing awareness of the impact of anthropogenic activities on the environment drives the adoption of clean technologies to minimize negative effects and threats [9]. An optimum process is characterized by low cost, energy and material savings, minimal waste using renewable resources, high-quality accessible materials, recyclability, safety, fewer operations, and ease of repair and modernization, considering ecological, technical, and economic factors [10]. In this context, alternative bio-based composite materials are used; these refer to the blending of two or more materials to create a product with enhanced properties compared to each component on its own [11]. In this line, one innovative option is represented by mycelium-based composites which, by adjusting the substrate and processing technique, can be engineered to achieve desired structures and functional properties [12].

Mycelium composites consist of lignocellulosic particles reinforced and surrounded by a network of randomly arranged mycelium fibers, creating a multiscale structure [13]. In recent years, mycelium has gained increasing interest in academia and industry due to its low energy consumption during growth, its near-zero byproduct generation, and its broad potential applications [14]. Mycelium-based materials (MBMs) are an emerging class of bio-based materials developed in recent decades, offering a promising alternative to traditional materials [6], and it is used in different industries such as leather [15], [16], [17], architecture [18], [19], furniture [20], [21], thermal and acoustic insulation [22], [23], construction [24], [12] and packaging [23], [25], [26]. Various initiatives around the world have demonstrated the potential of mycelium-based composites as functional and sustainable materials, with companies such as Ecovative Design (https://ecovative.com/) and MycoWorks (https://www.mycoworks.com/) developing innovative fungus-based products including biodegradable packaging, thermal insulation, and leather alternatives, thereby reducing reliance on plastics and animal-derived materials.

Mycelium is the root-like underground network of fungi, made up of thin filaments that spread extensively beneath forest soil and serve as the vegetative part of the mushroom by interconnecting and binding substrate materials as it grows [27]. Fungi are a significant group of eukaryotic organisms with an extensive evolutionary history dating back approximately 1.2 to 1.5 billion years [28]. Mycelium works like a natural glue, connecting to various organic materials nearby—such as coffee husks, sawdust, straw, wheat bran, and bagasse—and weaving them into a tight, dense network of fibers [29]. Studies show that disposing of agricultural waste like sugarcane bagasse, wheat straw and rice husks is a major issue in developing countries, and, with increased farming, more waste is expected [30], [31]. Common practices such as landfilling and composting cause environmental problems, but recent research suggests reusing agro-waste in construction materials offers a promising solution [32]. Thus, research shows that reusing agro-based waste helps reduce pollution from conventional construction materials like cement and addresses environmental issues related to landfill disposal of agricultural waste [33].

Given the growing interest in sustainable materials, this study aims to analyze the state of the art on the use of mycelium-lignocellulosic biomass composites as an alternative to conventional materials, with a particular focus on their development in the Ecuadorian context. The review considers key aspects such as fungal species, cultivation processes, types of substrates and residues used, environmental impacts, current challenges, and potential applications. This study is divided as follows: The next section will discuss mycelium-based materials, section three aims to present the results of the analyzed data such as fungi species found, their uses, and the substrates employed, among others. Finally, section four seeks to outline the prospects of using mycelium for the development of sustainable materials in Ecuador.

LITERATURE REVIEW

Mycelium-based composites (MBCs)

Mycelium-based composites (MBCs) derive their name from mycelium, the filamentous root-like structure of fungi responsible for mushroom formation [34]. Mycelium-based foams (MBFs) and mycelium-based sandwich composites (MBSCs) constitute the two main types of composite materials developed from mycelium [35]. Mycelium-based foams (MBFs) are created by growing fungi on small amounts of agricultural waste, whereas mycelium-based sandwich composites (MBSCs) are produced by embedding a core material between outer layers made from natural fiber fabrics such as hemp, cellulose, or wood [27], [36]. These composites are created by growing fungal mycelium on organic substrates such as straw, sawdust, woodchips, cotton, or rice husks [37], [38]. As the fungus colonizes the substrate, its hyphae absorb nutrients from the cellulose-, hemicellulose-, and lignin-rich material, forming a dense, three-dimensional network. This network binds the substrate together, resulting in a solid, lightweight, and biodegradable material known as a mycelium-based material (MBM) [39]. Compared to traditional materials, these alternatives, which generate less pollution and waste during manufacturing, use, transport, and disposal, while also being economically viable, are increasingly regarded as sustainable alternatives [40], consequently making MBCs a promising option within this category.

