Biotechnology Design

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Research Article

Cite this article: Im H-S, Ryu M-S, Kim B-J, Eo J-K, Park E, Tagawa S, and Shin H-J (2025). Eco-friendly masks with a blend of mushroom fiber and cotton. *Biotechnology Design*. **4**, e1, 1–9. https://doi.org/10.1017/S2977905725100048

Received: 19 July 2025
Revised: 19 July 2025
Accepted: 5 August 2025

Keywords:
Mushroom pulp; bio-textiles; nonwovens; sustainability; mushroom fruiting body

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Eco-friendly masks with a blend of mushroom fiber and cotton

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Abstract

This study discusses the production of Eco-friendly mask using mushroom-based pulps through physicochemical treatment of mushrooms. Ultimately, it explores an approach to reduce the usage of petrochemical materials. Through the treatment of fruiting bodies from two mushroom species, *Pleurotus ostreatus* (Oyster mushroom) and *Flammulina velutipes* (Enoki mushroom), pulp was produced. Then, it was used in wet-laid sheet processing to fabricate both pure MBP sheets and composites blended with cotton. The manufactured textile was subjected to various property analyses, including antibacterial test and was also used to produce a mask prototype. In conclusion, although improvements in breathability are currently needed for practical application, the potential for further research is vast and promising. This study contributes to the advancement of sustainable, biodegradable materials as a solution to environmental challenges posed by the widespread use of synthetic polymers.

Introduction

Humanity is increasingly suffering from the impacts of severe global warming, driven by various environmental factors, with unprecedented warming trends observed since 2023 (WMO 2024). With the increasing frequency of weather events, the concept of net-zero has emerged, prompting various countries to pursue greenhouse gas reduction technologies and sustainable alternatives actively (Davis *et al.* 2018). Significant contributors to this issue include the processing and use of petrochemical substances, livestock farming and the cultivation of crops (Singh *et al.* 2022; Rathinamoorthy *et al.* 2023; Zhang *et al.* 2023). Furthermore, the increased use of plastic-based disposable masks due to COVID-19 has significantly accelerated pollution, with citizen science data showing that the proportion of mask litter on streets rose nearly 80-fold, from less than 0.01% to over 0.8% following the pandemic (Wang *et al.* 2023). To mitigate this issue, the use of bio-based masks has increased, leading to related research initiatives (Hill *et al.* 2020; Sankhyan *et al.* 2021; French *et al.* 2023). Plastic disposable masks are mainly disposed of in conventional ways, such as landfills or incineration. Over time, these plastic fibers may fragment into microplastics, contaminating terrestrial and marine ecosystems (Aragaw 2020; Xu and Ren 2021; Rathinamoorthy and Raja Balasaraswathi 2022). To mitigate these environmental issues, biomaterials, such as cotton masks, have been increasing in recent years.

However, cotton is also a crop that consumes significant amounts of water and requires pesticides during cultivation. Therefore, reducing its usage is essential to mitigate environmental pollution. Research shows that producing 1 kg of cotton fiber requires over 20,000 liters of water (Jans *et al.* 2021). Furthermore, the energy and water consumption associated with cotton fiber production and use is significantly higher than that of synthetic fibers – ranging from 2 to 10 times more than other crops (Rana *et al.* 2015). This high resource demand poses a serious risk of exacerbating global water scarcity over time. The cultivation of water-intensive crops such as cotton accelerates the depletion of agricultural water supplies, intensifies regional water shortages and negatively impacts ecosystems (Chapagain *et al.* 2006). Cotton's slow early growth makes it particularly susceptible to weeds, requiring extensive herbicide applications from the sowing stage (Tariq *et al.* 2020). Cotton cultivation, which accounts for 2.3% of global farmland, consumes 16% of the world's insecticide (Zhang *et al.* 2023). These chemicals not only pollute soil and water and damage ecosystems but also pose significant health risks to nearby residents and crops (Teysseire *et al.* 2020).

For these factors, it is crucial to develop eco-friendly alternatives to plastics and cotton. Mushroom-based material is a solution due to its unique structural component, hyphae, which form a natural fibrous network. This network not only mimics the properties of traditional fibers but also offers significant environmental benefits (French *et al.* 2023). Mushroom cultivation requires far less water and land compared to cotton, and it produces minimal chemical waste. Additionally, mushroom-based fibers are biodegradable, making them a sustainable choice for reducing the environmental footprint of textile production.

Thus, mushrooms have the potential to serve as an innovative and sustainable substitute for cotton-based products in the textile industry.

