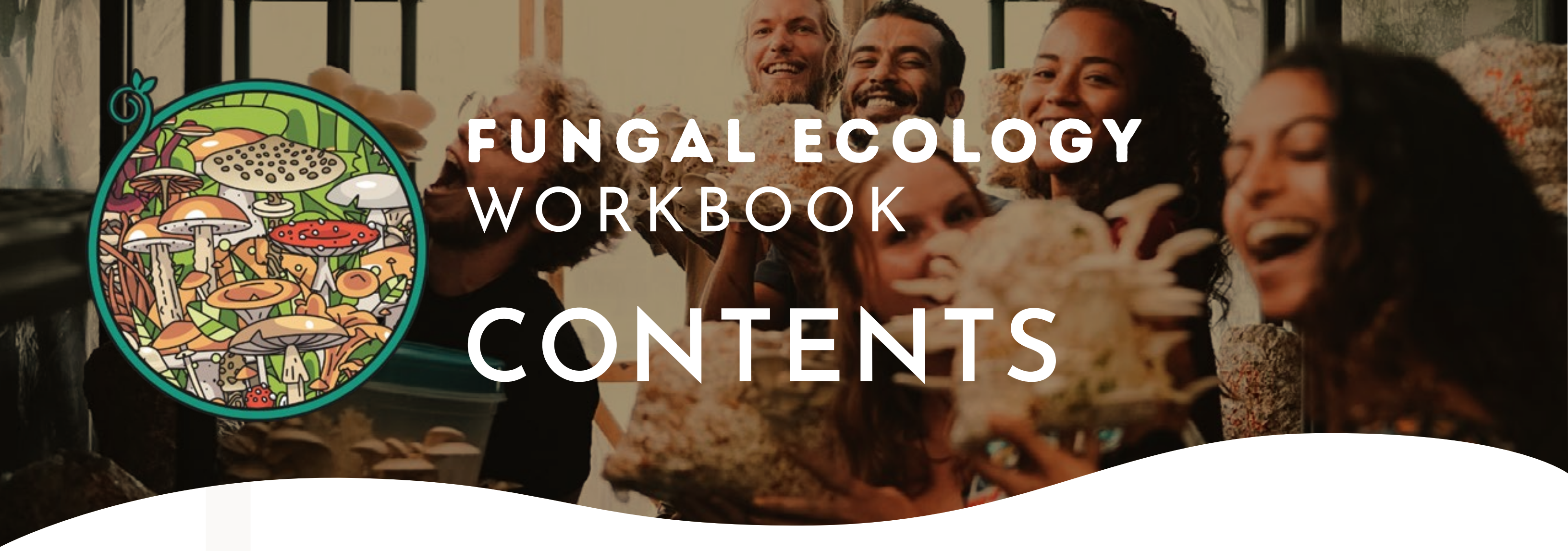
# FUNGAL ECOLOGY COURSE

## STUDENT WORKBOOK

FUNGIACADEMY.COM

FUNGI ACADEMY



# FUNGAL ECOLOGY WORKBOOK

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MODULE 1

# INTRODUCTION

# WELCOME TO THE FUNGI ACADEMY FUNGAL ECOLOGY COURSE!


I am Jasper Degenaars, Hyphae Headmaster of Fungi Academy, grade-A amateur Mycologist, and your host for this course. *I am so happy you made it!* And to be honest, it's a small miracle that we made it to the point you're here right now. This has been an ongoing passion project for quite some time.

When we first drafted the outlines for this course, we thought something along the lines of *"Let's do a quick course with 10, 10-minute video lessons, then get back to doing other stuff!"*

Fast forward to today and this course is a monster of a thing with **39 curated video lessons, +20hrs of educational, mushroom content, 50.000 words of script, and 200 pages of workbook.** This is a massive, massive project!

Along the way, we had our creative director and animation team change, which is the perfect moment to thank the person who stepped up and filled both voids: Corie!


Corie Bidgood

**Without Corie and the people who pre-ordered this course, this course would never have seen the light of day.** Everyone say it together now...

**"Thank you, Corie!"**

Okay, enough about the making of the course. So, what's this thing all about?

We at Fungi Academy love all mushrooms and Fungi. We love their expressions and the archetypes they embody in the natural world around us, whether it's as a director in the orchestra of life or as the hidden alchemist beneath our feet. But we'll leave it to our friends Miguel A. Naranjo Ortiz and Toni Gabaldón, who put it much more eloquently:

> *"Fungi only merit a brief mention in high school textbooks, and very rarely occupy a central position in university-level biology degrees, generally falling between the fields of botany and microbiology.*
> ***Yet Fungi are literally everywhere, shaping the world as we know it. They can be found in the stratosphere & the bottom of the Dead Sea, from Antarctic glaciers to torrid deserts, from the gut of flies to deep oceanic sediments."***

# 1.1 INTRODUCTION

This course on fungal ecology and Fungi's role in ecosystems is **intended to cultivate in you the same love and appreciation for these ancient, omnipresent, quintessential life forms that we at the Fungi Academy have.**

I like to say that **the more we understand something, the more capacity we have to love it.** So consider this course a giant love letter to Fungi aimed to get you and everyone else in love with Fungi as much as we are! Or at the very least, give you some cool facts to tell at your yearly family gathering!

In this course, **you'll learn about the role of Fungi in the evolution of our planet and their relationships with other organisms like our plant, animal, and bacterial brothers and sisters.**

You'll learn about the different types of Fungi, such as **mycorrhizal, saprophytic, parasitic, and endophytic Fungi, as well as other Fungi symbiotic organisms like lichens** and the trillions of organisms living inside you!

You'll also learn about **the role of Fungi in different food chains,** from the forest to the savannah to the concrete jungle.

Finally, we'll finish this course by discussing **new ways in which Fungi can help us improve damaged ecosystems, clean up polluted environments** and allow us to live more harmoniously with nature.

New studies and techniques like **mycoremediation and mycofiltration** are very promising, but there are so many more ways to use Fungi, like **creating the raw materials necessary for construction, fashion (hello, myco-leather!), textiles** and more!

At the end of this course we know you'll find yourself enthralled by Fungi, even more in love with the fantastic world around us, and exceedingly grateful for all of the magical fungal organisms that made this very existence happen.

Thanks so much for being here and supporting us. We can't wait to show you the fruits of our hard loving labor.

As always, mush love,

Jazzy J

# 1.1 INTRODUCTION

## IN THIS MODULE, YOU'LL LEARN:

- How to Navigate this Course
- What are Fungi
- Uses of Fungi
- Fungi Jargon
- Fungal Taxonomy
- The Mushroom Life Cycle.

## HOW TO NAVIGATE THIS COURSE

So, how do you get the most out of this course?! We recommend you listen to Terrance McKenna:

*"Take it easy, dude. But take it!"*

In other words, **we don't recommend binge watching this course.** If you do, it'll be difficult to retain much of what we share.

Instead, it's better to watch a lesson, let it sink in, maybe check out the extra reading material you can find in the lesson notes or in the workbook, read over the workbook, and meditate on it.

Write things down in your own words, share it in the comment section, and do whatever it takes for you to have a clear grasp on the subject before moving forward. Then, if you still have the attention span, feel free to go onto the next lesson.

**To dive deeper down the rabbit hole, we have offered a bunch of extra reading and watching material for every module along with all of the links to our source material. You will also find links to some free youtube videos we like or have made.**

**Plus, for every module, we have invited an expert in the field to host a Mushroom Masterclass on their subject of expertise!** *You can find these online in your* ***Student Dashboard.***

This should provide more than enough to munch on before the deep hunger for more fungal knowledge becomes insatiable!

Of course, these are just guidelines. We aren't here to tell you what to do! Now go figure it out yourself!

**P.S.**

Don't forget to reach out if you have any questions or need support. We aim to be like our mycelial mentors by creating a web of relationships and that means connecting with you!

# 1.2 INTRODUCTION

## WHAT ARE FUNGI?

Okay, what even *are* Fungi? How is that different from mushrooms!?

**Fungi** is the overarching name of the biological queendom that includes any member of the group of eukaryotic organisms that include microorganisms like yeasts, molds, and mushrooms.

The other distinct kingdoms of biological life are Bacteria, Archaea, Protista, Plantae, and Animalia.

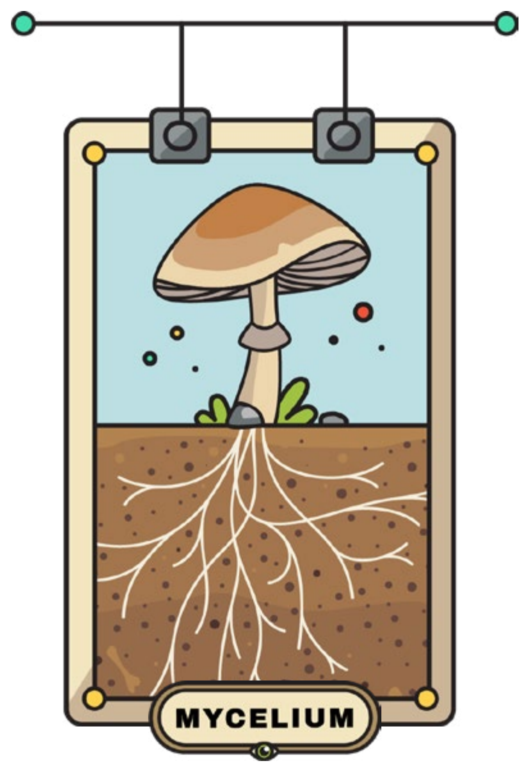
The singular name for Fungi is **fungus**. A fungus is a **species**, which is a more specific distinction within the Fungal queendom.

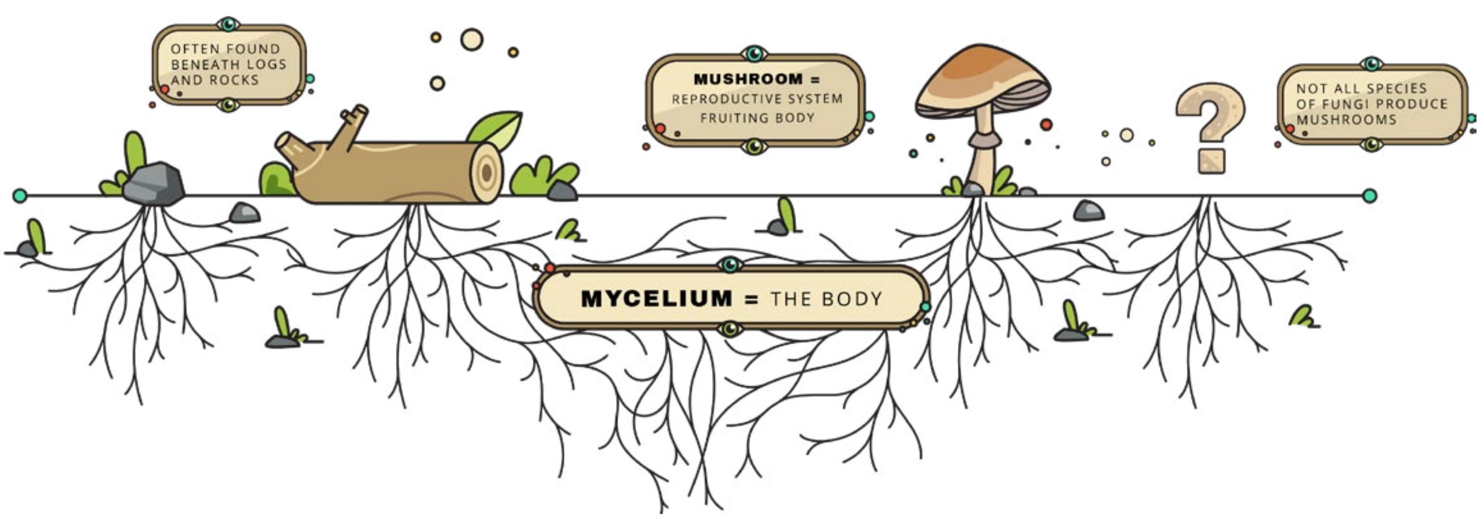
A fungus is assigned to a particular species based on its similarities and common traits to other Fungi within the same species.

