Mushroom Mycelium-Based Biodegradable Packaging Material: A Promising Sustainable Solution for Food Industry

Jennifer Nathania Pohan1*, Yudhistya Ayu Kusumawati1, and Asri Radhitanti1

1Visual Communication Design Department, School of Design, Bina Nusantara University, Jakarta, Indonesia 11480

Abstract. It is undeniable that many environments and areas are still full of waste. What's more, it's increasing annually. With a growing era, the use of plastic has also increased, especially in online sales that involve plastic as a package protector. With 40% of plastic production going to the packaging sector, an environmentally friendly replacement would be helpful. Furthermore, plastic materials such as styrofoam are considered harmful to both environment and human health. Mycelium is one of the materials that are affordable and easy to obtain. It is a fungus part that can bind and form a strong material with the support of sawdust. With characteristics similar with polystyrene, society, especially MSMEs, is expected to use this material as a substitute.

1 Introduction

Due to their convenient and inexpensive production, plastic materials are widely demanded by people worldwide. They have been the ideal product for most industries and consumers since hundreds of years ago, making them reliable in today's modern economy. However, with the increasing number of plastics, decreasing waste space, and the reuse-lifestyle rejection, people indirectly contribute significantly to environmental destruction. Plastic waste has become the uppermost cause of soil and water pollution. Only a tiny percent of 0.5-1 billion plastic worldwide is recycled annually, and it takes more than 20-100 years to break down [1]. A study by Gall and Thompson claims that such a large amount of plastic waste could damage nearly 700 species of marine life in the past two decades and gradually increase with the continuation of wild plastic waste dismissal.

Although several parties and factors are involved in this issue, the packaging industry has a higher impact, accounting for approximately 40% of plastic production (Plastic waste, 2018). According to Salesforce’s reports, digital sales have escalated by 71% in April-June and 55% in July-September of 2022, which created a rise in the usage of packaging materials.

Polystyrene or Styrofoam is one of the few packaging products widely used as single-use plastic. It is beneficial when it comes to protecting things such as food, electronics, and other fragile products. Although it's a light, affordable, and heat-resistant material, it contains harmful substances that are dangerous to human health, causing neurological effects and an increased risk of diseases such as leukemia if exposed for an extended time. It is also said to be one of the most environmentally harmful waste types currently available, severely damaging the planet's ecosystem [2].

* With the issues slowly becoming more apparent each year, the need for biodegradable plastics has also increased. Fungi materials featuring sawdust are one of the potential solutions for this problem. Though seen as unpleasant organisms, fungi have a crucial role in decomposing natural wastes, making them essential in our ecosystem [3].

The utilization of fungi occurs since its component, known as mycelium, provides a crucial role in the production of the material. Mycelium is the part that develops rapidly, creating miles long of microscopic white fiber, covering the seed husks, and binding it into a strong and biodegradable material. According to the latest studies, mycelium-based materials could offer similar features to polystyrene materials. From organic plastics to furniture, it can also be a form of packaging. Its lightweight, easy to mold and produce makes it the perfect material for delivery. Furthermore, due to the affordable prices of raw materials and disposal, mycelium clearly can help avert future environmental problems [4-9]. With a more environmentally friendly alternative already provided, mycelium-based material needs to be used efficiently by society, particularly MSMEs and other sectors that are heavily involved in plastic waste. With the extremely high number of online shoppers, MSMEs and other businesses need to pay more attention to plastic usage and environmentally safe packaging such as mycelium-based material.

2 Literature Review

To fully observe the possibility of utilizing mycelium material for packaging, it is necessary to be aware of other required substances. Sawdust, also known for its
environmentally friendly material, is one of the main components that contribute to the creation of mycelium-based packaging.

2.1 Previous research

Based on further observations, there are several journals with similar topics regarding the research, as follow:

• “When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials” by Elvin Karana using Material Driven Design method. Through these studies, several experiments presented the characteristics of mycelium. Furthermore, this journal shows the optimal application of mycelium-based material and other opportunities it can achieve.

• “Renewable Mycelium Based Composite – Sustainable Approach for Lignocellulose Waste Recovery and Alternative to Synthetic Materials – A Review” by Galena V. Angelova using qualitative method. According to the journal, Mycelium helps in the movement of a sustainable economy and minimizes waste. Its components have similar characteristics to polymer materials, enabling them to be utilized effectively in construction, architecture, and other fields.