Fungal Species

Mycelium-based composite starts by selecting fungal species. From this perspective, it is important to understand that mycelium is composed of hyphae; thus, its physicochemical properties are determined by the traits of these hyphae, and understanding the shape and features of the mycelium is essential when choosing fungi as a biological resource [34]. From this perspective, it is essential to recognize that hyphae can be classified into three types: i) generative, ii) skeletal, iii) binding [26], [41], [42], [43], [44], and their essential characteristics are compared in Table 1.

Table 1. Comparison of Hyphal Types in Fungi

Generative hyphae	Skeletal hyphae	Binding hyphae
Develop reproductive structures		
Typically, thin walled	Thicker, longer, and rarely branched.	Thick-walled, often solid, and often branched
Frequent septa	No septa	Few septa
Clamp connections (moderately branched)	No clamp connections (unbranched)	Highly branched

Considering these three hyphal types, mycelium networks can be classified as monomitic, dimitic, or trimitic based on the types of hyphae they contain. Each type differs in structure and strength, influencing the mechanical performance of the resulting material, as shown in Table 2 [43], [26], [44], [45].

Table 2. Types of mycelial networks and their characteristics

Mycelial Network Type	Hyphal Types Included	Structure	Mechanical Properties
Monomitic	Generative only	Simple, less rigid	Weaker mechanical performance
Dimitic	Generative + Skeletal (or Binding)	Moderately structured	Better mechanical strength than monomitic
Trimitic	Generative + Skeletal + Binding	Highly structured and dense	Strongest mechanical performance

Selecting an appropriate fungal species requires evaluating several key factors, including growth rate, mycelium density, ease of cultivation, toxicity level, cost of the growth medium, and the structural characteristics of the mycelium [46], [47]. Basidiomycetous fungi are commonly selected to produce bio-composites because of their strong capacity to break down lignocellulosic materials and their inherent adhesive properties, which enhance the structural integrity of the final product [48], [49]. Under these circumstances, the key biological activity that enables fungi to form Mycelium-Based Materials (MBMs) lies in their ability to colonize lignocellulosic biomass through hyphal growth, which acts as a natural binder that fuses substrate particles into solid structures [42]. This process is driven by the secretion of extracellular enzymes such as cellulases, hemicellulases, oxidases, chitinases, and proteases [50], which break down complex organic compounds into simpler, soluble nutrients that the fungus can absorb and metabolize, thereby facilitating both substrate degradation and structural cohesion [44]. These enzymes are capable of degrading cellulose through cellulases, hemicelluloses through hemicellulases, degrading lignin through oxidases [51], breaking down chitin through chitinases, and hydrolyzing proteins through proteases [52]. Saprophytic fungi, one of the three general fungal categories alongside pathogenic and symbiotic types, are primarily responsible for decomposing organic matter through the secretion of enzymes that break down complex compounds into simpler molecules, which are then absorbed as nutrients [53]. This fungal group is particularly significant in materials science due to its ability to convert organic waste into mycelial biomass. Based on their role in the ecological succession of decomposition, they are classified into: primary colonizers (characterized by rapid growth and the breakdown of simple compounds), secondary colonizers (which rely on the initial activity of primary fungi to access more complex substrates), and tertiary colonizers (adapted to highly microbial environments and capable of degrading the most recalcitrant residues) [54]. *Ganoderma lucidum* and *Pleurotus ostreatus* are among the most widely used fungal species in mycelium-based products, largely due to the valuable medicinal, nutritional properties associated with their fruiting bodies and biological activities [23].

