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EDITORIAL

Challenges in mycelium-based composites

Desafíos en materiales aglomerados miceliares

Among biobased and environmentally friendly materials, mycelium composites are regarded as strong candidates to replace single-use rigid plastics – such as expanded polystyrene – and to serve as key components in sustainable insulation panels or interior design elements. These materials consist of a hyphal network produced through solid-state fermentation with filamentous fungi of lignocellulosic waste substrates, including sawdust, spent coffee grounds, grain husks, hay, and other industrial plant residues. These particulate materials serve as both nutrient sources for the fungal strain and structural components of the composite, as they are not fully degraded during colonization.

In recent decades, notable progress has been made in the production of these biodegradable structures. Nevertheless, their market adoption remains too limited to generate significant sustainability benefits. While this pace is typical for products seeking to displace established petroleum-based materials and compete with the long-standing plastics industry, it is worth examining which strategies could accelerate the implementation of this promising technology.

As is often the case with emerging developments, production costs represent the principal barrier to reaching commercial viability. In this context, the search for low-cost substrates has become an active area of research, partly driven by its relevance to edible mushroom cultivation. In terms of published studies and funded projects, this line of inquiry far exceeds efforts to improve energy efficiency in production. This imbalance is noteworthy, given that the primary economic and environmental burdens for these industries are not the substrate costs but the energy and water consumption associated with raw material disinfection[1]. As an example, a study[2] shows that the shift from conventionally produced electricity (UAE electricity grid) toward more sustainable sources (renewable electricity grid plus credits from waste diversion) significantly lowers climate change values from 4.28 to 0.05 kg CO_2 equiv. kg^{-1}, compared to 4.54 kg CO_2 equiv. kg^{-1} for polystyrene and 6.81 for polyurethane foam. However, according to the same work, even in the most sustainable scenarios, electricity still accounts for 53% of the environmental impact. While it is encouraging to see that this kind of study on mycelium composite production is beginning to account for energy use and carbon emissions, the predominant approaches to controlling competitive microbiota still rely on high-temperature treatments, while research into lower-cost, lower-impact alternatives remains limited. Progress in food mycology has been substantial in recent years[3], and these well-established research programs could expand their impact by contributing to the development of safe, mycelium-based secondary packaging, drawing on their expertise in strain selection and spoilage prevention.

Regarding mechanical performance, significant advances have been made through the inclusion of taxonomically diverse fungal species. Whereas early work focused on commercially available edible mushroom species like *Pleurotus* spp., the use of aphyllophoroid species with complex hyphal systems as is the case of *Ganoderma* spp. or *Funalia trogii* has broadened the potential applications of these composites[4]. Additionally, modulating hyphal differentiation in these fungi may offer further opportunities to enhance mechanical properties[5].

Ongoing research beyond mycology and microbiology is also needed. Developing methods to improve resistance to water, insects, mites, and premature degradation would considerably expand the range of viable applications. Furthermore, establishing standardized norms specifically designed for mycelium composites would support faster adoption by the packaging and insulation industries. Legacy testing parameters derived from wood and plastics do not fully capture the distinctive advantages of mycelium-based materials – such as biodegradability – nor do they adequately address challenges like friability and heterogeneity. A clear and consistent set of standards would facilitate communication with industrial sectors seeking solutions for diverse applications. For example, while compression resistance in expanded polystyrene can be controlled through density selection, the performance of fungal composites depends on multiple interacting factors, including substrate

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type, incubation time, growth conditions, and the chosen species or strain.

These considerations indicate that substantial research and development efforts remain necessary before mycelium-based materials can achieve broader market entry. However, technical progress alone is insufficient. Success will also require coordinated support from regulatory bodies and sustained financing and investment. Initiatives in developed countries increasingly promote the phased replacement of plastics across multiple applications. Accomplishing this transition depends not only on research funding but also on financial support to scale up biodegradable alternatives. Start-ups currently lead the way in bringing novel materials to the market, while larger firms tend to adopt new technologies more slowly. This lag delays the investment needed to cover the costs of medium- and large-scale production trials. Encouraging collaboration between the entrepreneurial ecosystem and established companies that could integrate these technologies in the near term is essential for achieving the scale and continuity required to meaningfully contribute to a circular economy.

A longer-term perspective on the profitability of microbial materials may also be warranted, particularly in the context of funding evaluations. Decisions on investment and financial support often rely on cost-benefit analyses that emphasize short-term returns under current market conditions. Such an approach is difficult to reconcile with a market landscape dominated by the plastics industry, particularly when the environmental costs of conventional materials are not reflected in economic comparisons. Moreover, a fair assessment should account for the value of using organic by-products as substrates, which might otherwise incur disposal costs associated with treating them as residues. Although consumer acceptance for these materials has not been studied, assessments of this important parameter must be conducted considering the environmental impact on public opinion.

In response to narrow or negative initial profit margins, many start-ups developing microbial materials initially target higher-priced market segments. These include secondary packaging for cosmetics and luxury goods, design objects, and even acoustic insulation components for audio equipment. This approach typically emphasizes the environmental benefits of the materials and appeals to brands oriented toward higher-income consumers. Although the direct sustainability impact of such products may be limited, their visibility and public appeal can help build momentum for broader adoption. They also provide a more stable pathway for companies to manage production costs while establishing a market presence – an important factor in securing early-stage investment.

As in many past cases, emerging technologies must navigate a demanding initial phase before production processes are refined and public acceptance develops. Funding and investment programs that support this stage will help build companies capable of securing a strong market position as soon as conditions become favorable, granting them a notable competitive advantage over those entering the market only after profitability has been established.

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