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Fungal Mycelium; The Key to a Sustainable Future

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Fungal Mycelium; the key to a sustainable future

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Abstract

This study focuses on fungal mycelium-based packaging as a biodegradable replacement of polystyrene packaging. In this thesis project, there will be a thorough study of the characteristics of fungal mycelium and how it can be combined with other products to create biodegradable packaging. Polystyrene packaging is unsustainable and poses threats to human health and our natural environments. It is pivotal that alternative packaging options for polystyrene are researched and tested to prove reliability as packaging systems develop. Research questions answered in this thesis include: Can fungal mycelium be a biodegradable replacement for plastic/polystyrene packaging at a large scale? What is the longevity of fungal mycelium? Do the benefits outweigh the costs? How does humidity affect the growth/creation of mycelium-based products? What are the optimal growing conditions for fungal mycelium? What have other studies found out about fungal mycelium? Objectives of this experiment are to determine the effectiveness of fungal mycelium blended with hemp and to determine whether it can be a

replacement for polystyrene packaging on a large scale. This thesis paper is structured into five sections: 1) Introduction, covering background of polystyrene and continuing to introduce the concept of fungal mycelium; 2) Methods and Materials, covering the instruments and methodology process of the experiment; 3) Experiment, testing the properties of fungal mycelium and polystyrene; 4) Results and Discussion, assessing the effectiveness of mycelium as a packaging product agent; 5) Conclusion, discussing the likelihood of implementation and potential of mycelium. Overall, mycelium offers viable, affordable alternatives for polystyrene packaging on a global scale. For a biodegradable packaging transition to occur, research grants and governmental investments are required for scientists and researchers to continue their work.

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Introduction

As many of us are aware, the climate crisis has arrived, and the world must make radical changes. If future generations want a chance to live and thrive in such a manner that past and current generations have, then our waste habits and plastic usage needs to be seriously reviewed. Humans have developed selfishly by abusing resources and overconsuming. Many individuals do not consider how much waste they generate daily. When new things are acquired, we often discard old things. With so many items being distributed and our global population rising, the usage of polystyrene packing is increasing dramatically. “Expanded Polystyrene (EPS) or Styrofoam, is a petroleum-based non-biodegradable foam**,** which the EPA and International Agency for Research on Cancer consider styrene a ‘possible human carcinogen’ and ‘such materials can have serious impacts upon human health, wildlife, and aquatic environment, and the economy’” (Lewis). As humans continue to evolve, we require more “stuff” in order to get by, but only a small percentage of individuals realize the impact of their consumption. We use non-sustainable products without considering the cost it has on our planet. It is up to those who know and care to promote a change. If we redevelop the entire system of packaging production, then we have made a step. One way this step might occur is through the use of fungal mycelium.

Fungal mycelium is not an everyday conversation point. Most of us just consider mushrooms as a cooking ingredient. Researchers across the United States are slowly discovering the array of environmental benefits and healing powers fungi can provide. Let us get into the specifics of what mycelium is. Mycelium is defined as ‘a vegetative part of fungus bacteria which consists of a mass of branching threadlike hyphae’ (Munks 2003). It makes up the body of a basic fungus and is primarily grown on soil surfaces. In simple terms, it is fungi’s root system. The initial research portion of this project was to learn about mycelium and how it might be applied to manufacturing products. Mycelium serves as a binding agent for surrounding materials. It can be blended alongside agricultural waste products to create structured, biodegradable products. This product decomposes at a fraction of the speed of plastic and polystyrene. This research paper will expand on the blending process of fungal mycelium and previous experiments companies have accomplished. The goal of this product is to replace or reduce the use of existing packaging products used by major companies such as Amazon, FedEx and so on. There is potential to replace products that take thousands of years to break down in a landfill with packaging products that can be 100% composted and 100% recycled.

A process known as microbinding occurs which combines fungi alongside an agricultural waste product such as woodchips, corn stalks, corn husks, hemp, buckwheat, wheat straw, and more. Products that are high in lignin and carbohydrates allow consumption for fungal mycelium which creates energy to accelerate the growth and binding process. Combing mycelium with a common product, such as wood chips, allows for mycelium to fuse the woodchips together, creating a solid, stable structure. The products can be grown in any type of shape, which then creates an interior mold of the exterior shape. The molding process requires no additional heat or energy. It is a clear, sustainable practice.