Substrates

Fungi naturally grow on decomposed organic matter from plants, fruits, and animals; their growth and quality depend on conditions like temperature and humidity, as well as the suitability of specific substrates and supplements [55]. The most used substrates for producing mycelium-based materials include lignocellulosic biomass, such as wood chips, sawdust, straw, coconut powder, garden waste, and bagasse [56], [46], [57], [58]. These substrates originate from three main sources: agricultural by-products, industrial waste, and post-consumer materials [59]. The key reason these substrates are selected is their composition, which makes them highly suitable for fungal growth. Lignocellulosic biomass consists of structural polysaccharides including cellulose (30–50%), lignin (15–30%), and hemicellulose (25–35%) that form the structural components of the plant cell wall [60], along with smaller amounts of non-structural elements such as pectins, waxes, pigments, tannins, lipids, and minerals [61], [62]. Their exact composition depends on the species and origin of the biomass. Cellulose ranks among the most abundant on Earth and consists of a linear polymer comprising approximately 100,000 glucose monomers joined by β-(1–4)-glycosidic bonds [63]. Hemicellulose is a complex group of polysaccharides found mainly in the primary and secondary plant cell walls, that consists of various pentoses (β-d-xylose, α-l-arabinose), hexoses (β-d-glucose, β-d-mannose, α-d-galactose, α-l-rhamnose, and α-l-fucose), and glycolytic acid (α-d-glucose fermentation acid, α-d-4-O-methyl-glucose acid, and α-d-galacturonic acid) [64]. Lignin, on the other hand, the second most abundant natural biopolymer after cellulose, is the only renewable aromatic polymer produced in large quantities that makes up 8–38% of the dry weight of lignocellulosic biomass and stands out for its heterogeneous nature and thermoplastic properties; structurally, it is an amorphous polyphenolic network primarily derived from three monolignol precursors: coniferyl alcohol (G unit), p-coumaryl alcohol (H unit), and sinapyl alcohol (S unit) [65]. Glucose is a vital nutrient for fungal development, and many fungi obtain it by breaking down cellulose from the substrate [66]. Therefore, selecting an appropriate substrate involves considering factors such as (1) nutritional content, (2) availability and abundance, (3) degradability, (4) cost, (5) textural and structural properties, and (6) compatibility with the fungal strain [66]. During mycelium growth, fungi release enzymes like laccase, lignin peroxidase (LiP), and manganese peroxidase (MnP) to break down cellulose, lignin, or both in the substrate, while hemicellulose is generally degraded by most species, allowing the mycelium to bind together and form a block-like structure [35], [67]. In this context, wood chips, sawdust, straw, coconut powder, garden waste, and bagasse are chosen for their suitability for fungal development and their rich lignocellulosic composition [27].

Among the many options, wood-based substrates are particularly suitable for fungi that naturally degrades lignocellulosic matter, such as *Ganoderma lucidum* and *Trametes versicolor* [68], [69]. However, even among lignocellulosic materials, the rate of mycelium colonization and the quality of the final biomaterial can vary depending on the substrate used [27]. As the mycelium grows, it colonizes the substrate, forming a dense network of interconnected fibers called hyphae that are composed mainly of biomolecules such as chitin [27], which is a biopolymer forming the innermost layer of the fungal cell wall, providing reinforcement and structural strength [26]. These fibers act as a natural adhesive and form different networks as reported in table 2. This network binds the particles together into a cohesive and solid material, significantly improving its mechanical and functional properties [70]. The most suitable composition of the substrate will depend on the fungus in question as well as the material application [48].

Once the fungus and substrates are chosen, the next step is to treat the substrate to eliminate or reduce the presence of bacteria, insects, or competing fungi that might hinder the growth of the selected fungi. This treatment can be carried out using one of four main methods: sterilization, pasteurization, chemical treatment, or natural composting [48]. Each method has advantages and disadvantages, and important considerations include its effectiveness in preventing contamination, the amount of energy it consumes, the equipment it requires, and any chemicals used or environmental effects it may cause [48], [71]. Following the removal of competing microorganisms from the substrate, it becomes suitable for inoculation with the selected fungal species [48], [72].

MATERIALS AND METHODS

This study was conducted through a literature review using scientific databases such as Scopus and Google Scholar, as well as grey literature sources. The search was carried out using specific keywords, including mycelium-based composites, mycelium-based materials, fungal mycelium, mycelium applications, mycelium substrates, fungal materials, and fungal processes. A total of 77 documents were initially retrieved, which were then screened for relevance and quality, resulting in a final selection of 60 articles that formed the basis for the analysis presented in this manuscript. The collected data was organized and processed using Microsoft Excel, where basic descriptive statistical analyses were performed to support data interpretation. Finally, the results were compared with findings reported in the broader scientific literature and subsequently analyzed in the context of the Ecuadorian case.