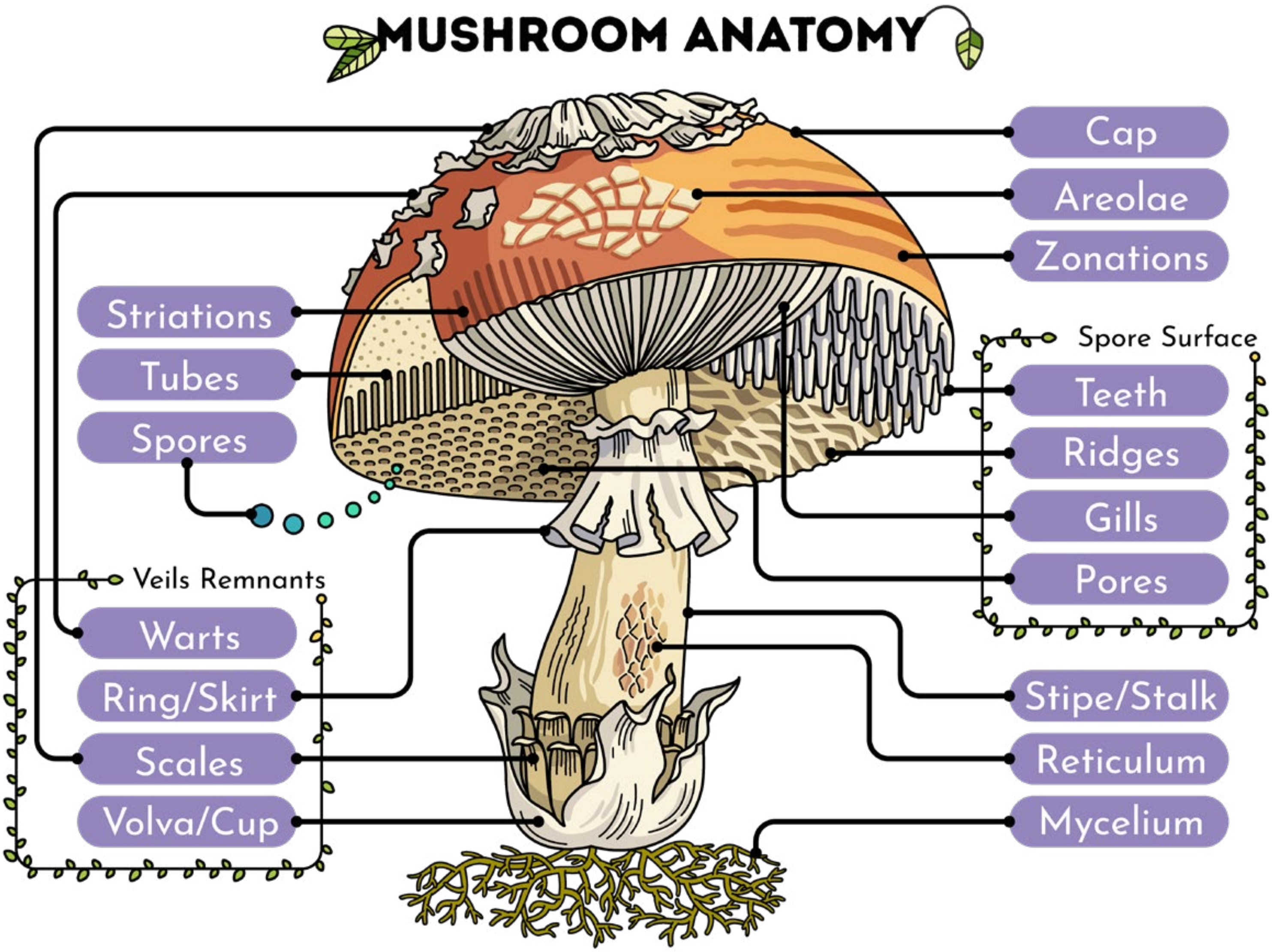
Most species of Fungi produce **mycelium**. Mycelium is a decentralized web of white tissue. You can **think of mycelium as the body or root structure of a fungus**.

**Mushrooms** are the reproductive systems of Fungi, also known as fruiting bodies. However, not all species of Fungi produce mushrooms.

Don't worry, we'll get into all of this more in depth later. For now, just consider this a crash course to get your mushroom mobile up to speed.





MUSHROOM ANATOMY
Cap
Areolae
Zonations
Striations
Tubes
Spores
Spore Surface
Teeth
Ridges
Gills
Pores
Veils Remnants
Warts
Ring/Skirt
Scales
Volva/Cup
Stipe/Stalk
Reticulum
Mycelium

Fungi are **heterotrophic**, meaning they cannot make their own food and must obtain nutrients from organic material. They digest this material outside their bodies before absorbing it through osmosis.

Fungi are considered **opportunists**; they can obtain nutrients from various sources and thrive in a wide range of environmental conditions. They also breathe in oxygen and breathe out carbon dioxide.

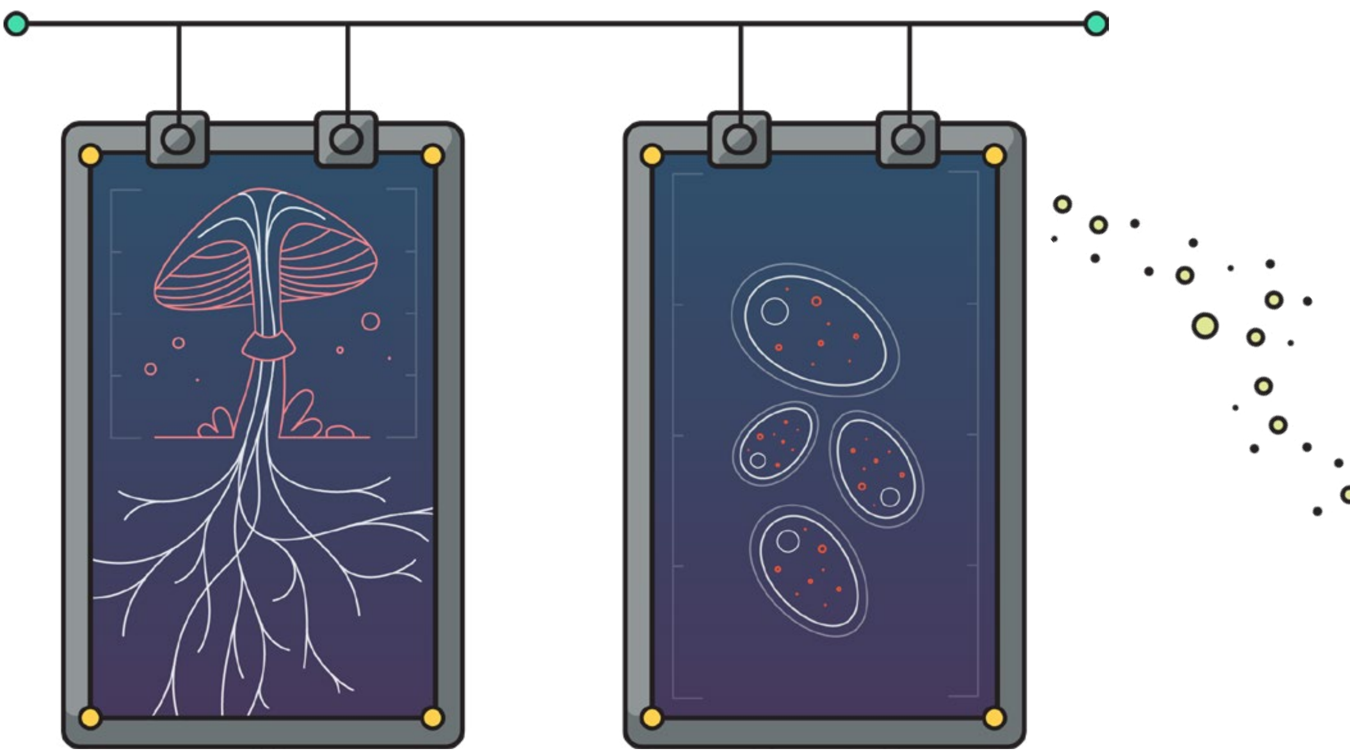
Fungi are extremely diverse. There could be at least **6 million species of Fungi worldwide**.


## MULTICELLULAR FUNGI

(MYCELIUM-FORMING, 99% OF KNOWN SPECIES)

## SINGLE CELLULAR FUNGI

(YEAST, 1% OF KNOWN SPECIES)



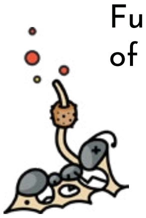
Fungi can be **multicellular** (these are mycelium-forming and make up 99% of the known Fungi species) or **single cellular** (AKA yeasts).

Fungi are everywhere and **may even persist in SPACE!**

# 1.2 INTRODUCTION

Fungi can be **saprophytic, parasitic, endophytic and mycorrhizal.** These categories are not distinct; there is a lot of overlap.

Most macrofungi (Fungi visible to the naked eye) are **saprophytic**; they obtain nutrients by breaking down organic matter. This is why Fungi are so vital to life on earth: they're one of nature's greatest recyclers.



**Parasitic Fungi** obtain their nutrients from other living organisms, primarily plants but also sometimes animals like insects.

**Endophytic Fungi** live inside the tissues of plants, for at least part of their life, without causing harm to the plant host.

**Mycorrhizal Fungi** are any fungus that grows inside the roots of a plant. This is typically a symbiotic relationship. Some Fungi fuse with plant roots, causing speculation that mycelium may have served as the original root systems of plants before plants developed the ability to grow their own roots.


## USES OF FUNGI

Fungi are essential to many **household and industrial processes.**

Single-cellular Fungi like yeasts play a crucial role in making many of our favorite things: **bread, wine, beer and some cheeses.**

Mushrooms can also be **culinary delicacies** of their own, like highly desired truffles.

Some species of Fungi have been used as medicine for hundreds and thousands of years like **Reishi** *(Ganoderma lucidum)*, the "Mushroom of Immortality," **Turkey Tail** *(Trametes versicolor)* a powerful anticarcinogenic, **Lion's Mane** *(Hericium erinaceus)*, a potent cognitive enhancer, and **Cordyceps** *(Cordyceps militaris, Ophiocordyceps sinensis)*, the "athlete's medicinal mushroom."

Fungi are used in the emerging **myco-materials** industry, transforming Fungi into strong, durable and sustainable materials to replace less eco-friendly materials like leather, brick, paper, and foam.

Finally, we could never forget our favorite mushrooms - those within the genus ***Psilocybe***. These mushrooms have been used by people worldwide for thousands of years to **heal our minds and bodies** and s**trengthen our relationship with the divine.**

Fungi aren't just useful; they're **VITAL** to this planet. **Without Fungi, we cannot survive.**

## FUNGAL JARGON

The weird and wonderful world of Fungi comes with its own weird and wonderful lingo. Here's a solid reference list to get you started.

**Autotroph:** An organism that can produce its own food using water, light, carbon dioxide or other chemicals. For example, plants make their own food from light energy via photosynthesis.

**Biotroph:** A parasitic organism that lives and reproduces in another living organism.

**Cellulose:** A complex carbohydrate that is the main constituent of plant cell walls and vegetable matter.

**Ecology:** The study of relationships among organisms and between organisms and their environment.

**Endo:** Internal; within.

**Endophyte:** An organism that lives inside plant tissue, between the cells. These relationships are usually symbiotic.

**Enzyme:** A substance produced by a living organism that acts as a catalyst to bring about biochemical or metabolic reactions. It speeds up the rate of a specific chemical reaction in the cell. The enzyme is not destroyed during the reaction and is used repeatedly.

**Epidermis:** The surface of skin. In plants, this is the outermost single layer of cells that cover leaves, flowers, roots and stems.

**Epiphyte:** An organism that lives on plant surfaces

**Exo:** External; from outside.

**Filamentous Fungi:** A large group of multicellular Fungi, commonly referred to as molds, containing branching tubular structures (hyphae) that form a mass of intertwining strands (mycelium).

**Fungus:** A member of the diverse Queendom of Fungi.

**Genet:** An individual fungal genotype or clone.

**Germinate:** The process of a seed or spore beginning to grow and develop. Seeds of plants germinate into sprouts. Fungal spores germinate into hyphae to form mycelium.

**Heterotroph:** An organism that cannot make its own food and must obtain nutrients from organic sources. For example, Humans, other animals and Fungi depend on eating organisms like plants, animals, and Fungi for nutrition.

**Hemibiotroph:** An organism that is parasitic in living tissue for some time and then continues to live in dead tissue.

**Hypha (hyphae, pl.):** Singular cells that grow into long tubes and weave together to form mycelium. Hyphae only ever become one cell wall thick.

**Lignin:** An organic polymer found in the cell walls of many plants, making them rigid. Lignin is the main constituent of wood.

**Metabolite:** A substance made or used when an organism breaks down food, drugs, chemicals, or its own tissue.

**Mushroom:** The fleshy, spore-bearing fruiting body of certain Fungi. Not all species of Fungi produce mushrooms, yet all mushrooms are Fungi.

**Mycelium:** The main body of a fungus, consisting of a network of fine filaments (hyphae) woven together in a decentralized network. Mycelium is almost always expanding in search of water and nutrients.

**Myco:** Relating to Fungi.

**Mycofiltration:** The ability of a network of fungal mycelium to filter out harmful contaminants from water.

**Mycology:** The scientific study of Fungi.

**Mycoremediation:** A form of bioremediation in which Fungi are deployed to remediate polluted environments. Studies have demonstrated the ability of certain species of Fungi to contain, break down and reuse toxic compounds in oil, diesel, and pesticides, among other harmful pollutants.

**Mycorrhizal:** A fungus that forms a symbiotic relationship with the roots of a plant by weaving together or growing inside the plant's root.

**Parasite:** An organism that lives on or in a host, using the host for nutrients and other benefits at the host's expense.

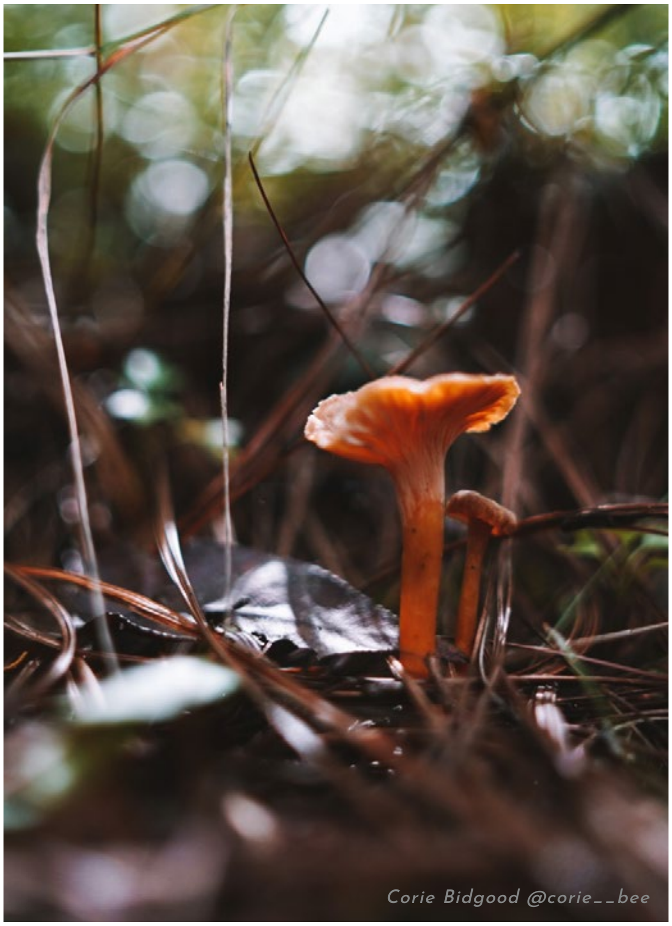
**Pheromone:** A chemical or mixture of chemicals released by an organism to its exterior that causes one or more specific reactions in a receiving individual.