The importance of this study is hopefully apparent. Our waste production is reaching a rate that is unacceptable, caused by habits that are damaging and unsustainable. According to the Environmental Protection Agency, over 250 million tons of consumer waste are generated annually in the US. Nearly a third of this waste is packaging/plastic material. "Out of every $10 spent buying things, $1 (10%) goes for packaging that is thrown away. Packaging represents about 65% of household trash." (USI 2020). Obviously, there are other problems higher on the totem pole, but it is important we tackle problems that have potential for being resolved. Mycelium-blended products could become a packaging product source for major producers and farmers, but it will not be a simple transition. Polystyrene products are *extremely* cheap, and *extremely* convenient. It will be difficult for large scale producers to ignore cheap convenient products if there are no consequences involved. Changes must be economically feasible to occur. It is up to policy to reshape plastic usage and to increase attention on sustainable based materials such as fungal mycelium. The goal of this project is to shed light on a concept with potential, with hopes others will also see its value.

Plastic and polystyrene debris are filling and damaging our oceans at an alarming rate. According to Forbes, plastic trash is predicted to exceed the mass of all fish in the ocean in the planet by 2050. To make matters worse, fish and birds often mistake packing peanuts as food which can cause internal damage if ingested. Even preceding this damage, however, the manufacture of polystyrene products releases hazardous air pollutants which pose threats to humans' respiratory systems. "Over fifty chemical byproducts are released during the manufacturing of polystyrene, contaminating the air, water and communities that live near these facilities." (CEHN). Cities are beginning to learn the detriments of polystyrene which is leading to bans and restrictions. Single use polystyrene products which includes plates, bowls and cups are being used less and less. Schools are investing in reusable containers to protect their children and cut down on waste.

The Sierra Club has strong feelings towards polystyrene, releasing the statement, "When polystyrene items finally do break down, they do not dissolve into benign substances: they just fracture into smaller and smaller bits called microplastics. These small particles present the greatest long-term danger, as these particles displace food supplies in the world's oceans. Once microplastics enter our oceans, they will stay there virtually forever, because they persist, and their removal is not possible." (Lewis).

Knowing that plastic and polystyrene are harmful, it is time to make change. The health of the planet is more important than convenience. Fortunately, there are companies already pursuing this. Ecovative Design LLC is a green biotech company based out of Green Island, New York, with their purpose statement being simple and strong: "To support life on Earth"

(Ecovative 2007). Founder of Ecovative, Eben Bayer, discovered it was possible to create a replacement for polystyrene, which led to the creation of his company. Ecovative are partnering with companies such as IKEA, DELL, and Bolt Threads to distribute their products in biodegradable packaging. They are researching the use of biodegradable mycelium materials for "bio-fabrication," and blending it with a product, like hemp, to fulfill customers' needs while being environmentally friendly.

Ecovative launched a project known as 'MycoComposite™' which is a, "patented biomaterials platform utilizing mycelium as a self-assembling, biological binder for hemp agricultural byproduct" (Ecovative 2007). MycoComposite™ creates high quality packaging products that are 100% recyclable and 100% compostable. They offer collaboration opportunities for major companies to provide custom mushroom packaging to their consumers. Local farmers supply agricultural waste products to Ecovative allowing them to take part in the blending process. Ecovative is taking waste to create an effective and high performing packaging product.

"To grow its products, Ecovative buys wood chips or agricultural waste from regional farms and cleans the debris, creating a suitable medium for cultivating mycelium. The bits and pieces of agri-waste are then mixed and treated with mycelium, which digests the waste, enveloping it into a white, fibrous root matrix. The mycelium-coated particles are then broken up and sorted into trays that serve as molds, in which Ecovative grows its products. After a few days, the mycelium hardens into solid structures that take the form of their receptacles. Once this process is complete, the structures are dried out so that they no longer can form spores or mushrooms. The resulting material is nontoxic, naturally fire-resistant, home-compostable, and suited to a variety of applications" (Kadirgamar 2017). The production process uses very little energy and produces a fraction of emissions when compared to polystyrene production.