RESULTS

Fungal species

Multiple studies converge on the use of fungal species from the genera *Pleurotus*, *Ganoderma*, and *Trametes* in the development of mycelium-based biocomposites, making them the three most employed fungal genera among all species explored for this purpose [13], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84]. Within these genera, species such as *Pleurotus ostreatus*, *Ganoderma lucidum*, and *Trametes versicolor* are among the most predominant fungal taxa used in mycelium-composite materials (Figure 1a). These three genera—*Pleurotus, Ganoderma,* and *Trametes*—are well known for their efficient mycelial growth and their ability to degrade lignocellulosic biomass, which likely explains their prevalence. *Schizophyllum* appears with moderate frequency, while *Fomes, Fomitopsis*, and *Lentinus* are used much less often, each cited in fewer than 10 cases. This distribution suggests a clear preference in current research for fungal genera with fast colonization rates and well-established biotechnological applications. Their frequent use may also be attributed to their availability, adaptability to different substrates, and favorable mechanical properties of the resulting mycelium composites [27], [66]. The predominance of these species in mycelium composite research can be due to their high enzymatic activity, ability to colonize a wide range of lignocellulosic substrates, and favorable growth kinetics. *P. ostreatus* consistently produces thicker hyphae than *Ganoderma lucidum*, regardless of the substrate; in this line, *P. ostreatus* forms dense mycelial networks with strong substrate bonding, making it ideal for durable mycelium-based composites [37]. The distribution of fungal species used in mycelium-based material studies demonstrates a clear concentration around a few dominant taxa. As depicted in Figure 1b, *Pleurotus ostreatus* accounted for the largest proportion of use, representing 29% of all recorded cases. This was followed by *Ganoderma lucidum* with 25% and *Trametes* *versicolor* with 19%, indicating their central role in MBM research. Less commonly used species included *Schizophyllum commune* (13%), *Fomes fomentarius* and *Fomitopsis pinicola* (each 5%), and *Lentinus sajor-caju,* which comprised only 4% of the total. These results suggest research focuses on species with known high biomass conversion efficiency and favorable mechanical properties for composite development.

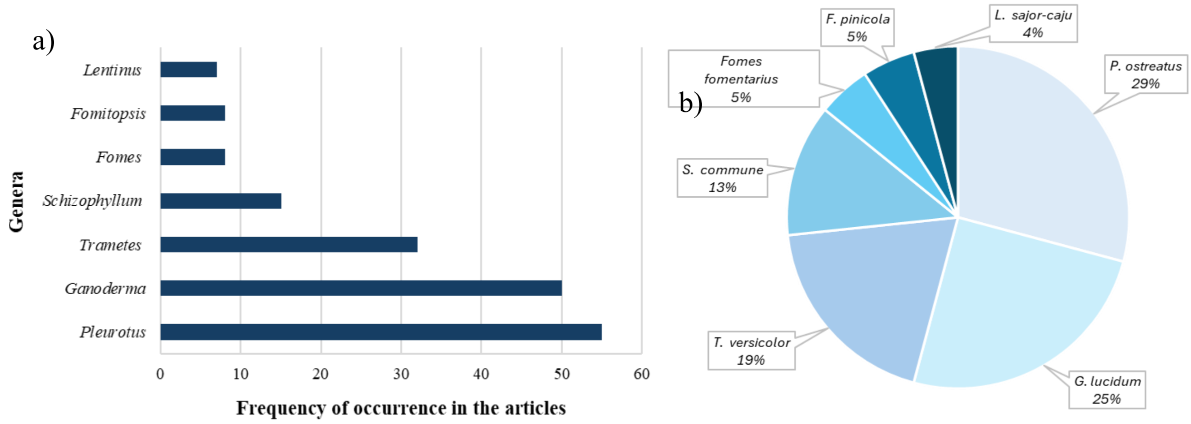

Figure 1. Most widely used species for mycelium-based composite materials (MBMs). a) Most frequently used genera, and b) most frequently applied species within each genus

Substrate types

A wide variety of substrates have been reported in scientific studies on MBM development. However, among them, agricultural residues consistently appear as the most widely used. These include plant-based by-products such as crop stalks, husks, and straw [85], [86], [87], [88], [89], [90], which are not only abundant and affordable but also suitable for supporting fungal growth. Forestry waste, including wood chips (apple, vine, eucalyptus, oak, pine), sawdust, wheat bran, oat husk, rapeseed cake [35], [47], [56], [79]; also appears frequently due to its high lignocellulosic content, making it a favorable medium for mycelial colonization. Agricultural residues included sugarcane bagasse, corn cobs, rice husks, maize bran, coffee ground [21], [73], [74], [91], [92], [93]. Other materials such as industrial by-products, chemical additives, or purified forms of cellulose are used less often and typically serve more specific functions. Components like laboratory media, animal waste, or simple sugars (e.g., dextrose) were mentioned rarely, suggesting they are not common in large-scale or sustainable applications [26], [38], [75], [80]. This reflects a broader pattern in which MBM research focuses on materials that are locally available and environmentally responsible. To summarize, the preference for plant-derived residues, especially those from agriculture and forestry, demonstrates a clear alignment between material performance and sustainable sourcing. These organic by-products not only support efficient fungal growth but also contribute to low-cost, scalable, and eco-friendly biomaterial production (Figure 2).