Mushroom-based materials: mini review

Mushrooms belong to the Kingdom Fungi, one of the five kingdoms of life, and are classified as eukaryotic organisms. They primarily utilize lignin or cellulose-containing wood and plant materials as their substrate (Elsacker *et al.* 2020). During growth, mushrooms form two main structures: the fruiting body, which facilitates reproduction, and the mycelium, which absorbs nutrients. Both the fruiting body (commonly referred to as the mushroom) and mycelium are composed of hyphae, a branched and fibrous structure with a polysaccharide cell wall. Hyphae exhibit radial growth by expanding their tips to absorb nutrients, continuously extending into new regions (Edelstein 1982). Mycelium is formed through the interwoven structure of hyphae, resulting in numerous entanglements that resemble the structure of nonwoven materials (Rathinamoorthy *et al.* 2023). Due to these properties, mycelium is considered a suitable candidate for developing eco-friendly materials. Research on the application of mycelium in various industries has been actively conducted (Shin *et al.* 2025), with notable examples including its use as leather alternatives (Raman *et al.* 2022; Crawford *et al.* 2024), packaging materials (Holt *et al.* 2012; Sivaprasad *et al.* 2021) and construction materials (Voutetaki and Mpalaskas 2024). Furthermore, some researchers have conducted life cycle assessments (LCA) to evaluate the overall sustainability of mushroom mycelium-based materials and assess their environmental impact (Iglesias *et al.* 2025; Akromah *et al.* 2024). However, progress in utilizing mycelium in the textile sector remains relatively slow. This study aims to advance the development of mycelium-based materials in the textile field, leveraging their unique structural properties and eco-friendly characteristics. In our previous study (Im *et al.* 2025), we reported that mushroom fibers and cotton fibers can be used to fabricate nonwoven fabrics. In this work, we attempt to extend the project to the development of face masks. A mycelium-based mask material was produced as an early-stage prototype intended for general consumer use. While high-performance applications such as surgical masks require further research and refinement, this study aims to evaluate whether the prototype demonstrates a baseline level of functional properties, laying the groundwork for future development.

Materials and methods

Materials

This study was applied to two different types of mushroom strain: *Pleurotus ostreatus* and *Flammulina velutipes*. Two fruiting bodies were purchased from the local market.

Methods

The purchased mushrooms were subjected to a standardized cutting process to adjust their length to 5–7 mm. Next, a physicochemical treatment and sheet-forming process were conducted based on previous research (Im *et al.* 2025). Final MBP dispersions were prepared in a 10 wt% solution. To produce the cotton-MBP composite, cotton fibers were uniformly aligned through a milling process and then cut to lengths to match the MBP fibers.

Table 1. Nonwoven classification by cotton-mycelium-based pulp ratio

Classification	Cotton	MBP
Cotton	100	0
Cot_MBP_20	80	20
Cot_MBP_30	70	30
Cot_MBP_50	50	50
MBP	0	100

Sample preparation

To analyze the physical, chemical and biological properties associated with MBP addition, sample compositions were prepared as outlined below, with samples organized as shown in Table 1 to facilitate morphological analysis based on MBP content. To produce a nonwoven textile with dimensions of 25 cm × 25 cm, the total fiber mass was adjusted to 12 g and introduced into the fabricating process. As mentioned in the Introduction, cotton contributes significantly to environmental pollution due to its intensive use of water and pesticides. Nevertheless, it was employed in this study as a reference material because it is widely used in existing nonwoven products and was expected to show reasonable compatibility with MBP during sheet formation. Rather than aiming for complete substitution, this study focused on reducing cotton usage by blending it with MBP, with greater emphasis placed on achieving a more environmentally friendly material composition.

Sheet-forming process

Sheet-forming machines used in this study were provided by the Korea Textile Development Institute, utilizing the samples prepared as described. The detailed process for the wet method used in manufacturing nonwoven and composite materials is as follows (Figure 1).

First, fibers that become raw materials for nonwoven and composite materials are manufactured using specific methods. Second, dispersion of the pulp is conducted using a beating stage with a circulating tank and tooth-head gear. This process consists of two stages: beating and releasing. In the beating step, the gear directly contacts the tank to physically impact and disperse the solution. In the releasing step, the gear is retracted from the apparatus to enable smooth water circulation within the tank. The third step is the sheet-forming process. This stage involves separating the liquid dispersion into its liquid and fiber components. When the square frame is secured onto the machine and the operation begins, water starts to fill the interior after approximately 10 seconds. At this point, dispersion is added. Once the water reaches a specific level, the bubbling process begins, during which air is injected into the machine. This process untangles the fibers while the water rises. After the water fully rises, the compressor within the machine operates to separate the water and fibers using the principle of vacuum filtration. Continuously, the couching process is employed, where pressure is applied to flatten the fibers and partially remove moisture. During this step,

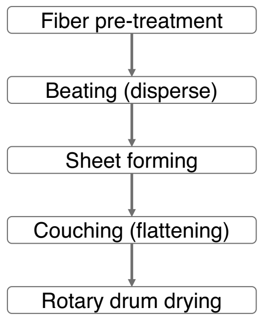

Figure 1. Nonwoven and composite material manufacturing steps.

a pressure of 3 bar is applied. The final process is the drying process, where the residual moisture is removed using a rotary drum dryer set to 121 °C, completing the production of the nonwoven and composites.

Mask prototype manufacturing

To begin mask prototype production, all necessary components, including the nonwoven textile material (such as Cotton_MBP composites), are prepared. The mask prototype was manufactured using the method shown in Figure 2. The manufacturing process for the mask prototype begins with gathering all components, including nonwoven textile materials such as cotton-based composites, strings, a nose bridge and a nose wire. After preparation, the design team refers to the manufactured blueprint to cut the fabric. Next, the fabric edges are stitched to create a seam allowance. The nose bridge is placed on the upper part of the fabric and partially stitched to make space for the nose wire. In the following step, the nose wire is carefully inserted into the space, and the stitching is completed. Additional stitching is complete, and wrinkles, details and other elements are applied according to the blueprint. Once the main structure is finished, the strings are attached to the sides of the mask using a machine. Finally, the completed mask prototype is thoroughly inspected to check its functionality. If the process is considered complete, it results in a prototype that is ready for testing or use.