During the research process, the following questions will be answered through researching previous studies and creating a comparative analysis:

- Can fungal mycelium be a biodegradable replacement for plastic/polystyrene packaging at a large scale?
- What is the longevity of fungal mycelium?
- Do the benefits outweigh the costs?
- How does humidity affect the growth/creation of mycelium-based products?
- What are the optimal growing conditions for fungal mycelium?
- What have other studies found out about fungal mycelium?

Methods and Materials

Once the answers to these questions are determined, we can spread knowledge of its importance and apply it to everyday lives. If it were a simple process, it would likely already be happening on a global scale. We need to learn if fungal mycelium can provide the more sustainable packaging we desperately need. There are existing studies which will be analyzed to better understand the criteria of mycelium. A physical comparison of polystyrene packaging and fungal mycelium blended with hemp will be conducted in this study. For reference, a comparative analysis is defined as ‘an item-by item comparison of two or more comparable alternatives, processes, products, qualifications, sets of data, systems or the like’ (Wilkinson 2013). Using a combination of previous studies, future research efforts, and an in-depth analysis of the physical properties of fungal mycelium, a proper judgement of the product can be provided.

Intensive physical properties that will be measured include density, boiling point, and melting point (Lumen 2020). Additional physical properties that will be measured will include fire resistance, water resistance, texture, structure, scent, weight, shelf-life, biodegradability, R-value and cost.

Figure 1: Hemp hurds blended with mycelium – Ecovative

After receiving results regarding properties of the two test subjects, there will be a better understanding of the strengths and weaknesses each subject brings to the table. This paper utilizes the results of Ecovative Design's study of the material properties of fungal mycelium hemp products. After gathering results for this project, we will analyze Ecovative's properties and expand on their results later. Their mycelium hemp mix consists of (95% hemp, 5% mycelium) where mycelium serves as a binding agent to fuse with the hemp. This mix is a "Grow-It-Yourself Material" that is offered by Ecovative to spread the use of mushroom packaging. Recreating their property tests will provide accuracy of results and give this research study additional information.

Many instruments are needed to firstly grow the mycelium hemp object. Starting with the "Grow-it-Yourself Material" mycelium-hemp hurds, provided by Ecovative Design. Next, we will need gloves, safety glasses, measuring spoons, flour, rubbing alcohol (to sterilize equipment), scissors, stock pot, plastic wrap, measuring cup, kitchen scale, and a growth form –

in this case a stainless-steel dish pan to mold the product. There are a set of steps that must be followed to effectively grow the product.

Three cups of water mixed with four tablespoons of flour will be added to the mycelium-hemp hurd mix. These additions will “activate” the product. The product will be stored out of sunlight, at room temperature, for approximately four days. After the four days have passed, the same measurements of water and flour will be added to the product in a mixing bowl for the second time. The additions will be properly mixed into the hemp hurd mix, giving it the consistency of wet mulch. Next, the product will be placed in a stainless-steel pan giving us an accurate mold size. After adding the mix to the pan, it will be sealed in plastic wrap, with a few holes poked at the surface allowing the product to breathe. Four days will pass once again, and the product can be extracted from the pan. This will create a dish pan shaped mold of fungal mycelium blended with hemp. Next, the product will be baked in the oven at 200 degrees Fahrenheit for thirty minutes. After creating the mold, the comparative analysis portion of the project can begin.

Figure 2: Polystyrene packaging side by side to mycelium hemp packaging (Rosenbaum 2016)

The products will be separated into two tables. Their physical properties will be compared side by side, to determine which product is more effective. Even prior to testing each product, it is apparent that each product has opposing strengths and weaknesses. Mycelium-hemp products are environmentally friendly but come at a cost. Polystyrene products are not environmentally friendly but are less costly to produce at a large scale.

As the methods list above, the product was mixed in a with all the ingredients in a stock pot.