• “Packaging Applications of Fungal Mycelium-Based Biodegradable Composites” by Rejeesh C. Rajendran using mixed methods. We can conclude from this journal that fungal mycelium-based materials aren't only for conventional non-biodegradable packaging but also potentially for other uses, such as air purification filters and insulating panels.

Table 1. Previous Research.

<table>
<thead>
<tr>
<th>Title</th>
<th>Researcher</th>
<th>Method</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials</td>
<td>Elvin Karana, Davine Blauwhoff, Erik-Jan Hultink, Serena Camere</td>
<td>Material Driven Design (MDD) Method</td>
<td>Mycelium-based material has many other opportunities besides packaging.</td>
</tr>
<tr>
<td>Renewable Mycelium Based Composite – Sustainable Approach for Lignocellulose Waste Recovery and Alternative to Synthetic Materials – A Review</td>
<td>Galena V. Angelova, Mariya S. Brazkova, and Albert I. Krastanov</td>
<td>Qualitative Method</td>
<td>Mycelium helps sustain the economy, minimizes waste, and can be used in construction, architecture, and other fields</td>
</tr>
<tr>
<td>Packaging Applications of Fungal Mycelium-Based Biodegradable Composites</td>
<td>Rejeesh C. Rajendran</td>
<td>Mixed Methods</td>
<td>Mycelium-based are studied because they can potentially utilize for other uses such as air purification filters and insulating panels</td>
</tr>
</tbody>
</table>

Table 1 above explain differences as well as similarities between each articles. All the conclusions equally states that Mycelium has a great potential to help avert future environmental problems.

2.2 Sawdust

Sawdust is a leftover material from the wood and timber industries. It is a suitable mycelium growth medium since it includes 60.8% carbon, 5.2% hydrogen, 33.8% oxygen, and 0.9% nitrogen. It is a sufficiently infinite and affordable material that has recently been studied for its capability to eliminate chemical compounds from water and wastewater, such as hazardous salts, oil, heavy metals, and dyes [10].

2.3 Mushroom Mycelium

Mycelium is a fast-growing vegetative section of a fungus that is commonly found in biological and agricultural wastes. It is a harmless and sustainable material that bonds to the media attached. Mycelium-based packaging is created by growing them into customized molds. With sawdust as a media, it'll bind together, sufficiently replacing polystyrene. Once the mycelium fundament has formed into the required shapes, the growth can halt by drying and heating.

2.4 Research Road Map

Fig. 1. Research Roadmap

The first stage in performing research is to decide and explore the topic of the problem. Considering the growth of e-commerce transactions also involves plastic, which worsens the existing situation, it then decided the research emphasis on environmentally friendly packaging. After further studies on the problems and solutions selected, the next step is performing a survey to gather data. After compiling adequate data and information, the next stage can initiate prototype development. Then, the final step is to finalize Micelya packaging, followed by testing it.

3 Research Method

With the use of the quantitative method, the data required to substantiate current research was through
directing surveys. In a questionnaire called The Use of Packaging in SMEs, 110 responses have collected through several questions regarding the impact of plastic waste, managing daily waste, and various types of eco-friendly packaging.

![Fig. 2. Plastic Usage on MSMEs](image)

From image 2.1, 51 out of 110 respondents (46.4%) still use plastic packaging for their business. It is clear that plastic packaging still plays an essential role; moreover, the majority of respondents considering plastic for its affordable price (68.2%), not easily damaged (51.8%), and durable (46.4%).

![Fig. 3. The Development of Micelya in Indonesia](image)

Regarding the research topic or the original objective of this questionnaire, this question introduces mycelium packaging and anticipates one of society's concerns about the package. It is shown that the majority of respondents (64.5%) are interested, and some are still considering (32.7%). In other words, mycelium packaging still has the potential to develop among Indonesian people, but with the expectation that its production is affordable, allowing it to be more widely accepted.