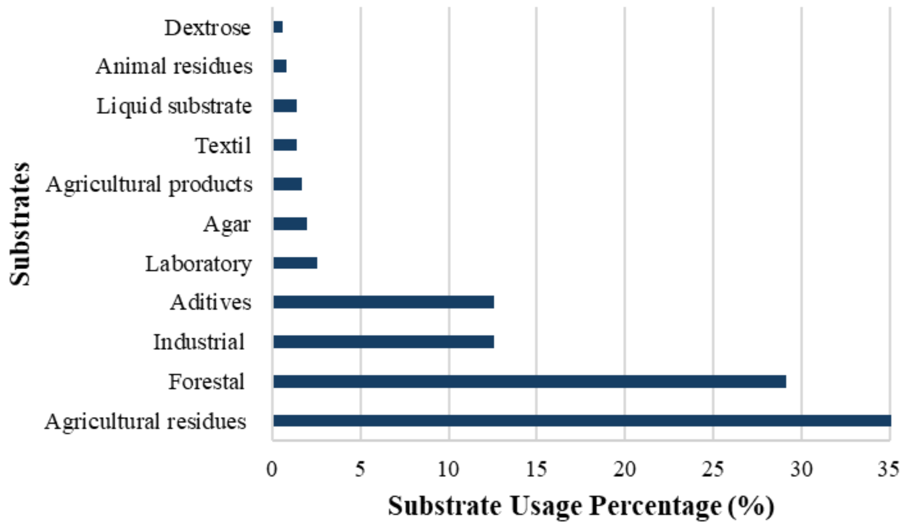

Figure 2. Common substrate types used in mycelium-based materials

Applications and products obtained

Figure 3 displays the range of sectors in which mycelium-based materials (MBM) have been applied, as identified in the reviewed studies. The data show a particularly high concentration of applications in the packaging and construction industries, both of which have actively explored sustainable alternatives to conventional materials. Additional uses include insulation systems and the textile sector, where the material’s flexibility and insulation performance have been leveraged. While areas such as interior design (e.g., furniture and acoustic solutions) and structural components are also represented, their relative share is smaller. A limited number of cases relate to bricks, fire-resistant uses, biotechnological applications, and sheet-based forms, suggesting ongoing experimentation in less traditional fields. Beyond illustrating dominant sectors, the treemap also highlights the relative diversity of emerging uses for mycelium-based materials. While packaging and construction clearly lead in terms of frequency, the presence of smaller application fields, such as biotechnology, fire resistance, and sheet-form composites, suggests that exploratory research is expanding the functional scope of these materials. Although these areas are currently less represented, their inclusion points to the adaptability of fungal composites and their potential for cross-sector innovation. This variety reflects not only ongoing material experimentation but also the versatility of fungal mycelium as a platform for developing sustainable alternatives in both industrial and design-oriented contexts. Among the most representative genera used for MBM, studies have identified *Pleurotus* as the most employed to produce packaging and panels, whereas *Ganoderma* has been reported for applications in construction. *Trametes* has also been extensively studied; however, its utilization remains less prevalent compared to the two genera mentioned before. Furthermore, studies indicate that the use of forestry residues is more common for *Pleurotus*, while *Ganoderma* is more strongly associated with the utilization of agricultural residues [67], [74], [84], [85], [86], [89], [92].