Mycelium-hemp product mixed with ingredients in a large stock pot

The product had a wet, sticky texture as anticipated. After mixing, the product was transferred to a stainless-steel dish pan. It was packed down and sealed with plastic wrap, poked with a dozen holes allowing the product to breathe. After sealing the product, it was stored in a low-light cool place for four days. After four days past, the product become much firmer and drier after growing for 96 hours. A slight amount of mold began to grow at the middle of the product, proving that the product is susceptible to mold, even after such a short period. After initial notes were collected after the growing period, the product was baked in the oven at 200 degrees Fahrenheit for 30 minutes, as mentioned above. After taking the product out of the oven, it was even drier and firmer, giving it the texture and consistency of a rectangular Styrofoam block.

Figure 3: Mycelium-hemp product - post oven baking

Each product was placed on a kitchen scale to gather initial weight. Texture, structure, scent were recorded after. For the first category, fire resistance, a lighter was held under each product for approximately one minute to see how it reacted to heat, results were then recorded. Next, each product was placed in a stock pot full of water for approximately one-minute, recorded results for water resistance afterwards. Shelf life was recorded by leaving each product for three weeks, then returning to see how each product aged. Next, biodegradability, R-value, cost, melting point, and density were recorded based off Ecovative's property charts.

Results and Discussion

After the product was baked, it was time for the comparative analysis portion to be completed. Learning about the properties of the two products is important to distinguish the differences between the two.

Table 1:

Physical Properties	**Fire resistance**	**Water resistance**	**Texture**	**Structure**	**Scent**	**Weight**
Mycelium product	Strong	Strong, susceptible to mold	Scratchy	Firm	Rotten	4.43 lbs
Polystyrene product	Weak	Strong	Smooth	Solid	None	2.13 lbs

Table 2:

Physical Properties	**Shelf Life**	**Biodegradable**	**R-Value**	**Cost**	**Melting point**	**Density**
Mycelium product	2-3 weeks	Yes	3.5 ft^2·°F·h/BTU	$3/lb (varies)	260°C	1.10 kg/m^3
Polystyrene product	1,000 years+	No	5 ft^2·°F·h/BTU	4 cents/lb	240 °C	1.06 kg/m^3

As the results show, each product has its fair share of strengths and weaknesses. This experiment allowed us to explore the properties of fungal mycelium and assess its effectiveness as a packaging material. The immediate differences became apparent when measuring density, as mycelium is nearly 100 times as dense. The two products shared a lot of similar properties, with relatively close melting points and R-values. The most notable difference of course being cost, with polystyrene at 4 cents per pound, and mycelium being on the more expensive end at $3 per pound. However, there is a silver lining for mycelium regarding cost. Programs invest thousands of dollars annually on clean up and recycling costs. Disposing of polystyrene products in landfills requires a much greater cost when compared to the sustainability of composting. The investments required for producing fungal mycelium are much higher, but the clear advantage is it being fully biodegradable. Realistically but unfortunately, the potential for profit overrides environmental in terms of packaging, so a lot of implementation of this product depends on research grants and governmental investments making the transition of biodegradable products possible.

Can fungal mycelium be a biodegradable replacement for polystyrene packaging at a large scale?

Yes, it can. Enacting policies whereby companies would be forced to pay a tax for non-biodegradable products would force them to explore and invest in biodegradable products such as fungal mycelium. A nationwide ban on polystyrene products would similarly force producers to look elsewhere.

What is the longevity of fungal mycelium?

Fungal mycelium has a short life span of about 2-3 weeks, depending on the condition it is kept in. After this time period it begins to break down very quickly and becomes susceptible to mold and other elements.

Do the benefits outweigh the costs?

It comes down to an ethical standpoint. Limiting waste is nearly impossible if the world continues to manufacture and use products that will sit in a landfill for thousands of years. Investing in biodegradable products is a vital step toward sustainable development.

How does humidity affect the growth/creation of mycelium-based products?

Humidity has a great influence on fungal mycelium. It speeds up growth time and enhances the mushrooms' buds. As for the blending process of combining mycelium and hemp, humidity is required for creating the product.

What are the optimal growing conditions for fungal mycelium?