![Fig. 4. Design Thinking Methods](image)

The following image depicts the application of Design Thinking to Micelya's research process. At the emphasize stage, it started by observing the problems. Upon further investigation, it turns out that plastic waste soared due to the increase in online transactions during the Covid-19 Pandemic. Moreover, styrofoam, which commonly uses in food and packaging, is identified as the most dangerous among other plastics. With problems already specified, the solutions given also need to be relevant. By applying 3R (Reduce, Reuse, Recycle), the approach used for this situation is environmentally friendly materials, such as mycelium and sawdust, as both are results of various waste.

Then, a survey is conducted at the defined step to collect data from society. Since the topic covers online transactions, the survey aims at individuals who have or plan to start a business. With this strategy, the research studied can address environmental concerns while still relevant to society's needs. After gathering sufficient data and information, Micelya's concept formed more clearly. At this step, all ideas regarding Micelya's product sample will be listed and selected according to the necessities of society. Micelya's formation is approaching completion as it enters the prototype stage. Start with the mycelium growth process with sawdust as media, customize the molding form, and refine the results. All necessary measurements will be recorded and revised along the way as the Micelya product develops. The final step is Test, which involves polishing the final product and resolving a defect that needs repair. At this rate, all processes are also being documented for upcoming products and development.

### 4 Result and Discussion

#### 4.1 Packaging Design Development

The research outcomes acquired are based on the design thinking method previously mentioned. From this method, the prototyping stage process starts with refining the packaging product, both the material used and the design, which includes color, elements, typeface, and layout. Perfecting the material starts with the main ingredient itself, namely mycelium. Materials such as mycelium rely on the ability to grow into lignocellulosic substrates and bind lose organic particles together, making applying synthetic binders unnecessary. Several types of fungi that have the potential on this research are Pleurotus ostreatus, Hypsizygus ulmarius, Ganoderma lucidum, and Trametes versicolor. Through various trials and selections, it is articulated that Trametes versicolor is the most effective fungi for utilizing sawdust to further recycling options, where the combination of these materials will create hydrophobic and flame-resistant packaging. Apart from that, by using entirely organic ingredients, this product in the form of packaging has the advantage that it will automatically decompose and decompose, be friendly to the environment, and be suitable for plants.

Based on Indonesian Plastic Industry Association and Central Bureau of Statistics, plastic waste in Indonesia reaches 64 million tons/ per year, with 10 billion plastic bags tossed into the environment or as many as 85,000 tons of plastic bags [11-12]. Likewise, with the survey results that have been collected, the data shows that the use of plastic is still rife, especially in MSMEs. Since technology has developed constantly and online purchases are increasing each year, this packaging aiming MSMEs out there who need packaging to protect the products they sell. With the establishment of this packaging, it is expected that
MSMEs and the whole community will be more motivated to use single-use packaging that is more organic and biodegradable. This desire is not merely a hope but also supported by the affordable pricing and the designs that convey messages that will persuade the public to participate in making changes to this world.

The use of color is also simple, by only using two colors. This is done so that packaging production does not involve too much ink which could harm the environment. Therefore, producing a packaging design requires only brown cardboard and ivory-color ink. To sufficiently support the previous point, the layout design is also made simple but still able to convey the message, including packaging materials and awareness-invitation messages. These points are then also backed and directed through the use of sans serif typography which can attract reader's attention with its casual and relaxed impression. Based on several studies, an experiment was conducted to test the effect of serif and sans-serif fonts. The results show that sans serif can make the reader fast and accurate in reading a word, especially for the younger generation [14]. Considering that they will be responsible for protecting the world in the future, the typeface chosen for this design is intended so that the younger generation also interested in making changes.

4.2 Mycelium-Based Biodegradable Packaging for Food Industry

Mycelium-based biodegradable packaging is an innovative and sustainable solution that has gained attention in the food industry. Mycelium refers to the underground root structure of fungi, and it can be harnessed to create a range of materials, including packaging.

A fungus's mycelium, which resembles a root and is made up of several branches with a threadlike appearance. Shiro masses on mycelia are fungi colonies that are found below or on the surface of the soil. It has a strong fibrous structure that can be used to create many sustainable materials for packaging, building, food, and clothing. As a substitute for plastics, it can be utilized to create materials like leather and edible plant-based steak. As a result, in the e-commerce sector, the quickly proliferating mycelium can offer a fantastic substitute for Styrofoam, which is gradually becoming outlawed in most countries due to its detrimental environmental consequences [4]. Because mycelium is biodegradable, sustainable, and regenerative, it can be produced cheaply and will likely be widely used in the future.