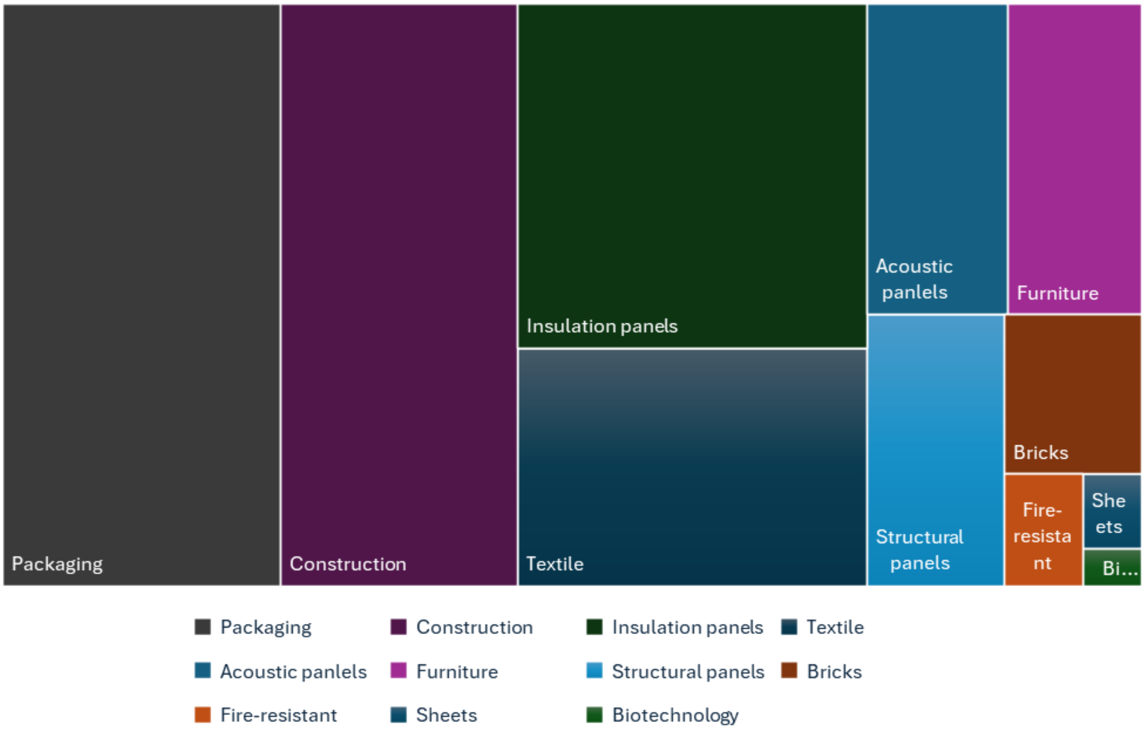

Figure 3. Main Fields of Application for Mycelium-Based Composites

Processes

The general process for producing mycelium-based materials (MBMs) (Figure 4) begins with the reception of the substrate, which must undergo a preparation phase, followed by inoculation and cultivation, molding and post-processing part.

Substrate preparation starts with ensuring all materials are clean. Subsequently, depending on the specific type of substrate, it may be subjected to grinding, sterilization (generally vapor sterilization), or pasteurization [37], [88], [94], due to competition between the target fungal strain and contaminating microorganisms present in the substrate can hinder the colonization process, which in turn may negatively impact the final quality of the product [95]. Once the substrate is prepared, the next step is inoculation, which involves introducing the mycelium into the substrate [96].

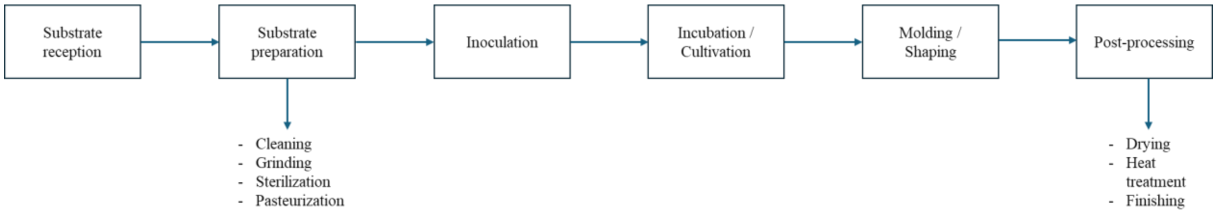

Figure 4. General processes used in MBM production

After inoculation, the substrate undergoes incubation or cultivation under controlled conditions (Figure 4). Figure 5 shows a horizontal bar chart comparing the relative importance of various biotechnological processes used primarily for the valorization of fungal resources. The chart presents eight categories, with Solid-State Fermentation (SSF) being the most prominent, followed by Liquid-State Fermentation (LSF) and other techniques with lower representation. SSF integrates key operations such as fermentation, pasteurization, and substrate conditioning to optimize microbial activity and product yields. LSF typically uses bioreactors to conduct submerged fermentation under controlled conditions, complemented by pasteurization and sterility management to ensure optimal growth. Semi-solid culture combines intermediate-moisture fermentation with pasteurization phases to prevent contamination. Genetically engineered fungal strains involve genetic modification combined with fermentation and, when necessary, pasteurization for culture safety. 3D bioprinting employs bio-structures derived from sterilized fungal cultures to fabricate complex materials. Biochemical extraction, nanocomposite fabrication, and protein extraction rely on upstream fermentation and thermal treatments to purify and stabilize bioactive compounds. Overall, the chart demonstrates the clear predominance of SSF as a key approach in fungal biotechnology, while highlighting the transversal role of fermentation, pasteurization, and controlled bioreactor processes across all techniques.