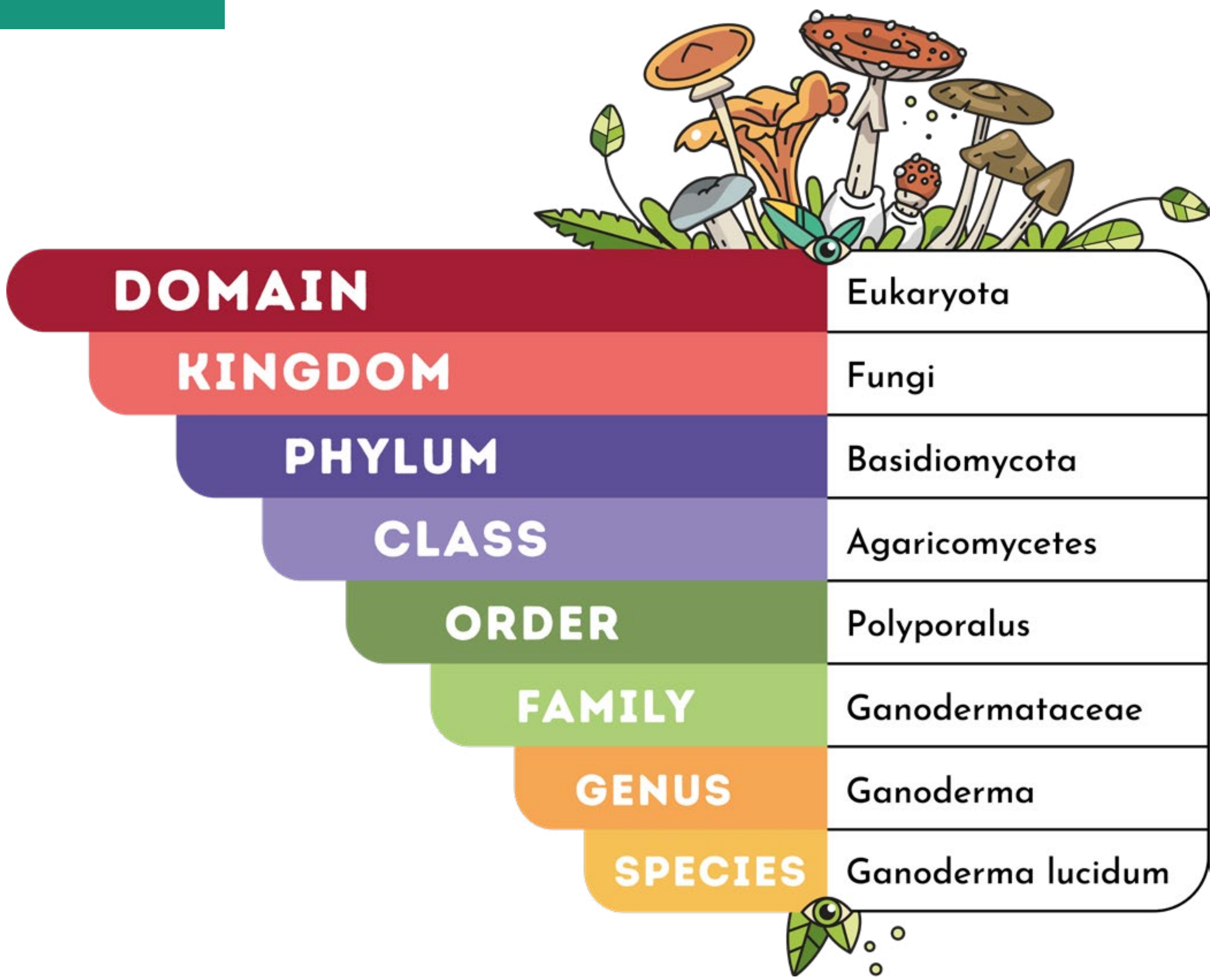
**Photosynthates:** The product of photosynthesis, usually sugars.

**Saprophyte:** An organism that obtains nourishment from dead or decaying organic matter.

**Spore:** A fungal asexual reproductive 'seed' released by fungal fruiting bodies (i.e. mushrooms). The protective layer of a spore is called the sheet, which can be so strong that some spores can survive the vacuum of outer space.

**Symbiosis:** A close ecological relationship between the individuals of two (or more) different species. Sometimes a symbiotic relationship benefits both species (mutualistic). Sometimes, one species benefits at the other's expense (parasitic), and in other cases, one species benefits whilst the other neither benefits nor is harmed (commensal).


*Corie Bidgood @corie__bee*




## FUNGAL TAXONOMY

This lesson, let's explore the tedious, I mean mystical(!!), realms of taxonomy.

First off, no, we don't have a team of trained biologists or mycologists behind the scenes. But that's all the better because that means we can get away with saying some, at times, outrageous statements not 100% rooted in the current scientifically accepted norms.

But have no fear. Anytime we start boarding the train out of science town toward, let's call it, "Jasper philosophizing town," we'll give you a warning.

As you will see throughout this course, we've relied on the work of amazing, hard working scientists way smarter than yours truly to weave this fungal story together. **Every module has a generous compilation of the resources we've tapped into for creating this course.** And if you are as nerdy as us, we highly recommend diving into these extensive and brain buzzling texts!

We tried defining taxonomy on our own terms but in the end, if you can't beat them, join them. So here it is, dictated directly from the modern library of Alexandria, Wikipedia.

# 1.4 INTRODUCTION

"In biology, **taxonomy** (from Ancient Greek τάξις (taxis) 'arrangement', and (-nomia) 'method') **is the scientific study of naming, defining and classifying groups of biological organisms based on shared characteristics.**

Organisms are grouped into taxa and these groups are given a taxonomic rank; groups of a given rank can be aggregated to form a more inclusive group of higher rank, thus creating a taxonomic hierarchy. **The principal ranks in modern use are domain, kingdom, phylum (side note that division is sometimes used in botany in place of phylum), class, order, family, genus, and species.**

The Swedish botanist Carl Linnaeus is regarded as the founder of the current system of taxonomy, as he developed a ranked system known as Linnaean taxonomy for categorizing organisms and binomial nomenclature for naming organisms."

Ok, out of Wiki-world and back to the REAL world.

**Binomial, or binominal nomenclature, is the two way naming system that we are probably all familiar with by now (e.g. *Homo sapiens*).**

We use this binomial nomenclature to avoid confusion that arises when we work with local names.

If I told you I found some eekhoorntjesbrood the other day and cooked it with some garlic and cream, you may be wondering if there is something wrong with me.

But if I tell you that eekhoorntjesbrood is the Dutch name for *Boletus edulis* (AKA "King Bolete" or "Porcini" mushroom), some of you might know what I'm talking about!

**Boletus edulis**
(Eekhoorntjesbrood)

**Binomial nomenclature is sometimes Greek but typically Latin, and there's a small problem (or opportunity, if you see it like us) with using a dead language for a naming system:**

No one truly knows how to correctly pronounce a language which has been dead for over 1,600 years.

So have no fear next time you try to spit out a Latin binomial name.

**THERE ARE ONLY RIGHT WAYS TO MISPRONOUNCE LATIN!**

## STARTED FROM THE BOTTOM NOW WE HERE

To fully understand the taxonomic tree, let's start from the bottom.

For this example, we'll work with the Reishi mushroom, which has the binomial name *Ganoderma lucidum*.

Ganoderma lucidum
(Reishi)

***Ganoderma lucidum* is a species in the genus *Ganoderma*. The genus *Ganoderma* belongs to the family of *Ganodermataceae*,** which contains over 300 species split up between 8 genera (plural of genus). **These genera are:**

1. ***AMAURODERMA***
2. ***ELFVINGIA***
3. ***GANODERMA***
4. ***HADDOWIA***
5. ***HUMPHREYA***
6. ***POLIPOROPSIS***
7. ***TOMOPHAGUS***
8. ***TRACHYDERMA***

Further up the tree, **the family of Ganodermataceae belongs to the order of Polyporalus** which contains about 1,800 species including many of our favorite Fungi like Shiitake *(Lentinula edodes)* and Chicken of the Woods *(Laetiporus sulphereus)*.

**The order Polyporalus belongs to the class of Agaricomycetes** containing 17 orders, 1,147 genera, and about 21,000 species.

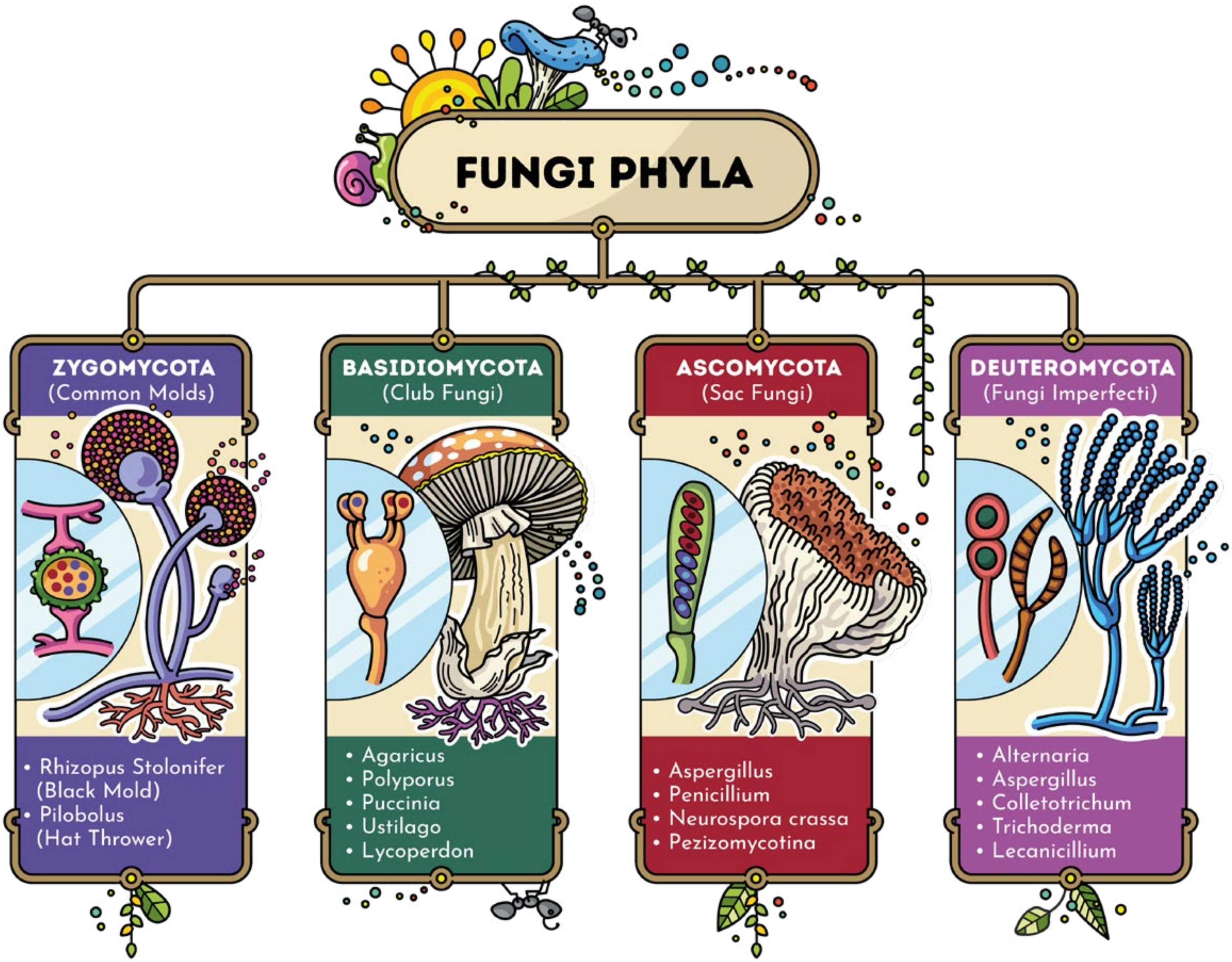
Now we've made it to one of the final branches of the taxonomic tree: the **Phyla.**

**Most of the Fungi we love belong to the Phylum of Basidiomycota,** which contains 16 classes, 52 orders, 177 families, 1,589 genera, and 31,515 species, to be exact. But Basidiomycota isn't the end of the line.

**There's also Ascomycota, which alongside Basidiomycota form the subqueendom Dikarya, also known as the "higher Fungi" or "Fungi perfecti."** Although these two phyla are the key players in our relationship and story with the Fungi, we cannot forget the unseen heroes of the queendom of Fungi:

Zygomycota, Glomeromycota, Microsporidia, Chytridiomycota, Neocallimastigomycota, Blastocladiomycota, Zoopagomycotina, Kickxellomycotina, Entomophthoromycotina, and Mucoromycotina.