The most optimal growing conditions are between a range of 25-30 degrees Celsius. Fungal mycelium performs well in low light warm areas with plenty of aeration.

What have other studies found out about fungal mycelium?

There are other mycelium researching efforts besides Ecovative Design. A student from Central Community College, Katy Ayers, wanted to create a boat made of mushrooms. Just as this study suggests, Ayers also believes the future lies in mycelium. "If the world is looking for a more sustainable future with less plastic and fewer landfills, the answer, according to Ayers, is mushrooms" (Stoiber 2019). Ayers collaborated with Ash Gordon; owner of Nebraska Mushroom LLC located in Grand Island. They built a canoe hammock mold, which held the mycelium materials over a two-week period. It was grown on Gordon's mushroom farm, and eventually formed into a boat which Ayers took on a six-hour trip down the Platte River. She wanted to test the reliability of mycelium and how it reacted when exposed to the elements. Ayers found that technological advancements can be achieved through mycelium, and it goes much further than biodegradable packaging materials.

Ash Gordon founded Nebraska Mushroom LLC in 2011, with hopes of educating the public on the vast benefits mushrooms offer. Gordon sells fresh mushrooms for consumption and offers a bulk of materials enabling you to grow your own mushrooms at home. A few of note include oyster varieties, shiitake, lion’s mane, reishi, and more. Nebraska Mushroom also offers affiliate farmer programs to add onto existing cropland.

Mycopolitan is a mushroom company based out of Pennsylvania, Philadelphia that distributes mushroom products all over the East coast. Their mission statement:

“At Mycopolitan, we strive to grow the very best chemical-free mushrooms for chefs and home cooks in the Delaware valley. We strike for ecological sustainability, and we work with fungi to regenerate soil and economic value. We support curious people of all ages with the tools and information they need to cultivate a relationship with fungi so that we can build a brighter future together” (Mycopolitan 2020). Similarly to Nebraska Mushroom, Mycopolitan offers lion’s mane, trumpet, chestnut, pioppino, shiitake, and many oyster varieties. Alongside cooking mushrooms, Mycopolitan offers outdoor mushroom blocks to add to your garden or compost bed. These mycelium mushroom blocks can be placed underground which enhances and restores soil quality and organic matter. They recommend adding it to your garden of perennials, but it performs under cropland as well.

Ehab Sayed, founder of BIOHM, is creating sustainable interior insulation for the UK housing market. “Biohm has developed the material from a vegetative part of mushrooms called mycelium, with attractions such as efficient insulation performance, natural self-extinguishing, air purification, and waste consumption. The insulation blocks are made from allowing fungus within the material feeding off sawdust to grow into a mold. Once dried, the material growth halts resulting in a rigid material which can be sanded and painted. “(Walsh 2018). This material may be affected differently based off climate but serves as a building block for housing insulation in the UK. The properties mycelium brings to the table allows for many binding agents which researchers such as Sayed are continuing to discover daily. “According to Biohm, the adoption of the Triagomy method could produce 40% to 90% reductions in the environmental impact of the construction process and a 42% carbon footprint reduction." (Walsh 2018).

Conclusion

Fungal mycelium blended with hemp has adequate properties and characteristics to serve as a biodegradable packaging material on a global scale. In this research project we gained a proper understanding of how fungal mycelium can be fused with other products to create an eco-friendly material. It does not pose the threats to human health as polystyrene does and has a wide variety of benefits to our health. As Amazon and other competing companies continue to expand, the demand for packaging and shipping products rises. Consumers have created unsustainable habits because the shipping system has become so convenient and easy to utilize. Making a transition to biodegradable products will be difficult and slow, perhaps even frustrating for some, yet it is necessary. Policy enactment has power to promote such a change and convincing our government officials is the first step. For this to work, companies who utilize polystyrene products must pay a price for the damage they are inflicting upon the environment. Sustainability should be on the minds of everyone. The annual waste and emissions we are creating is reaching a level that is unprecedented, so we must act before it is too late. Fungal mycelium has existed in nature this entire time, we just need to educate ourselves and continue to research. The solutions we desperately need exist right outside in our natural environments. The potential is there, we must continue to experiment and innovate for the sake of the planet.

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