Morphology

A Scanning Electron Microscopy (SEM) was conducted to analyze each nonwoven sample. The images were captured using an ultra-high-resolution field emission SEM (SU-8600, Hitachi, Japan). For optimal observation, each sample was subjected to Au coating before analysis, and measurements were conducted at an acceleration voltage of 15 kV.

Purity test

To manufacture masks using the nonwovens produced through this study, a purity test must be conducted in compliance with the requirements of the Ministry of Food and Drug Safety (MFDS). The testing method referred to the partially revised standards and testing methods for quasi-drugs, analyzing pigments, formaldehyde and fluorescent bleaching agents (Figure 3).

Pigment: A 10 g sample of the manufactured nonwoven composite is mixed with 100 mL of distilled water at approximately 80 °C, followed by a cold soak and filtration. A 50 mL portion of the filtrate is then placed in a tube. When observed from above, no color should be present in the solution.

Formaldehyde: A 1.0 g sample of the nonwoven composite is extracted in 100 mL of water at 40 °C for 60 minutes, then filtered. A 10 mL filtrate is mixed with acetylacetone reagent, reacted at 40 °C for 30 minutes and rapidly cooled. The detection solution should not display a stronger color than the potassium chromate reference.

Fluorescent whitening agents (FWA): The nonwoven composite sample is exposed to Ultra violet (UV) light in a darkroom and should not fluoresce. If it occurs, a secondary test is conducted by cutting the fluorescent area, leaching it in an ammonia solution at pH 7.5–9.0, adjusting the pH to 3.0–5.0 with HCl and rechecking under UV light after washing and dehydration.

Antibacterial test

The biological resources used in this research were distributed from KCTC (Korean Collection for Type Cultures). The antibacterial activity of nonwovens with MBP incorporation was evaluated using *Staphylococcus aureus* KCTC 1621. The strain was subcultured at 37 °C for 48 hours before use. The liquid medium (1.0×10^5 CFU/mL) was prepared using serial dilution. Test specimens (0.4 g each) were autoclaved and divided into 50 mL conical tubes. Specimens were treated with bacterial suspension, neutralized immediately and diluted for plate counting. The remaining samples were incubated with bacterial suspension at 37 °C for 18 hours, then neutralized, diluted and analyzed. Colony counts were determined after 24 hours of incubation. Each sample was repeated 3 times to ensure reliability. The analysis was conducted in accordance with the testing method outlined in KS K 0693. The results were statistically analyzed using R software (ver. 4.4.2) and R Studio environment with the Tidyverse package (ver. 2.0.0).

Pore test

The pore test involved measuring porosity using a porosimeter (CFP-1200 AE, Porous Materials Inc., USA), following the ASTM F 316-03 (2019) standard test methods for pore size characteristics of membrane filters by bubble point and mean flow pore test. It is performed by passing gas through dry, wet and semi-wet samples and measuring flow rates as a function of pressure. The pore size distribution is analyzed between the dry and wet samples, providing detailed insights into the pore structure and distribution.

Results and discussions

Nonwoven sheet manufacturing

To produce nonwoven materials, two mushroom strains, *P. ostreatus* and *F. velutipes*, were utilized with blending ratios of 0%, 20%, 30%, 40%, 50% and 100%. As the content of mushroom mycelium pulp increased, the total operating time for the nonwoven manufacturing process also increased proportionally. At 0% and 20% blending ratios, the process required approximately 20 minutes, while 30% took 50 minutes, 40% took 90 minutes and 50% required 150 minutes. Based on these results, a concentration-time relationship graph was designed, as shown in Figure 4. Between the 20–40% blending ratios, there was no noticeable difference in the nonwoven structure. However, at a 50% pulp content, the pulp structure disappeared, resembling the results obtained with 100% pulp in the Sheet former operation. Mycelium pulp, primarily composed of polysaccharides, contains