Laetiporus sulphereus
(Chicken of the Woods)


FUNGI PHYLA
ZYGOMYCOTA
(Common Molds)
• Rhizopus Stolonifer (Black Mold)
• Pilobolus (Hat Thrower)
BASIDIOMYCOTA
(Club Fungi)
• Agaricus
• Polyporus
• Puccinia
• Ustilago
• Lycoperdon
ASCOMYCOTA
(Sac Fungi)
• Aspergillus
• Penicillium
• Neurospora crassa
• Pezizomycotina
DEUTEROMYCOTA
(Fungi Imperfecti)
• Alternaria
• Aspergillus
• Colletotrichum
• Trichoderma
• Lecanicillium

# 1.4 INTRODUCTION

All these together form the king, or queendom, of Fungi. Add in the plants, animals, and many single cellular organisms, and we're now up to the **"domain" of Eukarya, comprising organisms with nuclei in their cells.**

**Currently there are about 150,600 described species of Fungi with an estimated two to an incredible 11 million total species sharing the globe with us.** Yes, this lesson on taxonomy was created after our introduction lesson, which we know, says a different number. Get used to it with Fungi; genera, species and the whole shabam can switch on a whim!

And with the advancement and increased accessibility of genetic analysis like the **polymerase chain reaction (i.e. PCR)**, we are rediscovering where species and genera of Fungi belong on the taxonomic tree all the time.

If you want to learn more about DNA barcoding of Fungi, **we have a free video on youtube with Alan Rockefeller going through his whole process.**

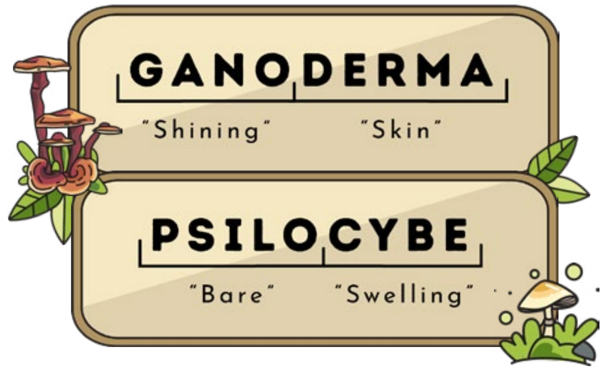
Ganoderma tsugae

Named after host species

## THE NAME GAME

Before we go, let's talk a little bit about the naming of genera and species. Like with the genus *Ganoderma* (Gano = shining, derma = skin, i.e. "shining skin") or the shining skinned Fungi, **the genus is often named after a distinctive characteristic of the Fungi within the genus.**

Take the Psilocybe genus, for example. **Psilos in ancient Greek means "bare" or "naked" while kúbe means "head" or "swelling", giving the genus the meaning "bare headed."**




But the species name can be chosen by the researcher, or team of researchers, that first describe it.

With *Psilocybe cubensis* (AKA "magic mushrooms"), it was named after its initial location of discovery, Cuba.

***Ganoderma tsugae*, on the other hand, is named after its host species, the Hemlock tree** (*Tsuga canadensis).*

And another **Psilocybe, *Psilocybe ovoideocystidiata*, was named for its microscopic characteristics** since it has ovoid cystidiated spores when seen under a microscope.

Psilocybe ovoideocystidiata

Named after microscopic characteristics

# 1.4 INTRODUCTION

**It's quite common to name a species after a well respected individual**, like *Psilocybe allenni,* which was named after John W. Allen, though it's generally considered poor practice to name a species after oneself. Or the newest Psilocybe mushroom, ***Psilocybe stametsii***, discovered in a cloud forest in Ecuador by our Fungal Facilitator Giuliana Furci of the Fungi Foundation and named after mycology's most famous man, Paul Stamets.

**But the crux of it all is that there are no rules! If you describe it first, you can name it first.** And luckily enough, there are also scientists with a sense of humor.


***Spongiforma squarepantsii*** **is a real name for a real fungus, described in 2011 and named after everyone's favorite sponge living in a pineapple deep under the sea... Spongebob Squarepants!**

With over 10 million estimated species of Fungi and only about 150,000 described species, **everyone can find, describe and name a new species! That means you too!** So go out, walk through your local ecosystems with open eyes, and you never know what new discoveries are lurking right outside your door.

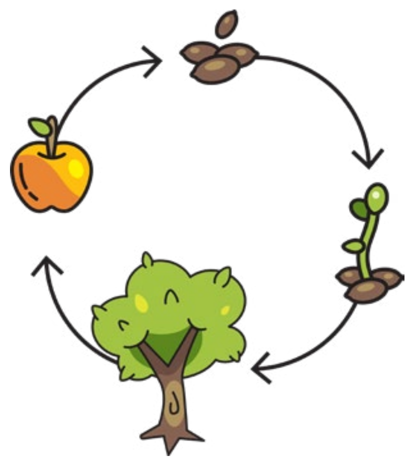
## THE MUSHROOM LIFE CYCLE

Before we dive into the life of a mushroom, let's start with something a little more accessible.

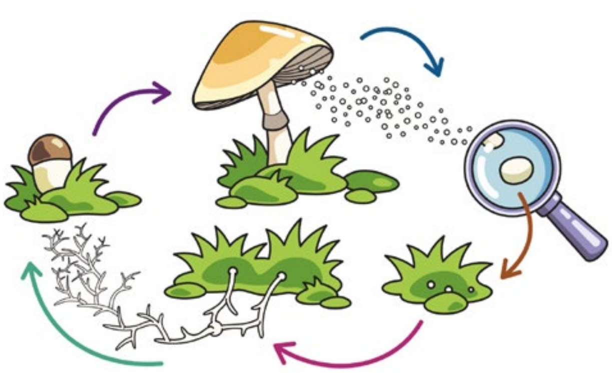
Do you know the lifecycle of an apple tree?

A seed transforms into a sprout. The sprout transforms into a tree. And the tree eventually creates an apple, carrying more seeds!

Pretty simple, right? Lucky for you, the mushroom life cycle works quite similarly. **Here a simple analogy to help:**



**Spore = Seed**
**Hypha = Sprout**
**Mycelium = Tree**
**Mushroom = Apple**



With fungi, **a fungal spore germinates into a hypha** (singular). **Next, the hyphae** (plural of hypha) **weave together to form mycelium.** And then, **a bunch of mycelium forms a mushroom!**

That being said, there are some key differences.

**Mushrooms are not plants!** They form their own queendom in the tree of life and are actually closer to animals than plants!

**Mushrooms,** just like us, **breathe in oxygen and exhale carbon dioxide. They cannot photosynthesize** and have to make due with the nutrients available in their environment.

Like we've mentioned before, **not all fungi produce mushrooms.** But Fungi species in the subqueendom **Dikarya** are capable of producing mushrooms.

**The 2 divisions in the Dikarya subqueendom:**

1. **Basidiomycota,** *(basido meaning pin)*
2. **Ascomycota,** *(asco meaning wine sack)*

**Some examples of Basidiomycota:**

- Oyster mushrooms *(Pleurotus spp.)*
- Sacred mushrooms *(Psilocybe spp.)*
- Fly Agaric *(Amanita muscaria)*

**Some examples of Ascomycota:**

- Truffles
- Cordyceps (e.g. *Cordyceps spp.* and *Ophiocordyceps spp.*)
- Morels (*Morchella spp.*)

# 1.5 INTRODUCTION

Before we bid you adieu, let's go on a journey through the mushroom life cycle!

Imagine being a *Psilocybe cubensis* mushroom. You want to reproduce but you need to make spores **(The creation of spores is called meiosis)**. So your basidia starts to create a structure to release your spores!

Okay, now picture being a spore!

A gush of wind blows by and you're released. Now a happy spore, you begin flying in the wind with all of your spore brothers and sisters!

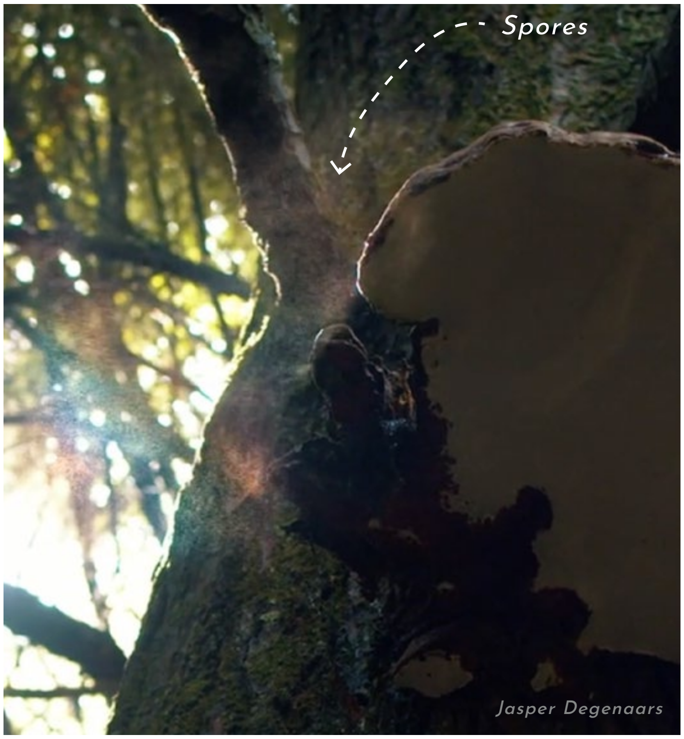
You land, luckily enough, on the perfect substrate! The conditions are right, so you and your friends happily germinate into hyphae. Hyphae at this stage are **monokaryotic, meaning they only have one nucleus in their cell.**

Hyphae love working together to form mycelium! Now, not all hyphae are born alike. Just like us humans, hyphae have sexes.

In Basidiomycota fungi, we often talk about mating type A and B. A and B means the mating types are compatible. But there isn't just one A and one B! **Some mushrooms have more than 339 *A* mating types and 64 *B* mating types all happily able to fornicate with one another!**

So, what happens when a type A meets a type B? Well, have you ever seen Dragon Ball Z? You know when two characters do this funny dance and they fuse to become one ultra powerful being? That is exactly what hyphae do!

**The compatible hyphae fuse or weave together and transform from a monokaryotic cell (one nucleus) into a dikaryotic cell** (multinucleate!) but now with the superpowers of both A and B! It's important to note, **mycelium is often formed by hyphae weaving together without fusing, and the process of Plasmogamy, where two monokaryotic create one dikaryotic, does not include the fusing of nuclei**.




But screw the details! Now you're a mycelium with monokaryotic cells and diploid cells all happily working together.

Yet, just like us humans, you want more out of life. You want to make sure the next generation can form life.

So all of you decide to start a massive building project. The goal? Build a big ole mushroom!

So everyone works together to create this amazing structure, even the hyphae that have not gone through Plasmogamy. Finally, you've done it! A mushroom mountain is built and spores are preparing to take off anew.

This is where our story ends and where the next story begins.

And this, my friend, is where we let you go.

Leave your comments and questions in the discussion box and we'll see you next lesson!

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MODULE

2

# THE FUNGAL EVOLUTION OF OUR PLANET

**Welcome to this lesson all about Fungi and the evolution of the planet!**

You think your Grandpa is old? Think again!
Fungi redefines the word OLD. Like, REALLY OLD!

## IN THIS MODULE, YOU'LL LEARN:

- The History of Fungi
- The History of Life on Earth

## HISTORY, HERSTORY, FUNG-STORY

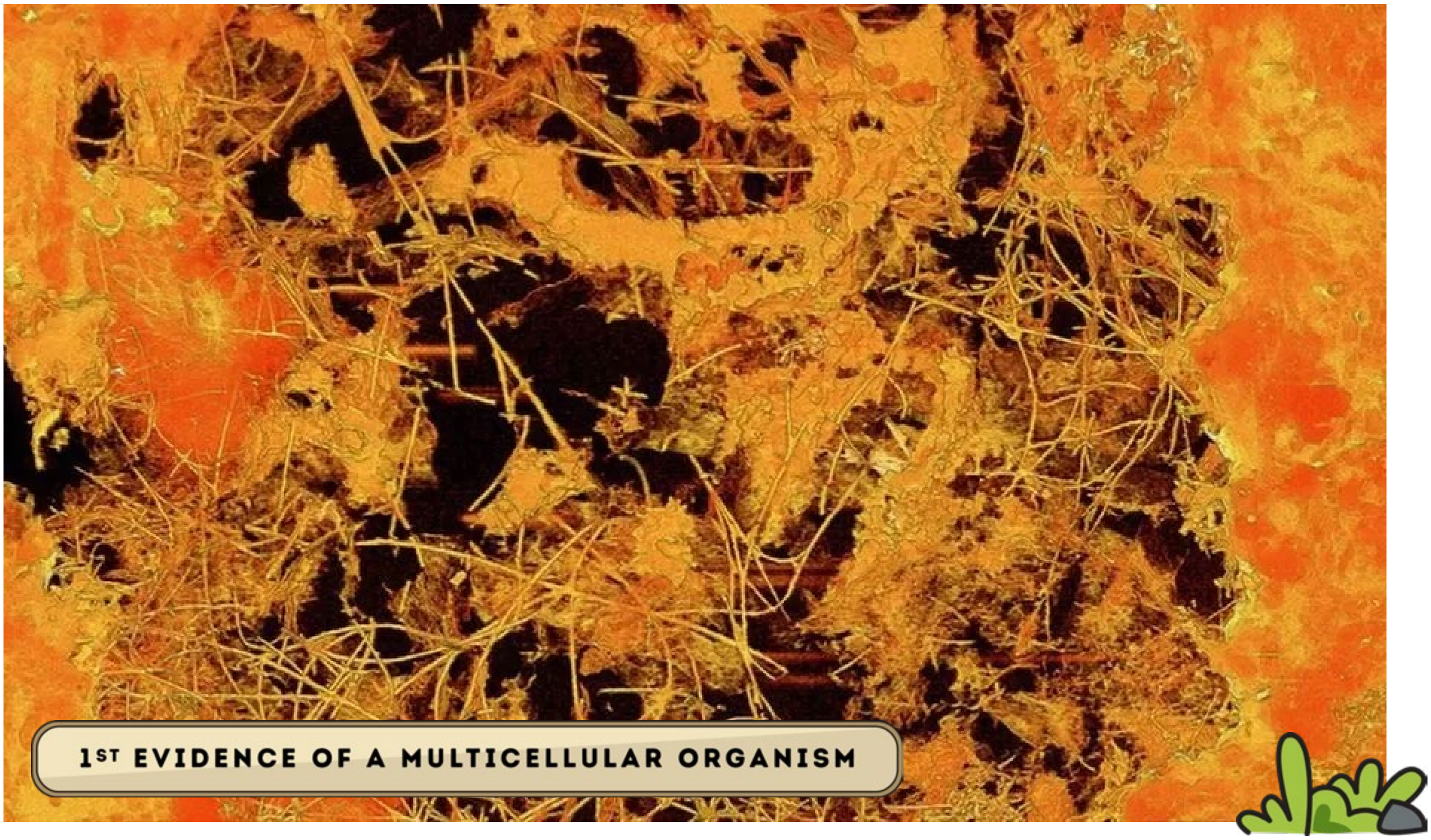
Before we start this module, we have to clarify that all these dates are based on fossil evidence. Fungi, by their temporal nature, aren't great at leaving massive fossils behind. Think of the density of a dinosaur bone compared to soft fungal flesh. **In reality, we simply don't know if fungi have been here from the start, when lichen or mushrooms popped onto the scene, or when the first mycelium started to weave.**

Nonetheless, fossil records are all we have (until we finally invent a time machine or something, at least).