Because mycelia can be shaped into various shapes, the mycelium foam base has a wide range of applications in the packaging sector. The use of mycelium packaging in the food industry is anticipated to increase in the future because of factors including the growing customer preference for eco-friendly packaging and the growing concern about the environment.

The mycelium material produces foams that are sturdy, lightweight, easily molded, and biodegradable. They do not last as long as environmentally friendly and useful foams like polystyrene or Styrofoam, which are healthy for the environment. Even though mycelium foams might be thought of as biological materials, they have been shown to be stronger than polystyrene foam or polyurethane goods. Additionally, it is flame and water resistant, which are advantageous qualities for...
uses like apparel and packaging. For use in the delivery packing, whether for one-time use or longer-term storage, strength and lightweight are desirable qualities. Mycelium packaging, also known as myco-materials or mushroom packaging, refers to a sustainable and biodegradable alternative to traditional packaging materials. It is made from the root structure of mushrooms, known as mycelium, and has gained attention for its numerous advantages. Here are some of the benefits of mycelium packaging.

1. Sustainability: Mycelium packaging is an environmentally beneficial substitute for traditional packaging materials like plastic and Styrofoam because it is made from renewable resources, such as agricultural waste. It decreases the need for fossil fuels and the amount of carbon emissions produced during production and disposal.
2. Biodegradability: Mycelium packaging's biodegradability is one of its key benefits. Mycelium-based goods have a natural ability to breakdown and break down after use, returning to the environment without leaving behind toxic residues or adding to long-term pollution.
3. Versatility: To fit varied products, mycelium packaging may be molded into a variety of shapes and forms. It can be used for insulation, cushioning, and protective packing, offering top-notch protection during travel.
4. Lightweight and Strong: Materials made from mycelium are both light and remarkably strong and long-lasting. They may successfully protect fragile goods without using a lot of material. Additionally, the lightweight design saves money on shipping and energy.
5. Customizability: Mycelium packaging can be made to meet certain product dimensions, guaranteeing a tight fit and the best possible protection. It offers flexible solutions for various packaging demands and may be customised to a variety of industries, including electronics, food, cosmetics, and more.
6. Natural antibacterial qualities of mycelium make it resistant to germs and fungi, and it also has fire-resistant capabilities. Furthermore, it naturally resists fire, which helps increase the safety and security of packaged items.
7. Less Waste: Mycelium packaging is biodegradable, which contributes to reducing the world's waste issue. Businesses may dramatically minimize their contribution to landfill garbage and advance the circular economy by using mycelium-based materials.
8. Positive Brand Image: Businesses can improve their brand image and attract environmentally conscious customers by adopting sustainable methods and employing mycelium packaging. It shows a dedication to minimizing environmental effect and can set businesses apart in the marketplace.

5 Conclusion
From this research can be seen that the condition of the surrounding environment is so apprehensive. Advances in technology have indeed brought many conveniences to human civilization. With advances in technology, people can get through various difficult times such as the pandemic. But how good is this development if it has such a detrimental impact on the earth? The use of plastic packaging has soared with the times, especially with online sales. It is time for people to pay more attention to what they use in their daily lives, including small businesses. With this problem in mind, an idea came in the form of eco-friendly packaging. Through various stages and research, it has finally been executed through the establishment of mycelium packaging, along with a design forming an invitation to join the use of environmentally friendly packaging.

Applications for mycelium material are numerous, and it has many advantages over non-biodegradable materials. Additionally, it is becoming more popular and attracting the interest of huge corporate giants in the e-commerce and packaging industries thanks to its low manufacturing cost and abundant natural resources.

For instance, businesses like Dell and IKEA have already begun employing packaging materials made of mycelium for their products. Additionally, because of its durability and leakproof qualities, packaging made from mycelium is widely used by the cosmetics industry. The adaptable qualities of mycelium make it a preferred choice for companies worldwide. With this alternative, it is hoped that MSMEs can start using packaging that is more environmentally friendly so that the use of various types of plastic can decrease and public awareness will also increase.

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References