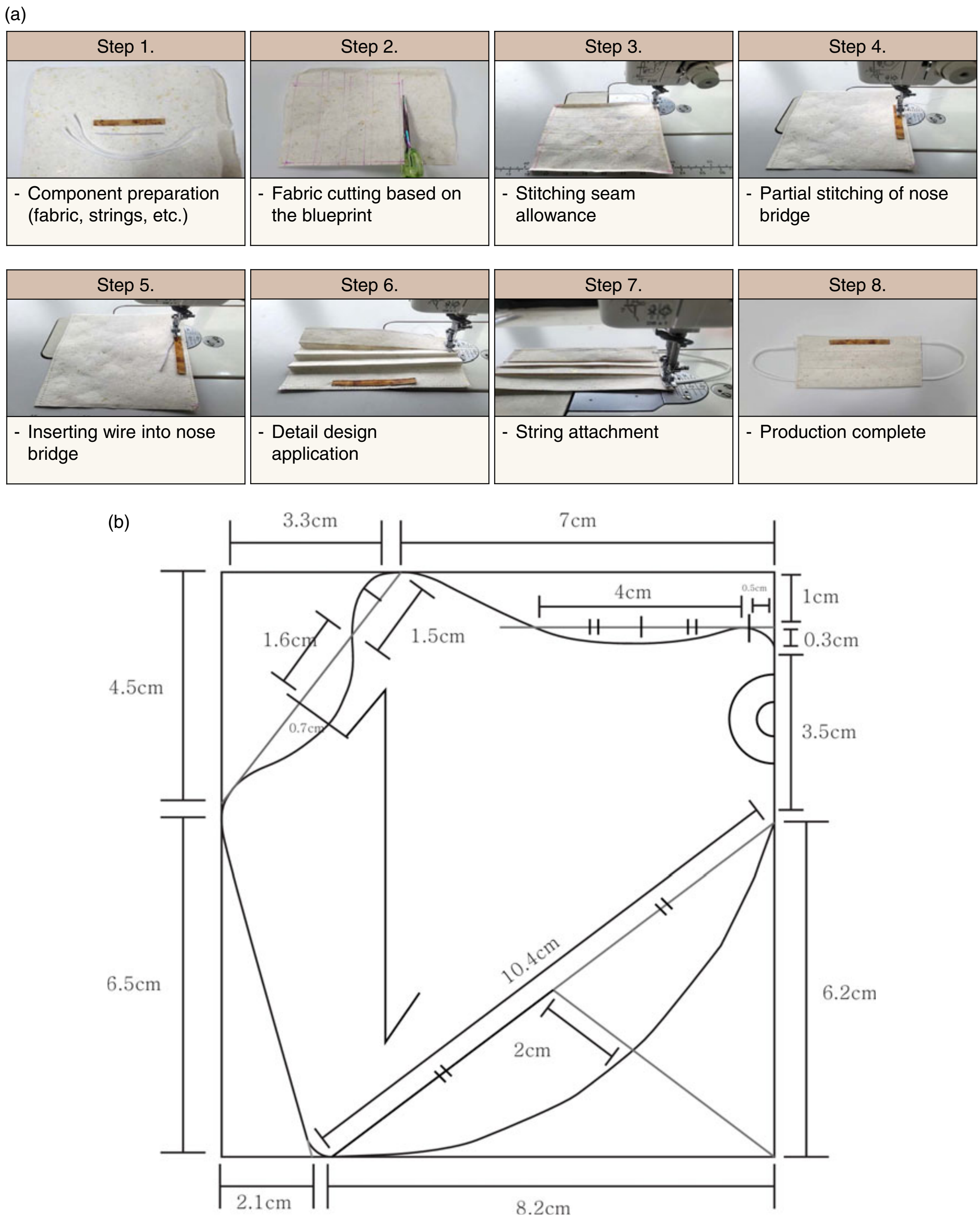

Figure 2. **(a)** Prototype mask production process and step-by-step, **(b)** Blueprint example of mask prototype production.

hydroxyl groups on its surface, contributing to its high-water affinity (Boateng and Yang 2024). This affinity is believed to cause an increase in processing time for higher pulp content. Considering production efficiency, a 20% ratio was found to offer the greatest time advantage for producing composites within a limited timeframe. Therefore, the mycelium pulp content for the nonwoven composite used in mask production was determined to be 20%.

Antibacterial test

The manufactured sheets were evaluated according to the KS K 0693 standard. The strain used for testing was *S. aureus*, and the inoculum for the fabric (1.0×10^5 CFU/mL) was prepared based on the relationship between sterile media and cultured solutions after a certain incubation period and analyzed using a UV-Vis spectrometer. Assuming the cotton nonwoven as the standard fabric, the

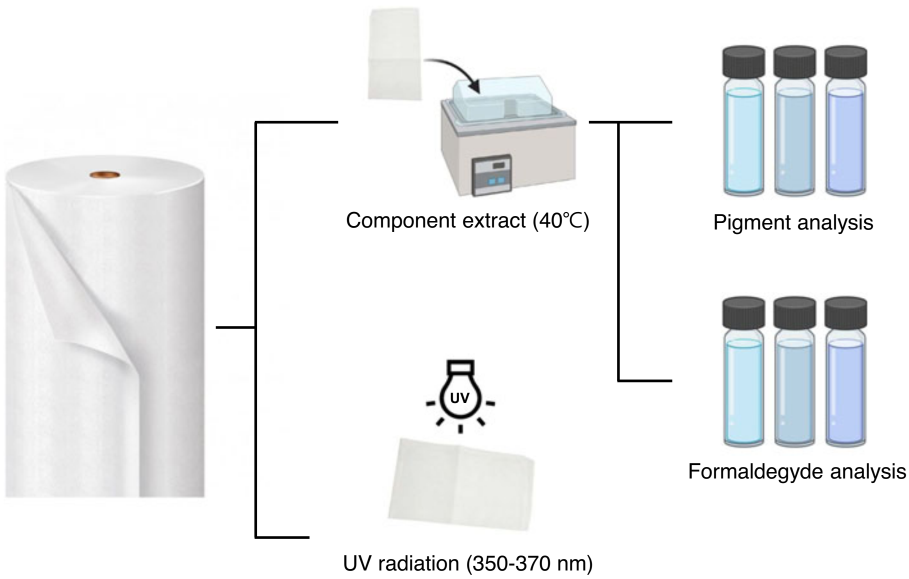

Figure 3. Summary of testing contents in the partially revised standards and testing methods for quasi-drugs (The figure was created with www.biorender.com.).