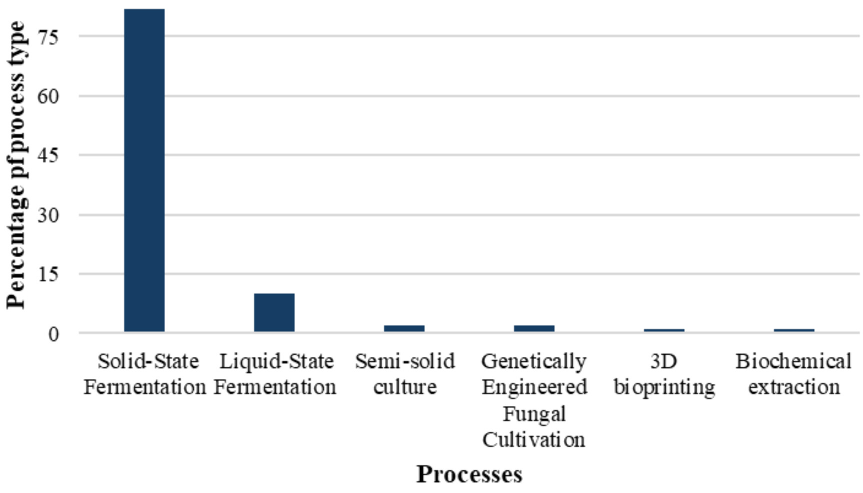

Figure 5. Common processes apply to mycelium-based materials

Finally, there is a post-processing phase which involves drying and finishing of the MBM (Figure 4). Surface finishing processes are typically employed on mycelium-based composites (MBCs) to refine their appearance, close surface pores, and safeguard the material from water infiltration and microbial degradation under service conditions [81].

PERSPECTIVES IN ECUADOR

In Ecuador, few studies have been conducted on the use of mycelium as a bio-based material. One such study is by Palacios and collaborators [97], who evaluated mycelium as an ecological material and explored mycofabrication in the country through liquid mycelium process (although they do not specify the species used) using wheat as substrate. They highlight that the material is renewable, biodegradable, lightweight and has excellent insulating capacity, positioning it as an alternative that fosters architecture more in line with the principles of sustainability and respect for the natural environment. In contrast, Ávila & Yánez [98] evaluated the growth efficiency of the mycelium of *Ganoderma lucidum* as potential use as textile in three organic substrates, i) eucalyptus sawdust (*Eucalyptus globulus*), ii) cane bagasse (*Saccharum officinale*), which recorded the best growth performance, and iii) ground bark of cocoa fruits (*Theobroma cacao*) through pasteurization process. However, experimental results showed that sugarcane bagasse contains lower levels of cellulose and lignin, and higher moisture content compared to other substrates. Another example was proposed by Valenzuela-Cobos and collaborators [99] who examined the potential for using two of the most widespread agricultural by-products such as waste substrates, specifically, green banana leaves (GBL) and sugarcane bagasse (SB) where the mixture composed of 80% SB and 20% GBL had greatest potential as cultivation substrates for *Pleurotus ostreatus* and *P. djamor* through liquid medium.

Of the two most used species worldwide, in Ecuador, a study was conducted on *Pleurotus ostreatus* with the aim of cultivating it using accessible and low-cost resources, without relying on automated controls for variables such as temperature and humidity. This approach is justified by its high nutritional value, including carbohydrates, proteins, fibers, and fats as well as its potential to support vulnerable communities and contribute to the knowledge and valorization of mushroom cultivation [100], [101], [102]. On the other hand, *Ganoderma lucidum* is neither as well-known nor as widely used as it is in Asian or European countries [103]. Nonetheless, several studies have demonstrated the considerable potential of this species for applications in the textile industry [62], as well as efforts to evaluate different substrates that optimize the growth performance of *G. lucidum* [104], [105], [106]. Agro-industrial waste in Ecuador has emerged as a valuable resource for bioplastic production. The country's agro-industrial sector generates approximately 2.2 billion kilograms of waste annually, which, through appropriate physical and technological processing, can be used as raw material for producing bioplastics [107]. Most of this waste originates from the production of rice, banana, cocoa, coffee, sugarcane, corn, African palm, hearts of palm, pineapple, and plantain[108], and the yearly production of these residues is shown in Figure 6. Therefore, it would be relevant to analyze the use of these residues to harness their potential in the development of mycelium-based composites, especially considering that studies primarily report the use of rice, cocoa, and sugarcane residues [109].