There's concrete, super-scientific-verified evidence of mycelium dating back to 810 million years ago. But the recent discovery in 2017 of a seafloor rock fossil indicates **fungi *may* have been around as early as 2.4 billion years ago!**

Current estimates are that life originated on Earth about 3.4 billion years ago. This estimate is based on very tiny filament clusters found in very old rocks and somehow these tiny filament clusters are the first evidence we have of life on this planet.

Fungi used to be classified in the Plantae Kingdom. In 1969, the five kingdom classification system was proposed to replace the old two kingdom (plants and animals) understanding.




From then on, Fungi have been recognized as its own distinct kingdom. Or as we like to refer to them in this course, Queendom.

Fungi are more closely related to animals than plants. **About 1.5 billion years ago, the ancestors of Fungi and Animals parted ways, becoming two separate lineages.** Of course, our unique and bold claim that all animals have fungal ancestors is still on the scientific table, too! One lineage (Animals) evolved to capture nutrients by surrounding its food with cellular sacs, the ancestor of today's stomachs. The other, Fungi, continued digesting their food externally.

## LIFE ON LAND

One of the most significant steps in the evolution of Fungi was **the development of branching fungal filaments** (that just rolls off the tongue, doesn't it?) – the first real 100% verified mycelium-like structure. This development originated about **715 to 800 million years ago.**

Also around this time, **Fungi seemingly made the jump to land** from their probable ancestors, aquatic molds.

# 2.1 THE FUNGAL EVOLUTION OF OUR PLANET

At this point, **Fungi started forming symbiotic relationships with algae and cyanobacteria.**

The fungi – via enzymes and digestive acids – mined minerals and nutrients and offered protection via its tough cellular wall. In exchange, the algae produced and provided sugars via photosynthesis.

## I'M LICHEN THE WAY YOU MOVE

What do you get when algae and fungi move in together? **LICHEN!**

**Lichens' ancestors appeared around 550 to 635 million years ago**, though they could be much older! It's believed Lichen has evolved at least four separate times.

The **algae/cyanobacteria – fungi relationship** most likely made it possible for plants to make the jump to live on land.

How? Lichen create soil by breaking down rock. They do this with acids, primarily Oxalic acid, and by growing in a rock's cracks (hopefully you don't have any lichen growing in your crack), slowly expanding in the cracks until the rock eventually bursts. Over millions of years, this is how a rock field turns into lush, mineralized soil. (Liking lichens? Don't worry, we have a whole module dedicated to these funky half-fungal organisms later).



## FAMILIAR FACES, THANKS TO FUNGI

So now we have lichens.

We have soil.

And plants are starting to move onto land.

But something is missing...

How are these new land-loving plant species supposed to access the nutrients and water in the soil?!

Fungi to the rescue, of course!

Around 480 million years ago, the first **mycorrhizal fungi** appeared in a form known as **Arbuscular Mycorrhiza**.

This emergence is extra funging fascinating because the first plant with roots, club mosses, only came onto the scene about 410 million years ago, meaning that fungi **specializing in connecting with plants were already 70 million years old by the time plants with roots started to sprout from the soil.**

Even MORE mind-blowing is that tons of the early fossils we have of plants with roots show signs of already being inoculated with Arbuscular fungi-like structures.

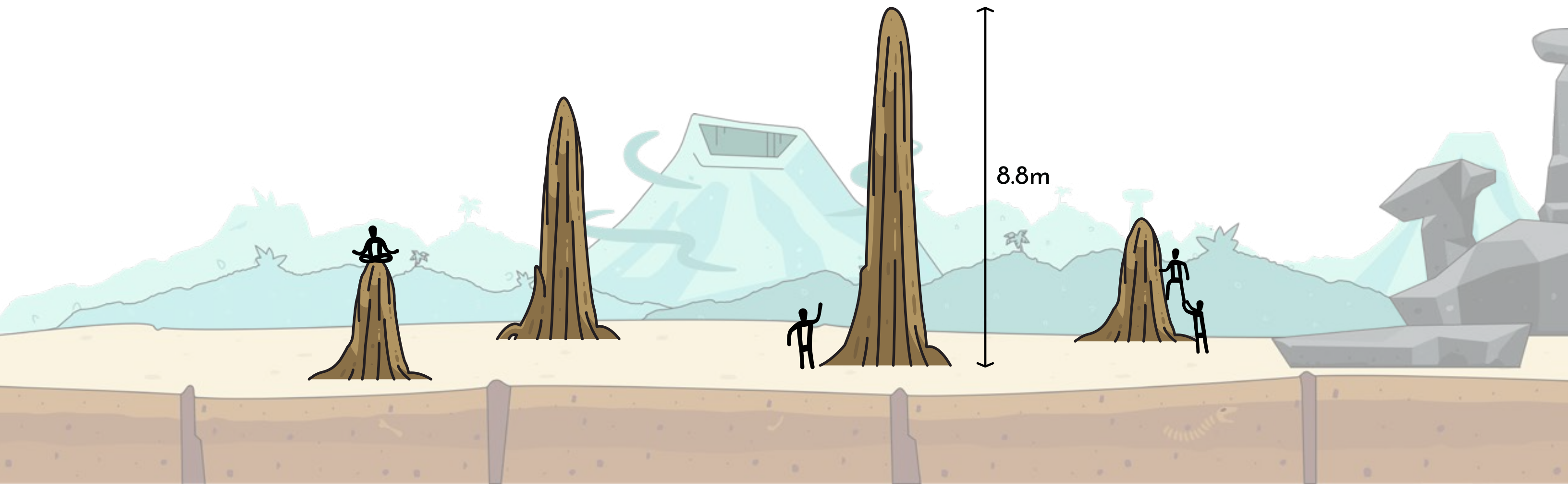
What could this mean?

**In our view, Arbuscular Mycorrhiza may have acted as a root system for plants before plants evolved their own roots,** allowing plants to access larger areas of soil, water & nutrients.

Arbuscular Mycorrhiza also helped build the soil around them by exuding a substance called **Glomalin.**

Glomalin, a sticky protein that helps soil particles stick together, **aids soil structure, and allows water and oxygen to penetrate the soil.** It also **provides nitrogen to the soil and can store significant amounts of carbon,** making it an extremely ecologically significant Fungal phylum.

# 2.2 THE FUNGAL EVOLUTION OF OUR PLANET




## MAMMOTH MEGA-MUSHROOMS!

So, rich fertile soil is forming, plants are flourishing, and the planet is rapidly becoming lush and green.

Enter a time…when Fungi ruled the world!! Mwahahaha!

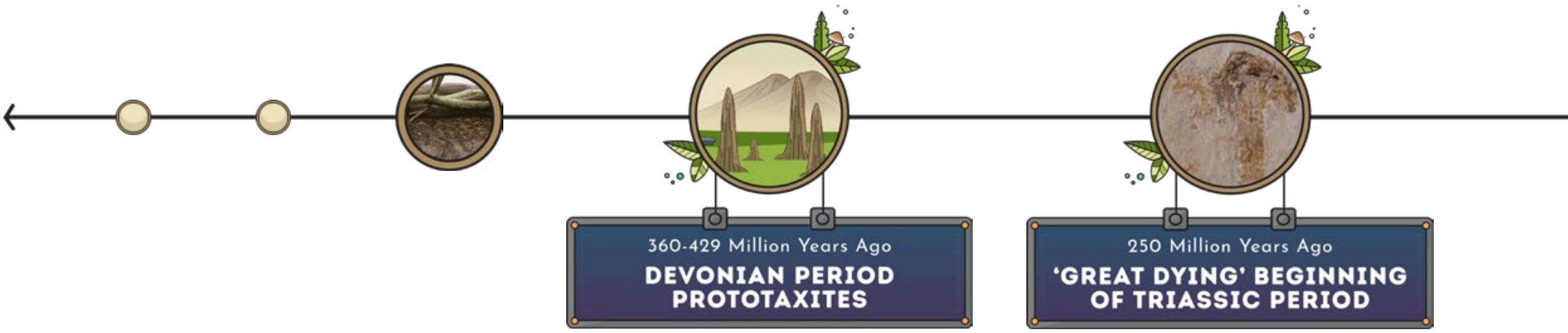
Before there was Megafauna or Megaflora, there was Megafunga!

Take, for example, the **Prototaxites.** When these organisms were first discovered, it was believed they were a yew tree or species of giant kelp. That is, until it was confirmed that they contained cells very similar to the fungi of today.

Common throughout the world during the Devonian period – 420 to 360 million years ago – **Prototaxites reached heights of 8.8 meters (28.9 feet), making them more than eight times the size of any plant alive at the time.** They dominated the early terrestrial landscape for 60 million years until they suddenly went extinct.

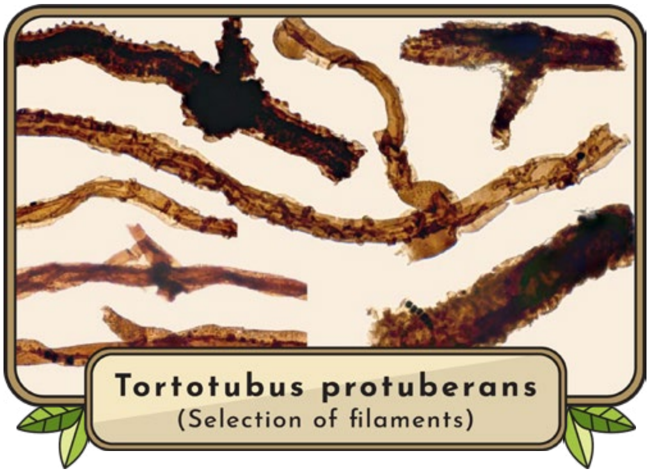
It's currently thought that Prototaxites may have been a giant lichen, and that it was so large it housed tons of organisms, like lichens, on its surface.

This is supported by fossil records of Protaxties showing tons of tiny holes, closely resembling insect burrows, along its body. Perhaps Prototaxites were an ancient insect skyscraper, an aerial operation center for, at the time, our flightless *entomologic friends.*



If you'd like to know more about these ancient Megafunga, we cannot recommend this EPIC video on Prototaxites by our friends over at PBS Eons enough.

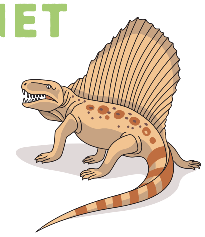
When Giant Fungi Ruled



Tortotubus protuberans
(Selection of filaments)

FUN(GI) FACT

During the Silurian period – about 440 million years ago – a filamentous fungus called *Tortotubus protuberans* appears in the fossil record. It's considered to be **the oldest known fossil of a terrestrial organism** and may have been the great **ancestor of all mushroom-forming Fungi.**



## THE GREAT DYING = THE GREAT FUNGAL FEAST

The Earth has experienced **five MAJOR extinction events** (six, if you count present day's).

The **Permian-Triassic extinction event**, around 251 million years ago, was a dooooozy.

Was it a meteor strike? A supervolcano eruption?