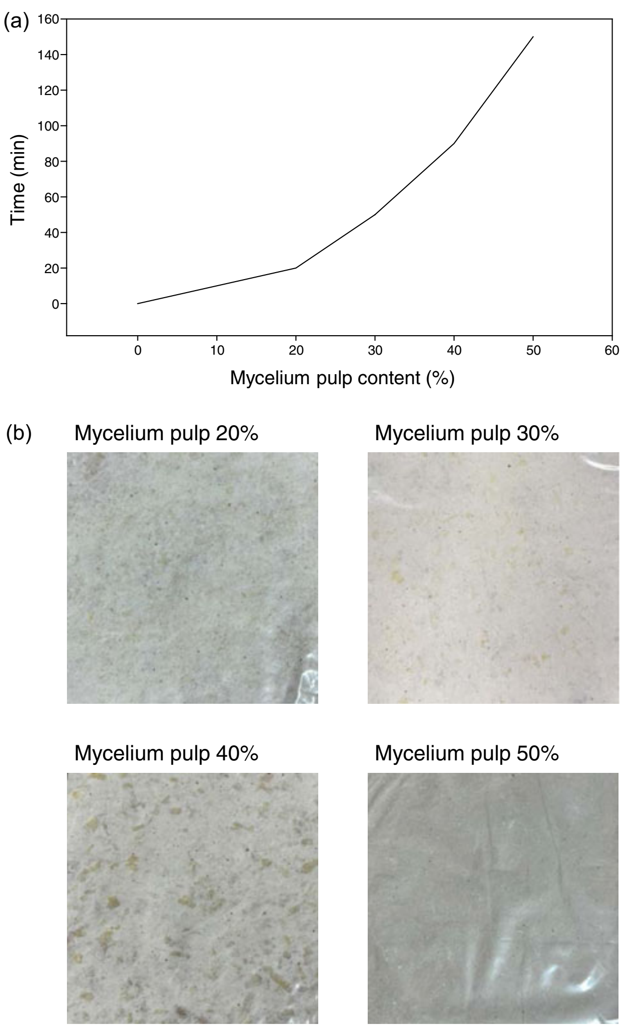

Figure 4. (a) Sheet-processing time based on mycelium-based pulp (MBP) content, (b) Cotton-MBP composites formed with varying contents.

results of the antimicrobial tests were as follows as shown in Figure 5. Compared to the viable cell count of the standard fabric after incubation (1.58×10^8 CFU/mL), the cotton-*P. ostreatus* composite (8.3×10^7 CFU/mL) demonstrated an antimicrobial efficacy of 47.47%, while the cotton-*F. velutipes* composite (1.8×10^5 CFU/mL) exhibited a significantly higher efficacy of 99.89%, indicating superior antimicrobial activity of *F. velutipes* over *P. ostreatus*. This difference in antimicrobial efficacy is presumed to be due to variations in the β-glucan content within the fungal cell walls. Previous studies conducted in Korea have demonstrated that mushroom extracts from *Lentinus edodes* and *Auricularia auricula-judae* exhibit antimicrobial activity against various bacteria, including *Escherichia coli*, *Pseudomonas aeruginosa* (Han *et al.* 2015; Yu and Oh 2016). Therefore, a comparative analysis of the β-glucan content in these two strains using a β-glucan assay kit should be undertaken in future research. It has been noted that prolonged or repeated use of masks may lead to bacterial growth on their surfaces. (Park *et al.* 2022). Nevertheless, the composite material produced in this study, which incorporates Mycelium pulp (especially from *F. velutipes*) into cotton, exhibited higher antibacterial efficacy compared to ordinary cotton-based materials, suggesting that its application to masks could suppress microbial growth and reduce hygiene-related risks during use. Such improved antibacterial properties may also help reduce unpleasant odors that can arise while wearing a mask and mitigate potential skin troubles. Consequently, the antibacterial functionality of fiber composites using Mycelium pulp could provide a significant advantage in the field of sanitary products, including masks.

Purity test

The purity test results for the manufactured sheets were summarized in Figure 6. In this study, formaldehyde, pigments and fluorescent whitening agents (FWAs) were not used, however, the analysis was conducted because these components are required for measurement in Korea when transitioning to actual product production (MFDS 2020).