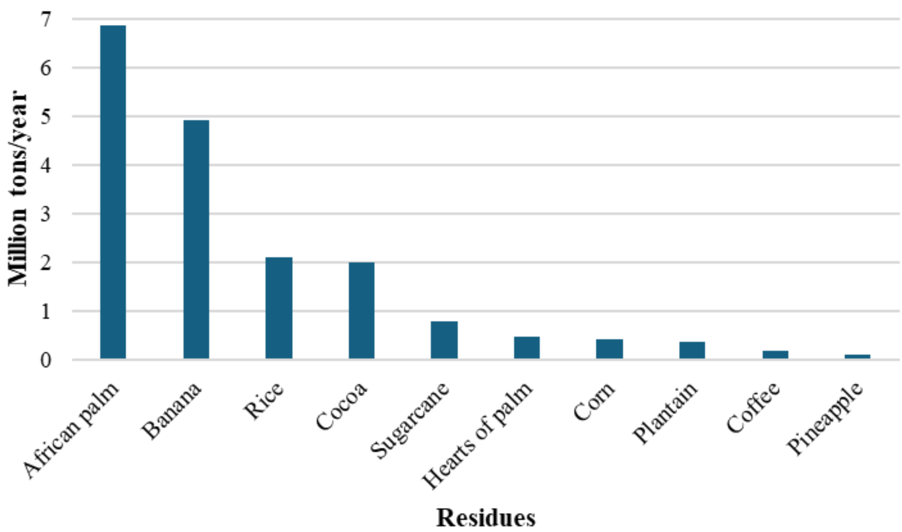

Figure 6. Million tons of residues per year generated in Ecuador

Ecuador holds a unique opportunity to foster circular economy practices through the development of mycelium-based materials (MBMs), leveraging the country's untapped biomass residues. The large volume of organic by-products generated by agricultural and agroindustrial activities, such as banana stems, cocoa shells, and forestry waste [108], [109] can serve as low-cost, renewable inputs for local MBM production. Unlike conventional materials that rely on finite or imported resources [110], MBMs offer a pathway to reintroduce waste streams into productive use cycles, adding both environmental and economic value. The decentralized nature of agricultural production across the country further supports the integration of small and medium scale biofabrication initiatives, potentially stimulating rural innovation and entrepreneurship. By aligning material development with ecological principles and locally available inputs, Ecuador can establish a new industrial model that prioritizes resilience, low-impact manufacturing, and long-term sustainability. In this context, MBM production is not only a technical solution but also a strategic opportunity to redefine how materials are sourced, used, and reintegrated into the biosphere.

LIMITATIONS

While this study highlights the potential of mycelium-based materials as a sustainable alternative for various applications, several limitations should be acknowledged. A key technical constraint lies in the variability of the materials' properties, which are influenced by the type of fungal strain, the substrate selected, and specific cultivation parameters. This inconsistency makes it difficult to establish standardized performance benchmarks, particularly for sectors like construction where compliance with safety and quality norms is essential. Furthermore, scaling up production poses practical challenges due to the need for controlled environments and contamination prevention measures, which can be costly and infrastructure dependent. In the Ecuadorian context, the field faces additional barriers, including limited availability of specialized research facilities, minimal public and institutional awareness, and the absence of local policies or regulatory frameworks that promote the development and use of bio-based materials. The findings in this work tend to reflect the most widely documented practices and may not fully represent emerging or less accessible innovations in mycelium composite development. Future studies with broader timeframes and collaborative networks will be essential to deepen understanding and foster more inclusive and representative insights.

CONCLUSION

The development of materials derived from fungal mycelium represents a promising alternative to conventional, resource-intensive construction materials. These biocomposites offer several environmental advantages, such as biodegradability, low energy requirements during production, and the capacity to incorporate agricultural waste. Beyond their functional and structural potential, mycelium-based materials align with growing global efforts to reduce carbon emissions and promote circular economy practices in the building sector. In the context of Ecuador, the adoption of mycelium-based materials could contribute significantly to sustainable development, especially in rural and peri-urban regions where agricultural residues are abundant yet underutilized. By integrating locally available biomass such as rice husks, cacao shells, and sugarcane bagasse into the production of mycelium composites, the country can foster eco-friendly innovation while addressing waste management challenges. This approach not only supports environmental goals but also opens pathways for community-based production models and green entrepreneurship

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