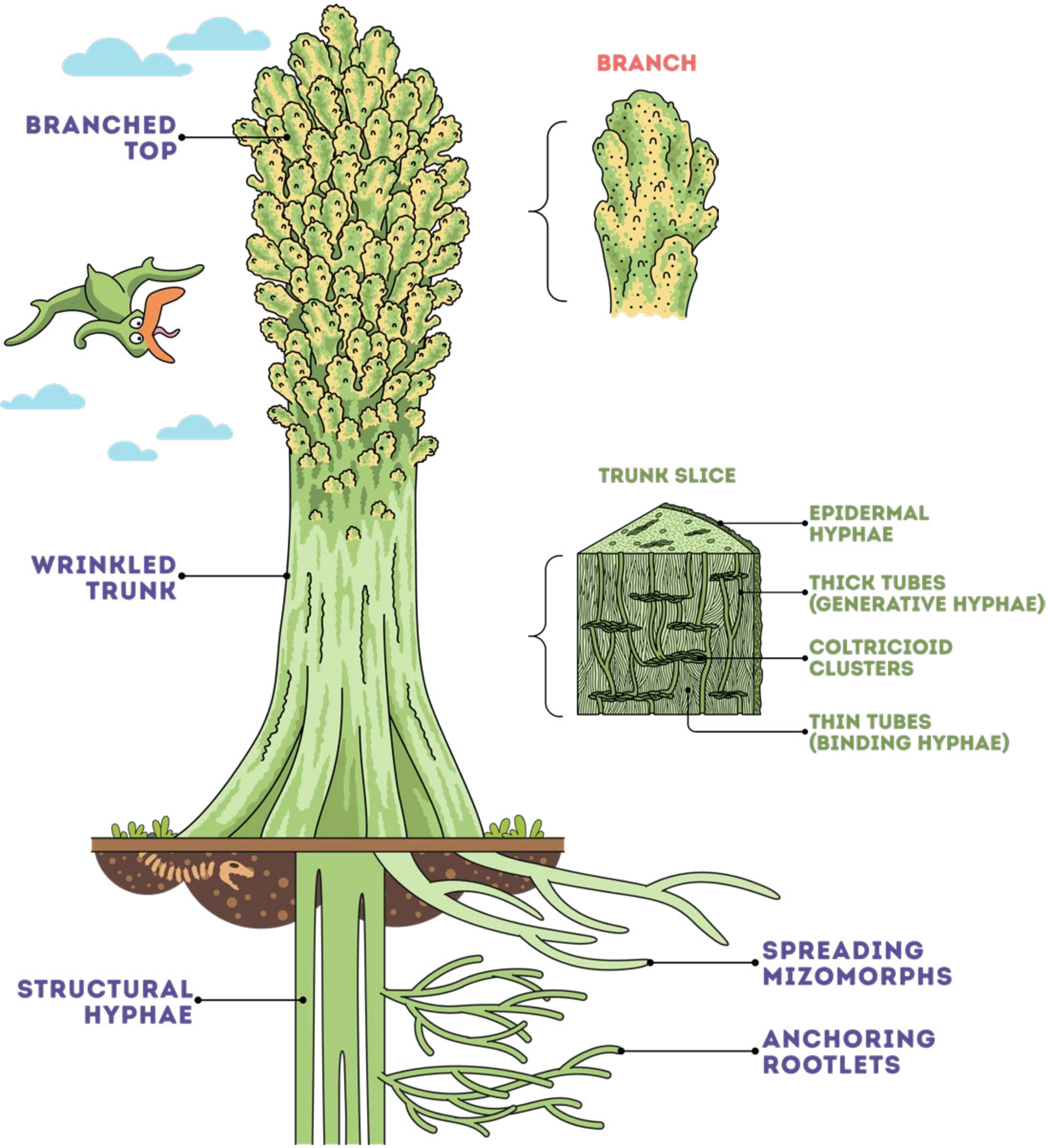
Whatever the cause, the Earth darkened under a cloud of dust and debris, blocking sunlight. Forests died. Soils eroded. The oceans and air were poisoned.

**57% of biological families, 83% of genera, 81% of marine species and 70% of terrestrial vertebrae were wiped out.**

Fungi, specifically a fungus known as Reduviasporonites, were there to clean and eat all the death and decay up. In fact, Reduviasporonites was so bountiful that in some layers of the crust just after the Permian-Triassic extinction event, we hardly find anything but Reduviasporonites fossils!

Shortly after this massive extinction, dinosaurs began their reign. Concurrently, **the first easily recognizable cap and stem mushroom, *Gondwanagaricites magnificus*, also appeared, about 130 to 115 million years ago.**

# PROTOTAXITES



Corie Bidgood @corie__bee

Around this time, **Dikarya**, a Subkingdom of Fungi that contains all our favorite fungal entities, began to rapidly take over the globe.

The Subkingdom **Dikarya is divided into two Phyla.** This split is due to the different methods the fungi use to distribute their spores.

There are **Ascomycota, which distribute spores via sac-like structures.**

And there are **Basidiomycota, which use pin-like structures.**

*Side note: now is a good time to check out the bonus lesson on the [Mushroom Life Cycle!](#)* The workbook write up for this lesson can be found in your Module 1 workbook chapter.

**Ascomycota** includes fungi like:

- Yeasts (Saccharomycetales)
- Ergot *(Claviceps spp.)*
- Morels *(Morchella spp.)*
- Cordyceps *(Cordyceps spp. & Ophiocordyceps spp.)*

The Fungisaur: Mycotheratops

**Basidiomycota** includes most of the mushrooms people think of when they hear the word "mushroom":

- *Psilocybe* e.g. *Psilocybe cubensis*
- *Amanita* e.g. *Amanita muscaria*
- *Agaricus* e.g. grocery-store favorite *Agaricus bisporus* (AKA button mushrooms)
- *Pleurotus* like *Pleurotus ostreatus*

So, now we've got mushrooms and dinosaurs… what a time to be alive!

But alas, all dreams must come to an end. We now know that **a meteorite the size of Mount Everest slammed into the Earth near the Yucatán peninsula in Mexico around 66 million years ago,** causing another mass extinction.

**Almost no four-limbed vertebrates weighing more than 25 kilograms (55 lbs) survived.** Fortunately, a small shrew-like mammal survived and thrived, becoming our ancestor. And, of course, Fungi also survived and thrived.

Massive catastrophes have occurred repeatedly, and fungi are the safety net, consuming the death and decay and creating space for the few surviving organisms to bounce back and flourish.

## OUR FUNGAL FOREFATHERS

Fungi are a cornerstone species. They have been around longer than anything else on this planet, have survived every mass extinction event, and afterwards, have paved the way for life to return again and again to this amazing planet.

**Without fungi, all ecosystems would collapse. They are the ultimate creators of abundance.**

Our survival as a species depends on allying with these elder organisms. They are here to help Earth's ecosystems as well as humanity's bodies and minds.

They are here to clean up the mess we make. **If we can be more like fungi, focused on ensuring the health and stability of our ecosystems, we, in turn, will thrive too.**

Speaking of thriving, you just made it through lesson two!
Next up, the Wood Wide Web of Mycorrhizal fungi! Say that ten times fast!
And don't forget to leave your comments and questions in the discussion box.
We'll see you next lesson!

*Corie Bidgood @corie__bee*

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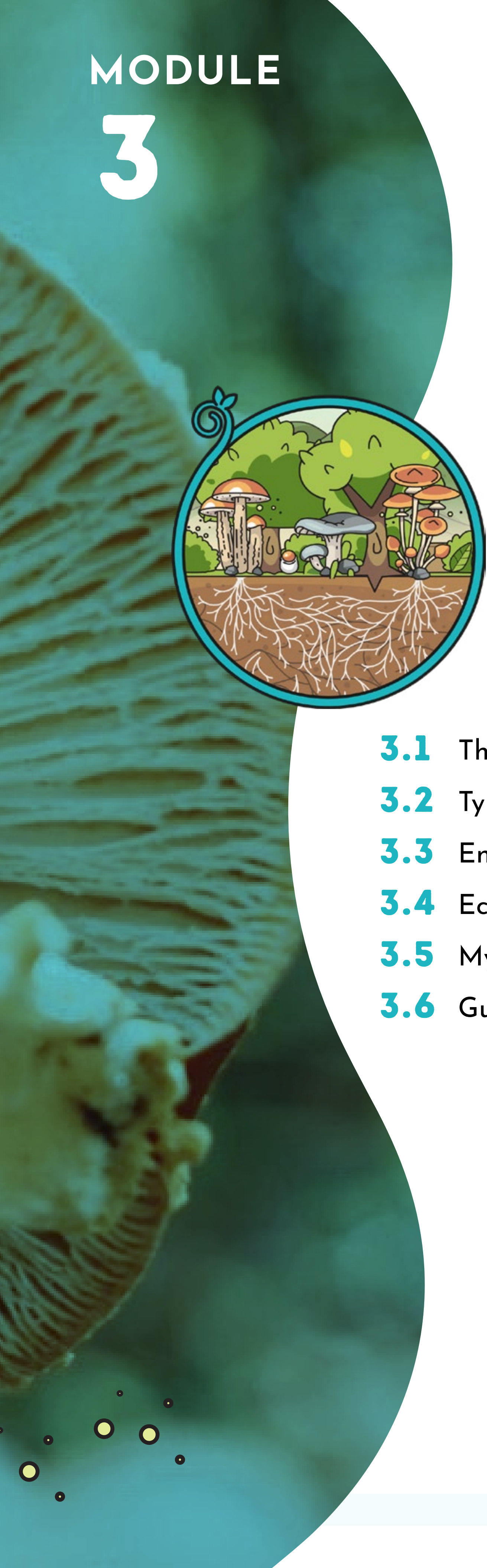
MODULE

3



# THE GLOBAL MYCORRHIZAL NETWORK

# 3.1 GLOBAL MYCORRHIZAL NETWORK

## THE WORLDWIDE MYCORRHIZAL NETWORK

Mycorrhiz... What? Huh?
Let's work like Fungi and break it down, baby.

**Myco means "related to fungi."**

**Rhizal means "related to roots."**


So, Mycorrhizal is an umbrella term that covers **all the Fungi that form mutualistic symbiotic relationships with the roots of plants.** These relationships are known as mycorrhizal connections.

Mycorrhizal networks serve as **an extended root system for plants**. This allows the plant to access **a larger area of the forest than it would be able to access with only its roots.. By reaching a larger area in the soil, the plant has more access to water and nutrients** and therefore is more resilient!


Connecting to a mycorrhizal network can **expand the reach of a plant's root system by up to 1000 times!** It also **allows trees to absorb nutrients in the soil it wouldn't otherwise be able to access thanks to fungi's ability, via its digestive enzymes, to break down complex molecular structures into more digestible forms.**

Mycorrhizal networks also connect different plant individuals and species together, enabling interplant-etary resource and information exchange.

That's right! **Mycorrhizal mycelial networks allow plants to talk and trade with each other,** hence its nickname the **Wood Wide Web!**

**Mycorrhizal fungi are:**

- Abundant (**they connect with the roots of over 90% known plants!**)
- Seemingly omnipresent
- Thrive around trees

(A single acre of old-growth Douglas fir forest can contain 1690 kilograms of mycelium by dry weight!)

Like the prehistoric power couple we call lichen, this Mycorrhizal collaboration is also ancient. **There's evidence of these mycorrhizal associations in the first fossils of terrestrial root systems.** Our world would not have evolved the same way without them, yet we know so little about them!

Get ready for some heady words coming atcha! We're about to dig into the soil to shine a light on this curious companionship.

## IN THIS MODULE, YOU'LL LEARN:

- The Types of Mycorrhizal Fungi
- How Mycorrhizal Networks Work
- The Importance of Mycorrhizal Networks

## TYPES OF MYCORRHIZAE

There are seven different types of mycorrhizal fungi, each with a unique, hard-to-remember name. That's science, baby!

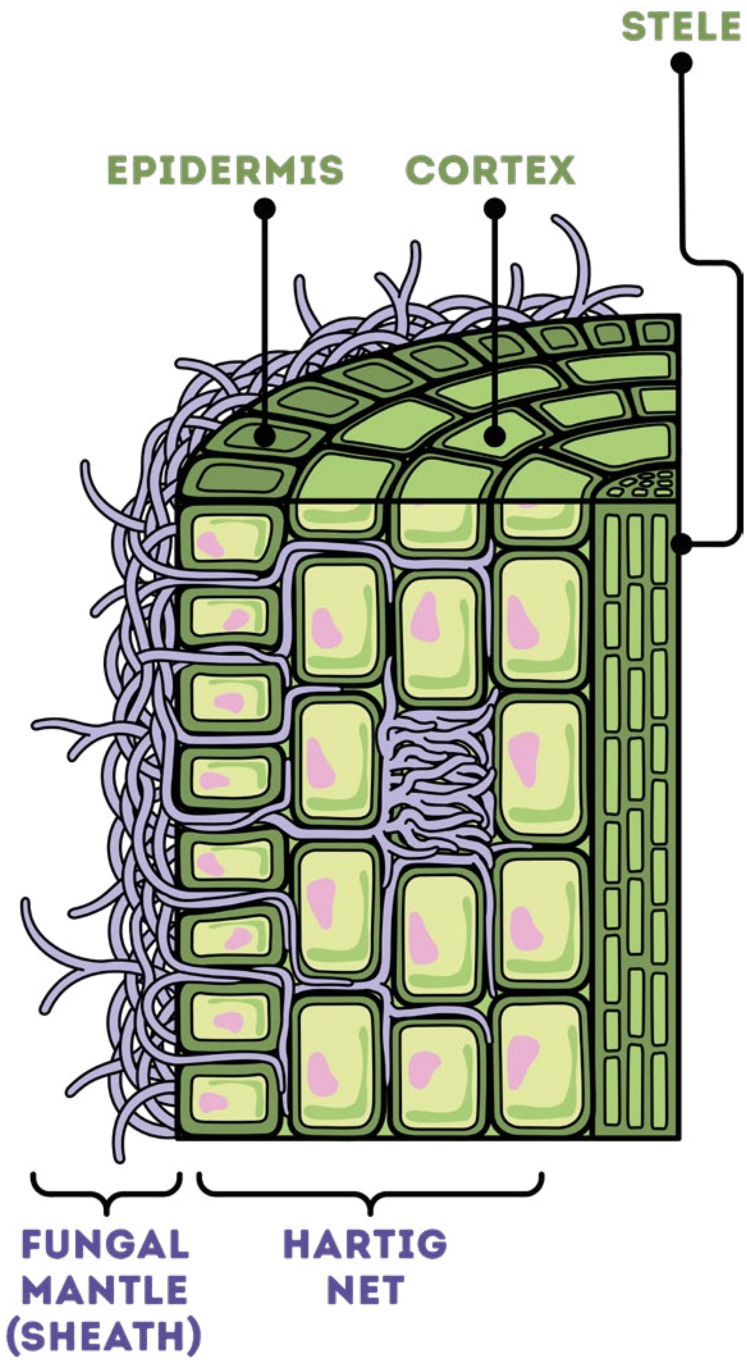
| Mycorrhizal Type | Fungal Taxa | Plant taxa | Intracellular Colonization |
|---|---|---|---|
| Arbuscular | Glomeromycota | Bryophyta<br>Pteridophyta<br>Gymnosperms<br>Angiosperms | Present |
| Ecto | Basidiomycota<br>Ascomycota<br>Zygomycota | Gymnosperms<br>Angiosperms | Absent |
| Ectendo | Basidiomycota<br>Ascomycota | Gymnosperms<br>Angiosperms | Present |
| Arbutoid | Basidiomycota | Ericales | Present |
| Monotropoid | Basidiomycota | Monotropoideae | Present |
| Ericoid | Ascomycota | Ericales<br>Gymnosperms | Present |
| Orchidaceous | Basidiomycota | Orchids | Present |

MAJOR CATEGORIES OF MYCORRHIZAL FUNGI AND THEIR ATTRIBUTES

Don't worry! That looks like a load of gibberish to us, too.