The purpose was to ensure that, in the event of detection due to possible alterations in fibers caused by physicochemical treatments, the product's integrity would not be compromised. The first

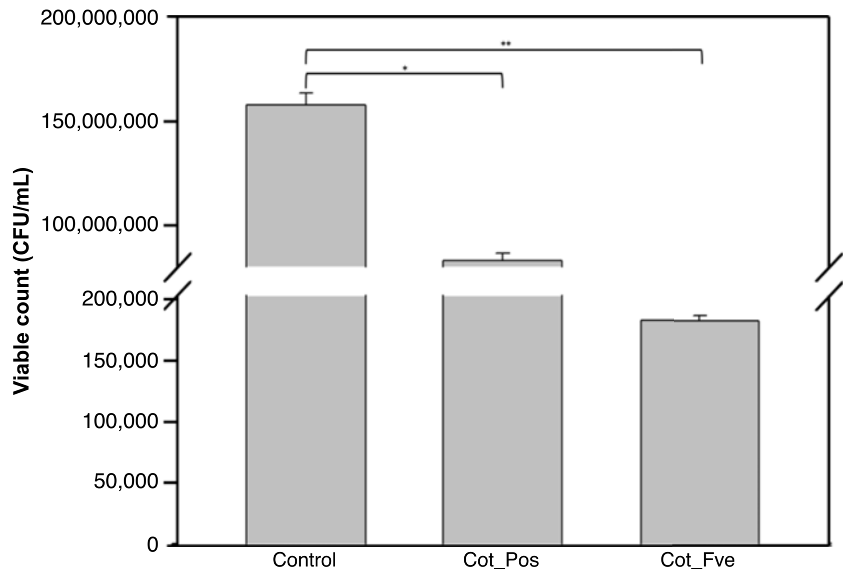

Figure 5. Antimicrobial efficiency of mushroom pulp addition using *Staphylococcus aureus* KCTC 1621. Control; cotton nonwoven, Cot_Pos; Cotton-*Pleurotus ostreatus* composite, Cot_Fve; Cotton-*Flammulina velutipes* composite. Statistical significance was determined using a two-tailed t-test. Bars with different letters indicate significant differences ($p \leq 0.05$: "*", $p \leq 0.01$: "**"). Error bars represent the standard deviation (SD).

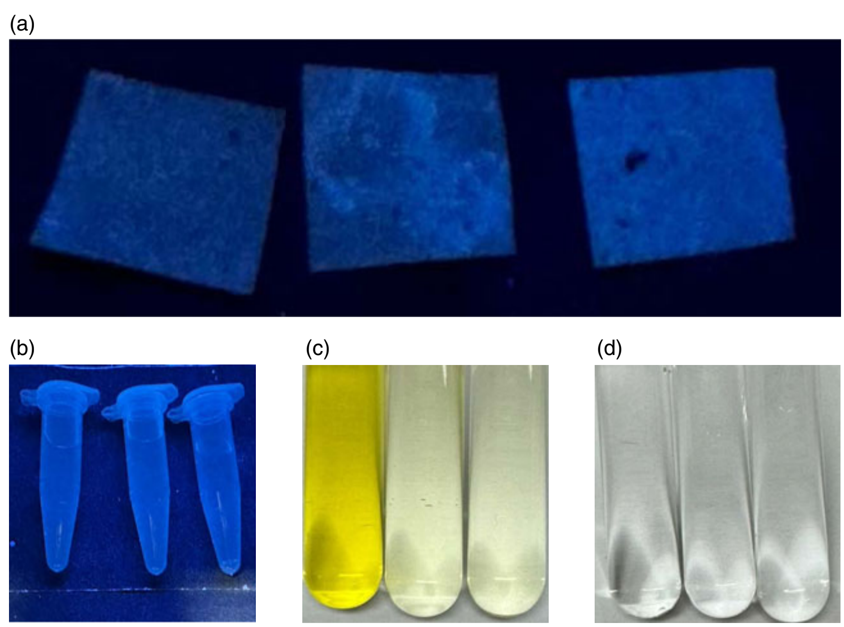

Figure 6. **(a)** Primary Fluorescence Whitening agents (FWAs) detection at 356 nm. Left; cotton nonwoven fabric, Middle; cotton-*Pleurotus ostreatus* composite, Right; cotton-*Flammulina velutipes* composite, **(b)** Secondary FWAs detection at 356 nm. Left; cotton nonwoven fabric extract, Middle; cotton-*P. ostreatus* composite extract, Right; cotton-*F. velutipes* composite extract, **(c)** Formaldehyde detection. Left; potassium chromate solution, Middle; cotton-*P. ostreatus* composite extract, Right; cotton-*F. velutipes* composite extract and **(d)** Pigment detection. Left; distilled water, Middle; cotton-*P. ostreatus* composite extract, Right; cotton-*F. velutipes* composite extract.

analysis is pigment. Comparing the pigment extracts with distilled water as the control, both yielded transparent liquids, indicating that no pigment was extracted. The second is formaldehyde measurement. The test results confirmed the absence of fluorescence emission. This test, compared against a standard solution of potassium chromate, showed lower coloration. Third is the FWA test. The sheets were observed to have fluorescence at 356 nm, so a secondary test is needed. No fluorescence emission was detected after observing the secondary-treated solution in a 1.5 mL Eppendorf tube under the same UV conditions. These results confirm that all achieve standards. The observed fluorescence in some sheets may be attributed to changes in molecular structure caused by chemical reactions (Fu and Nathaniel 2018). Phenolic compounds, under alkaline conditions such as NaOH, could dissociate into molecules capable of absorbing UV light and emitting fluorescence (Cao *et al.* 2023). Results were confirmed that detected below the standard levels or not detected, ensuring compliance with the standards.