To make it much simpler, mycorrhizae are commonly divided into just two categories:

1. **Endomycorrhizae**
2. **Ectomycorrhizae**




## ENDOMYCORRHIZAE

As the great Snoop Dawg once said...

*"Rolling' down the street smokin' Endo, sippin' on Gin and Juice.*

*Laid back*

*With my mind on mycorrhizal and mycorrhizal on my mind."*

Ok, that's not a direct quote, but we bet Snoop has enjoyed some mushrooms now and again. Anyways...

"Endo" means within, inner or inside. This means the **mycelium of endomycorrhizae penetrates the cell wall of the roots.**

Of course, fungi are punks and eschew all classification. For example, arbutoid mycorrhizal fungi can be classified as **"ectendomycorrhiza"** because sometimes their mycelium penetrates root cells and sometimes it doesn't.

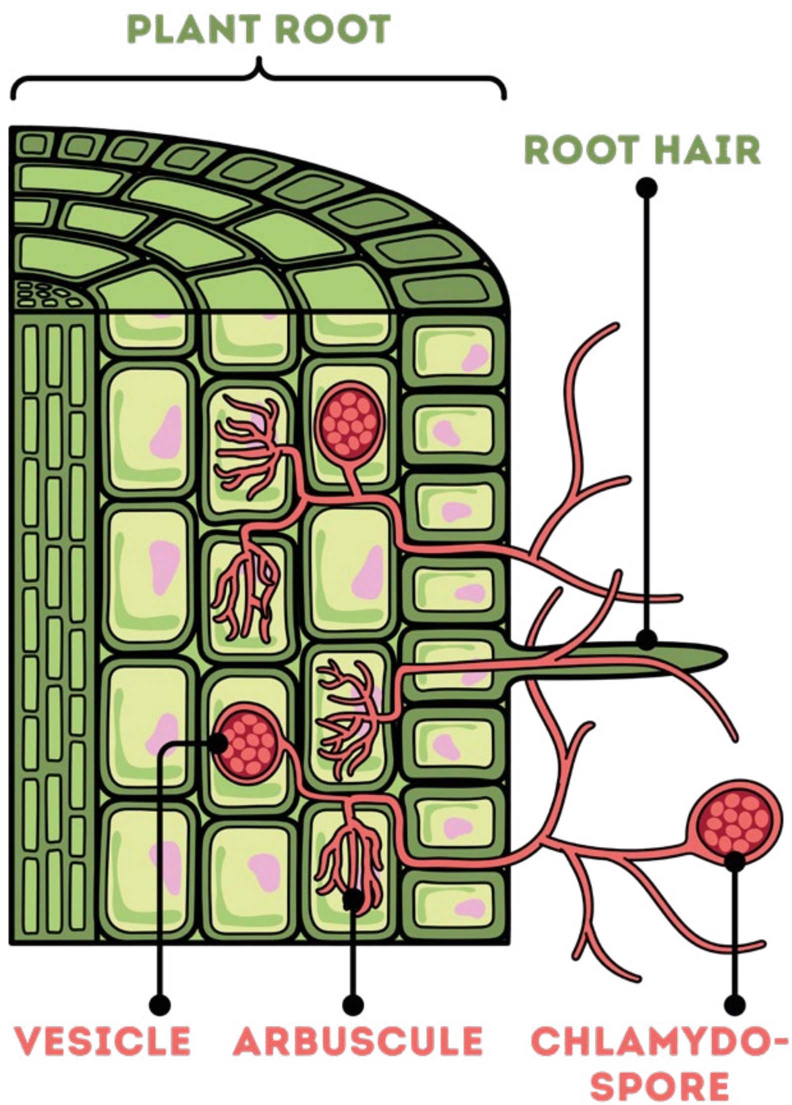
## ECTOMYCORRHIZAE

Not to be outdone, Eminem also once quipped...

*"Two mycorrhizal fungi
go round the outside,
round the outside,
round the outside."*

Okay, maybe that one was a stretch. But heck, we're trying to keep you entertained with all these weird words!

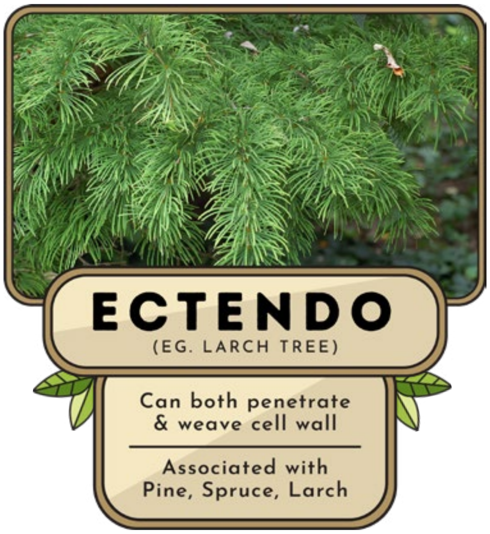
"Ecto" means external, outside or outer. This means **the mycelium of ectomycorrhizae fungi do not penetrate individual cells within plant roots. Instead, they weave around the cell walls.**




Now before we dig into our exploration of ectomycorrhizae and endomycorrhizae fungi, here's a brief little overview of the rest of those funky fungal words in the chart on page 38.

## OTHER MYRIAD MYCORRHIZAE MODELS

- **Ectendo Mycorrhiza:** We don't have much information on this group but we know **they can both penetrate and weave around cell walls.** These associations are mainly formed with the genera *Larix* (larch), *Pinus* (pine) and *Picea* (spruce).




- **Monotropoid Mycorrhiza:** This is one of the few examples of **plants parasitising fungi!** Plants belonging to the family *Montropaceae*, like the ghost pipe *(Monotropa uniflora)*, **do not photosynthesise and instead steal nutrients from the mycorrhizal network.**


- **Arbutoid Mycorrhiza:** These fungi create relationships with the plant family *Arbutoideae* (which includes the Manzanita species). Whilst very similar to Ectomyccrhizae, the main difference is that **Arbutoid hyphae penetrate the root's outer cortical cells.**


- **Ericoid Mycorrhiza:** These relationships are **formed with plants belonging to the *Ericaceae* family,** which includes the cranberry, blueberry, huckleberry, rhododendron and various common heaths and heathers. These plants are typically found in nutrient-poor, acidic soils like tundras and high-elevation grasslands worldwide (except Antarctica!)

# 3.5 GLOBAL MYCORRHIZAL NETWORK

- **Orchidaceous Mycorrhiza: All 22 to 25 THOUSAND species of Orchids form these connections.** Right after germination, an Orchid seedling will seek out a mycorrhizal partner. **The plant will only reach maturation,** thereby producing the stunning flowers we associate **with the *Orchidaceae*, with the help of their fungal friends.**


## GETTING INTO IT

**Endomycorrhizae** are a type of fungi that **penetrate and grow within the cell walls of plants.**

When we talk about endomycorrhizal fungi, it's safe to assume we're talking about Arbuscular mycorrhizae since they are, by far, the most abundant endomycorrhizal fungi.

Some think they are crucial to the life of ALL rooted plants!

FUN(GI) FACT

At least 85% of ALL plant species create relationships with Arbuscular mycorrhizae - and that's a conservative estimate!

This is an ancient relationship with **fossil evidence dating back to 450 million years ago**, by far the most ancient of all mycorrhizal relationships.

These fungi connect to many plant species simultaneously, forming a common mycelial network with **limitless potential for information and resource sharing** between plants in an ecosystem.

Peter McCoy sums it up:

> *"If any fungi are said to rule the world, it is the secret society of the arbuscular mycorrhizae."*

## 'ROUND THE OUTSIDE

Instead of penetrating plant cellular walls like endomycorrhizae, **Ectomycorrhizal Fungi weave around and connect between plant roots.**

They form these relationships with around 10% of plant families including birch (*Betulaceae*), eucalyptus (*Myrtaceae*), oak (*Fagaceae*) and pine (*Pinaceae*).

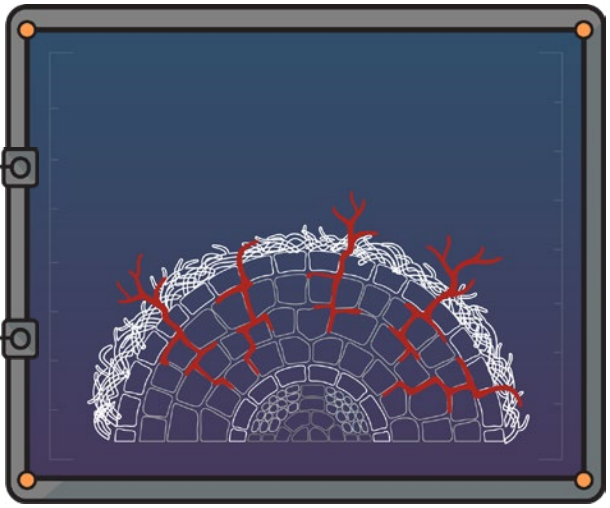
Black Truffles (*Tuber melanosporum*), Boletes, Chanterelles and *Amanita muscaria* are ectomycorrhizal fungi.

Since they only grow in relation to their plant partners, Ectomycorrhizal Fungi like Black Truffles are some of the most highly sought and expensive fungal bodies in the world, fetching up to $1,000 to $2,000 per pound!

Corie Bidgood @corie__bee

# 3.5 GLOBAL MYCORRHIZAL NETWORK

**The structure of ectomycorrhizal fungi** is composed primarily of three parts:

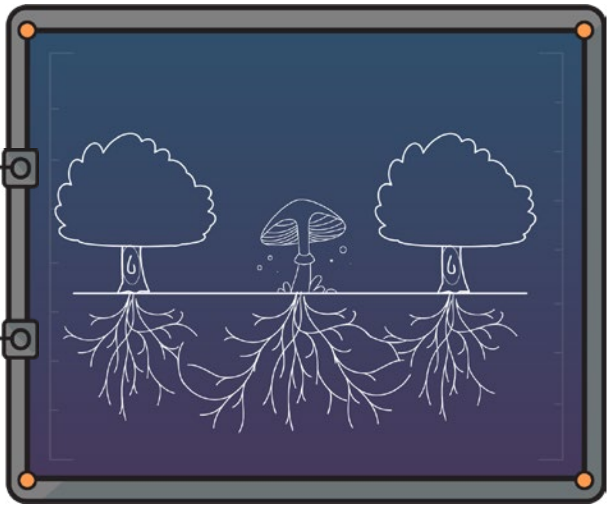


## 1 THE HARTIG NET:

This is the part of the fungus that grows into the roots of its plant ally without penetrating the cells of the root. This is where the exchange of nutrients happens between fungus and plant. The Hartig net is like the stockbroker of the forest, mediating deals between plants and fungi.

## 2 THE MANTLE:

This is the mycelium structure that grows around the plant root. A single mycelium structure can envelop multiple roots at the same time and can suppress the growth of root hairs, making the plant completely dependent on its fungal friend for water. It's like a smartphone; once you get used to having one, it's nearly impossible to live without it.



## 3 THE EXTRARADICAL HYPHAE:

These are the explorers and creators of the sub-forest highway, traveling immense distances in search of more plants to ally with. They're often credited as being the creators of the mycelial networks known as the Wood Wide Web. This is where nutrients and information are traded. Think of it as the Wall Street of the Woods.

## THE WOOD OF WALL STREET

As we've already learned in the last module, **mycelium served as the root system of plants before plants figured out how to make their own roots.**

**By the time the first plant roots evolved, the mycorrhizal association was already around 50 million years old.** For us, there is no doubt: mycorrhizae are the shepherds that led plants onto land.

It's estimated that **90% of terrestrial plant species partner with mycorrhizal fungi** and are dependent on these partnerships to obtain vital nutrients and water.

Mycorrhizal fungi can provide up to 80% of a plant's nitrogen and up to 100% of its phosphorus needs.