Mask prototype

The mask prototypes were manufactured from processed sheets using a defined mask production workflow (Figure 7). Three blueprint designs were employed: vertically foldable (Bird-beak shape), horizontally foldable and dental type. Each prototype required one sheet (25×25 cm^2) for assembly. Currently, plastic-based strings are utilized; however, their substitution with mushroom-based materials is an applicable alternative for the future. To assess this feasibility, components such as nose bridges and strings were manufactured using mycelium-based leather developed in previous studies (Raman *et al.* 2022; Jeong *et al.* 2023). The nose bridge application demonstrated no significant technical challenges. However, when

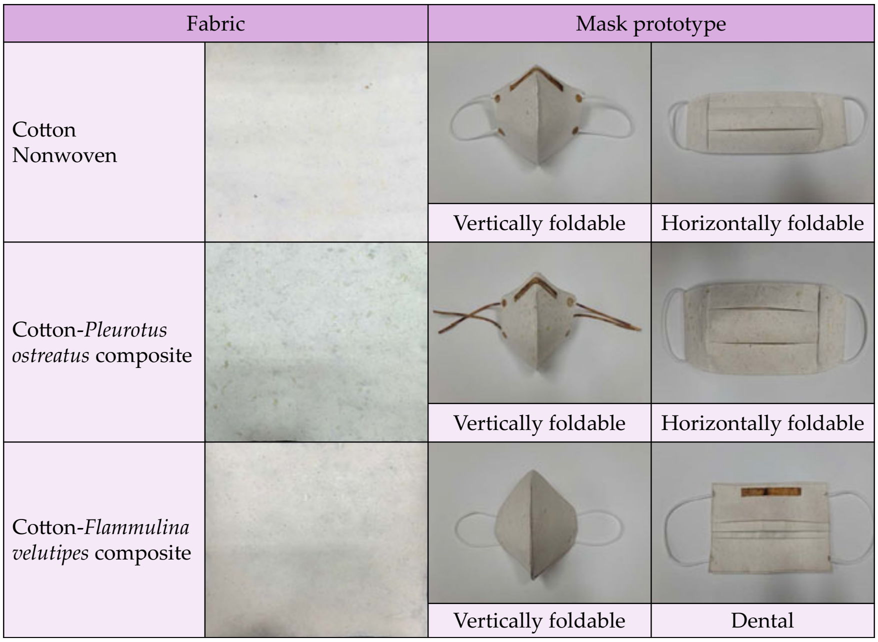

Figure 7. Design and sheet forming of mask prototypes with cotton and mycelium-based pulp composite.

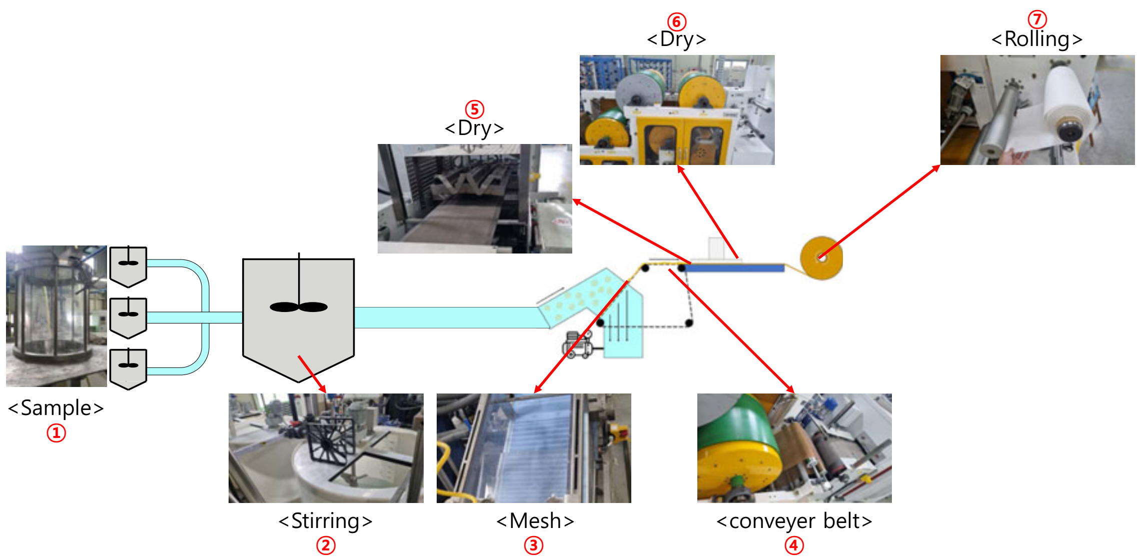

Figure 8. Schematic diagram and actual images of the pilot-scale sheet-forming process equipment owned by the Korea Textile Development Institute (KTDI).

attempting to use thin mycelium mats (cut 2–3 mm thickness) as strings, uneven mechanical properties led to localized failure and severing under tensile stress (Raman *et al.* 2022). These limitations highlight the need for future advancements in mycelium mats' uniformity and tensile strength. Furthermore, leveraging prior research on the extraction and processing of chitin/glucan complexes from fungal fruiting bodies or mycelium (You *et al.* 2024; Vadivel *et al.* 2024), it is proposed that monofilaments or multifilament structures could be engineered (de Oliveira *et al.* 2024). These structures could potentially achieve superior tensile properties compared to conventional plastics, enabling their application in string manufacturing while offering significantly enhanced environmental sustainability compared to current prototypes (Krishnamoorthi *et al.* 2022). MBP nonwoven composite samples do not exhibit elasticity like conventional textiles but rather have a texture like paper or leather. The variation in thickness suggests potential applications in apparel, interior design and other textile-related industries. However, a major drawback is its high moisture absorption, which leads to excessive water retention under humid conditions or heavy rainfall, weakening the structure and causing fiber disintegration and tearing. Unlike traditional textiles, the composite lacks elasticity, giving it a paper-like texture. However, when combined with natural materials such as Korean paper, Hanji (mulberry pulp paper), it presents a promising opportunity for the development of biodegradable and eco-friendly textiles, as its inherent biodegradability enhances its potential as a sustainable fiber source. Moreover, we believe that the prototype developed through this research can contribute to reducing plastic use, which has been an existing goal and mitigate environmental pollution caused by plastic, as it does not utilize plastic materials. Plastic-based masks release microplastics as they decompose under various environmental conditions when discarded in the soil or ocean (Dissanayake *et al.* 2021; Song *et al.* 2024), but it is made of natural ingredients, such as cotton and mushrooms, so they have little environmental impact even after decomposition. Furthermore, to exhibit leather-like characteristics and if sufficient sample quantities become available in future research, their applicability in products requiring durability, such as bags and cushions, should be explored. The processing of this material also presents certain challenges, particularly in sewing applications, as the material exhibits low puncture resistance, causing permanent perforations when stitched. This characteristic initially made iterative stitching difficult, but with repeated processing trials, workability improved, confirming that the material can be successfully used in textile applications with careful handling. Beyond mask production, the composites exhibit significant versatility for applications across various industries. Its potential as a biodegradable and sustainable material suggests broader research opportunities in textile innovation, eco-friendly product development and the design of functional materials. Future studies should focus on enhancing mechanical strength and moisture resistance to broaden commercial viability. Additionally, in this study, a batch-type process was employed, which limits the ability for continuous sheet production. For industrialization, a continuous wet process must be adopted. The continuous wet process can be viewed as an extended concept of the sheet former used in this research, maintaining the same fundamental principles but with modifications to enable continuous operation (Figure 8). For composite manufacturing, they can be suspended and mixed at predetermined ratios within a Continuous Stirred Tank Reactor (CSTR). The resulting suspension is then transferred through a continuous circulation system to a device where a conveyor belt and mesh move synchronously. Fibers are continuously deposited onto the mesh and transported along the conveyor belt, undergoing a drying process before being collected as fabric by the fabric collection unit. Equipment capable of implementing this process is currently available at Korea Texile Development Institute (KTDI), making it feasible to apply this method for industrial-scale production.

In addition to the mask application explored in this study, the potential of MBP materials for broader applications is also being investigated. We are currently developing a film-type material derived from MBP and have confirmed that it exhibits electrostatic properties, suggesting its suitability for use as a mask filter. Based on these findings, future studies will explore the integration of both MBP composites and MBP-based films in various applications such as biodegradable packaging, hygiene products and filtration media. These directions further support the value of MBP as a versatile biomaterial platform for sustainable product development.

Conclusion

For the production of mushroom-based materials, strains of *P. ostreatus* and *F. velutipes* were cut into uniform sizes and converted into MBP through physicochemical treatments. The MBP was mixed with cotton fibers and processed into cotton nonwoven and composites using a sheet former device as part of a batch-type process. As a result, nonwoven fabrics and composites with a size of 25×25 cm^2 were successfully formed. Antimicrobial activity tests revealed that composites containing *F. velutipes* exhibited antimicrobial efficacy of over 99%, showing significant differences compared to the control (cotton nonwoven). Analysis of FWAs, formaldehyde and pigments confirmed that all samples, including those containing *F. velutipes* and *P. ostreatus*, were below the regulatory limits. The nonwoven fabric and composites produced in this study were used to fabricate three types of mask prototypes: horizontally foldable, vertically foldable and dental types. Furthermore, through additional studies focused on mushroom-based string materials and enhanced antimicrobial properties, these materials are expected to serve as eco-friendly alternatives to conventional plastics and find applications in clothing materials through various processing techniques.

Data availability statement. Data available on request from the authors.

Author contribution. **Ho-Seong Im:** Conceptualization, Software, Methodology, Validation, Formal analysis, Investigation, Writing – Original draft and editing, Visualization. **Myung-Sook Ryu:** Mask prototype manufacturing, Writing – Review. **Baek-Jun Kim:** Conceptualization, Project supervision. **Ju-Kyeong Eo:** Conceptualization, Project supervision. **Eun-Su Park:** Conceptualization, Project supervision. **Satomi Tagawa:** Writing – Review and editing. **Hyun-Jae Shin:** Conceptualization, Supervision, Methodology, Resources, Data curation, Writing – Review and editing, Funding acquisition.

Financial support. This work was supported by the National Institute of Ecology (NIE), funded by the Ministry of Environment (MOE) of the Republic of Korea (grant number NIE-B-2025-18).

Competing interests. The authors have no conflicts of interest to declare for this publication.

Ethics statement. Ethical approval and consent are not relevant to this article type.

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