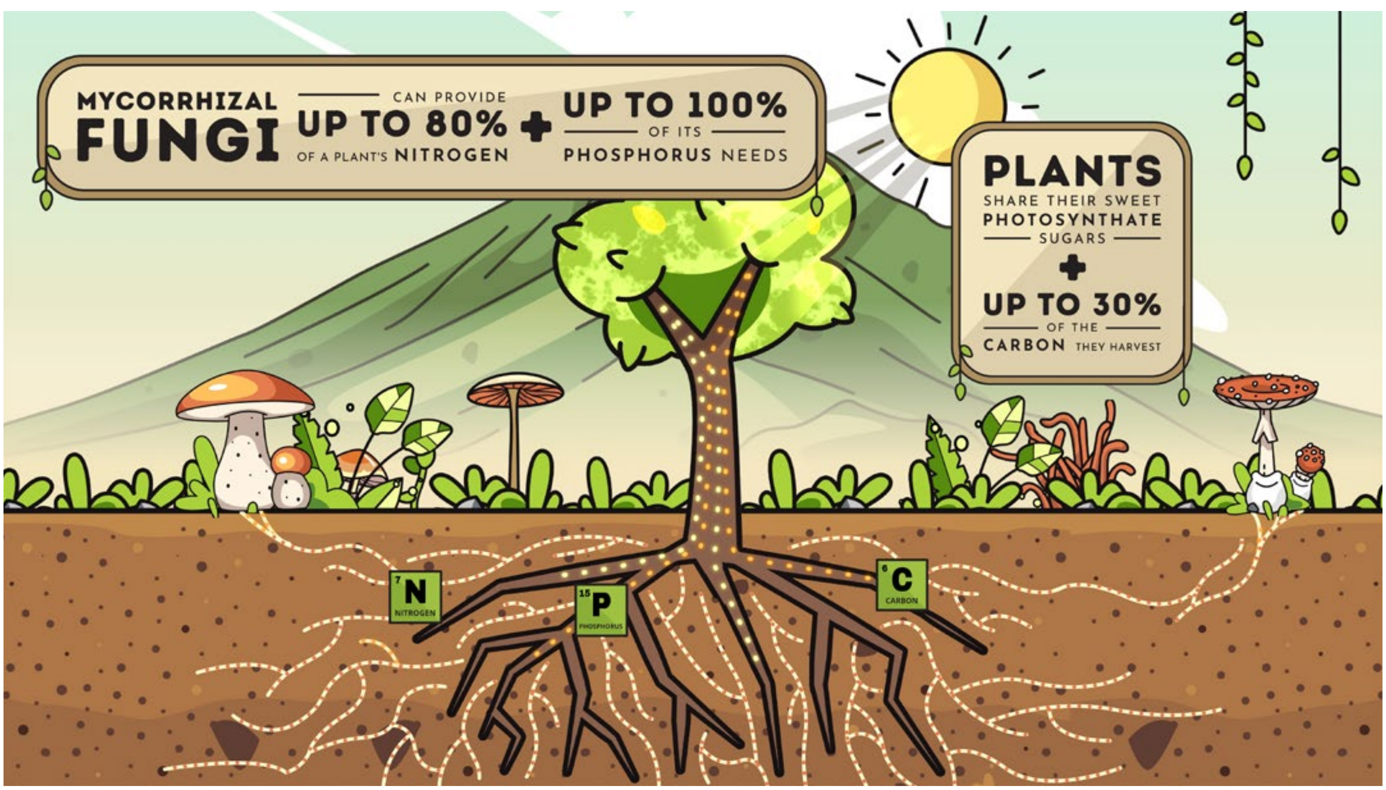
In return, **plants share their sweet photosynthate sugars** with the fungus.

They also **allocate up to 30% of the carbon** they harvest for trading with their fungal friends.

The capacity to form mycorrhizal networks is a significant evolutionary driver for both plants and fungi:

- Fungi in these networks benefit most by keeping its diverse portfolio of plant partners alive because the more plant partners it has, the more resilient its sugar/carbon source remains. We see it like this: if everyone around you is abundant, you in turn will also be abundant.
- **Plants in these networks grow more quickly** and have **better survival rates** than plants excluded from the network.

**These intricate, collaborative networks challenge the belief that all of life is in competition!** As we like to say, "If you want to go fast, go alone. If you want to go far, go together!"



## A FUNGI FIRST DATE

So, what exactly goes down when a plant and a fungus meet?

First, **they exchange chemical signals**, a quasi plant-fungi pheromone flirt.

The plant can refuse the fungi's first pass. In fact, the **fungi penetrates the plant's root system only *AFTER* receiving consent.**

And recently, I've started to see this exchange as something more than a flirtatious barter.

A question: What's your response to someone who wants to trade a precious resource?

First, you may have your doubts, thinking and rethinking the proposition.

Now, compare that with your response to someone who just gives you something without asking for anything in return. Maybe it's my Dutch nature to say YES to all the free things, but I love it.

Now imagine this special someone keeps giving you stuff for free.

What's your response? Do you always just accept, or eventually do you want to give something back in return?

Exactly! Reciprocity is a tool of survival and I don't think fungi are unaware of this principle.

In short, I think fungi give without asking anything in return and eventually the connected plant gives up its sweet sugar from the sun as a token of reciprocity.

Plants aren't monogamous, either. **Some Douglas fir trees make connections with over 200 different species of mycorrhizal fungi** during their lifetime.

Aside from the increase in surface area to mine nutrients that a plant gets from this association – from 10 to 100 times the area of the plant's leaves – **the fungal hyphae are also 50 times finer and have 60 times more absorption area than plant roots.**

And with fungi's unique ability to decompose large complex organic molecules, mycorrhizae are able to create nutrients from sources plants are unable to.

But water and nutrients aren't all that plants get from this relationship.

**Mycorrhizal networks also carry hormones, pheromones, DNA, viruses, bacteria & toxins.**

Studies have shown that **plants in mycorrhizal networks can resist disease far better than plants without these fungal friendships.**

Plants can also support each other via the networks.

**A plant being attacked by insects can send out distress signals through the network to warn other plants.** Those recipients can then start to produce defensive compounds to proactively prepare to fight off the parasite.

And Mama trees can communicate and support their own offspring with nutrients, using the network to support her baby until the sapling has the chance to grow big and strong itself.

Corie Bidgood @corie__bee

## A MYCO-MIRROR

Mycorrhizal networks are constantly changing. Their behavior is difficult to predict based on knowledge of the individual components. They can self-organize into new forms and behaviors depending on circumstances.

What else does this sound like? Humans!

In fact, humans and mycorrhizal networks are both classified as **"complex adaptive systems."** So are termite colonies, bees, cities, the internet and financial markets.

Another similarity between mycorrhizal networks and humans? We're both **heterotrophs**, meaning that we obtain nutrients from other organisms.

In the case of mycorrhizal networks, fungi obtain photosynthetic carbon compounds from plants.

However, we know that these fungi evolved from **Saprotrophic Fungi** (more on that in the next Module!), so many of them have the ability to decompose organic molecules like cellulose and lignin, too.

And like (most) humans, mycorrhizal fungi also like to be good guests and take care of their plant hosts. Some Orchidaceous mycorrhizae have been observed harvesting carbohydrates from decomposing organic matter and transferring it to support the young plants of their host species. Now that's a friend with benefits!

## GUARDIANS OF THE FOREST

We now know that a single mycorrhizal species can connect hectares of forest into a continuous network.

**We know that multiple plants of the same and different species can become physically linked and share water, nutrients, organic molecules and information.**

If that isn't already blowing your canopy, we honestly don't know what will.

But wait, the skeptic inside us is always wondering, how do we actually know this?

The truth is, it's extremely challenging to study these networks. Imagine trying to unearth ALL the connections in a forest ecosystem without damaging the roots or hyphae. Super impractical and problematic, to say the least.

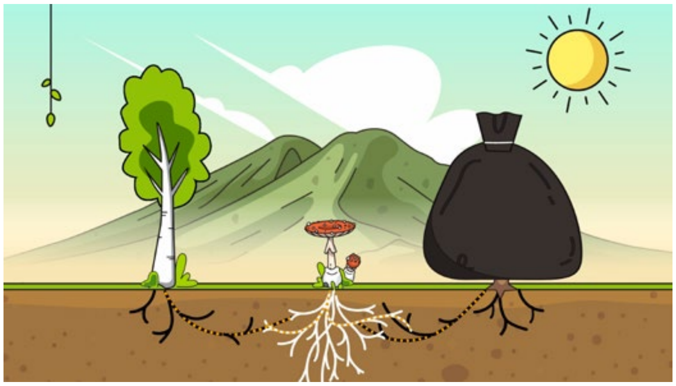
Fortunately, recent research developments means **we can use things like chemical tracers to track the transmission of compounds throughout a network,** allowing us to map the connections between plants and fungi.

Douglas Fir
(Pseudotsuga menziesii)

One great example is a forest in British Columbia, Canada. Researchers were able to approximate the architecture of a mycorrhizal network connecting 67 **Douglas Fir trees** *(Pseudotsuga menziesii)* via two different mycorrhizal fungi species using chemical tracers.

They found that the size of the trees was positively correlated with mycorrhizal connectivity. In other words, **the larger the tree, the more connected it was.** In another study, **researchers observed the flow of nutrients between a Douglas Fir and a paper birch tree** *(Betula papyrifera)* connected via the same mycorrhizal network.

In the experiment, researchers covered the Douglas Fir with plastic bags, inhibiting its ability to photosynthesize. In response to this fake shade, **the mycorrhizae reacted by transporting carbohydrates from the root zone of the unaffected paper birch to the roots of the Douglas fir.**



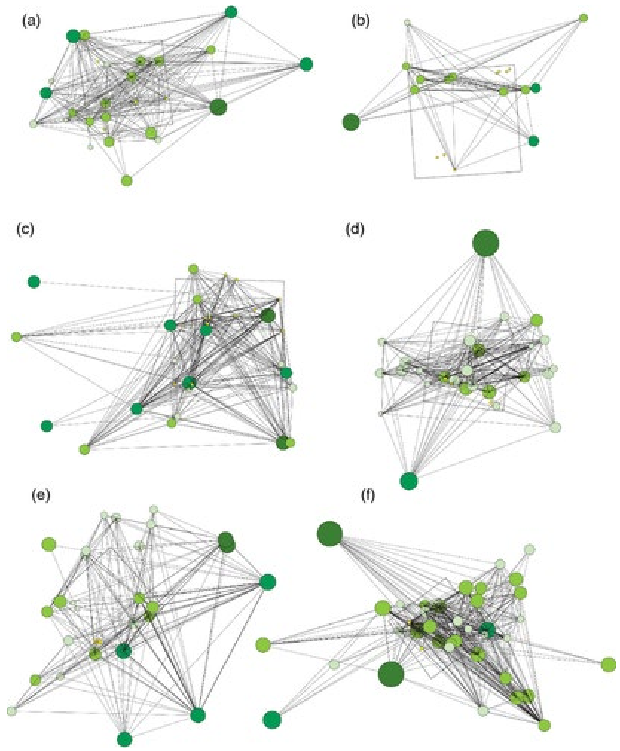
Researchers discovered around **9% of the carbon compounds transferred to the shaded Douglas fir originated from the paper birch.**

The most mind-blowing part? **This 9% was directly proportional to the amount of extra shade the Douglas Fir received!**

Other studies have demonstrated that **forest regeneration, establishment, growth and survival improve dramatically when young seedlings can successfully connect to an existing mycorrhizal network.**


For example, when Douglas Fir seedlings connect to networks containing the species *Rhizopogon vinicolor*, the seedlings were more drought tolerant than seedlings with no mycorrhizal connections. What's more, the seedlings fared better than other seedlings connected to different mycorrhizae species.

Two years after this study, a different experiment found that **the survival and growth rate of *Rhizopogon*-inoculated Douglas Fir seedlings were enhanced by as much as 50%!** Further studies on this particular relationship show that **the vitality of inoculated seedlings was most pronounced in areas of frequent drought or degradation.**




[Figure 1: Approximate architecture of a mycorrhizal network connecting a Douglas Fir forest in British Columbia, Canada. Circles represent trees, sized according to the tree´s diameter and coloured by age class. Lines represent the connections between trees. An arrow points to the most highly connected tree which was linked to 47 other trees through eight R. vesiculosus genets and three R. vinicolor genets inside the study area.]

# 3.6 GLOBAL MYCORRHIZAL NETWORK

That these complex, vital connections are quietly taking place beneath our feet and in the peacefulness of the forests is pretty surreal. And we're only just beginning to grasp how fungi and trees support and care for each other.

As we've learned about these networks, we've also learned how **many common forest management practices severely impact the presence and vitality of mycorrhizal networks.**

Practices like **slash and burn, clear-cutting, delayed seedling planting, and soil compaction** caused by heavy machinery use in our forests, as well as the **herbicides and pesticides** frequently used in forest and farm management, are **causing damage to these vital networks.**

We've already destroyed much of the world's old growth forests, and with them, their mycorrhizal networks.

But all is not lost. Thanks to the discovery of these networks and our improved information and technology, **we have the ability to help regenerate these vital ecosystems**.

So, next time you're walking through a forest, **take a moment to stop and think of the miles of common mycelial networks just beneath your feet.** They're busy communicating, trading, sharing and absorbing with each other, and ultimately, with you too.

Speaking of absorbing, did you absorb that jam-packed lesson alright? Don't forget to check out the recommended reading list below if you can't get enough about this topic.

And don't forget to leave your comments and questions in the discussion box.

We'll see you next lesson!

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MODULE

4

# SAPROPHYTES THE DECOMPOSERS

## SAPROPHYTIC FUNGI

Open wide! It's time for another mouthful of weird words. This time, your meal is a mouthful of organic matter!

Saprophytic refers to **organisms that get their nourishment from breaking down organic matter.**

In simpler terms, these are the fungi that make stuff decompose!

Saprophytic fungi feast on dead plant and animal matter, breaking down complex organic molecules and turning them into food for plants.

In no small way, **Saprophytic fungi are the beginning and the end of the food web, the great recyclers of our planet, the fungi that turn death and decay into food and life anew.**

Saprophytic fungi are everywhere! And it's a good thing, too. Without them, we'd be overrun with rotting, decaying dead matter.

Many of us have been shielded and have shied away from death and decay since birth.

*"Eww, the bread is moldy! Throw it out!"*

*"Grandma has gone to a better place."*

Does this sound familiar?

Well, we hope that by better understanding Saprophytic fungi, we can transform this fear and disgust into curiosity, wonder and gratitude. Because **without death, decomposition, and Saprophytic fungi, there would be no life.**

# SAPROPHYTES THE DECOMPOSERS

**IN THIS MODULE, YOU'LL LEARN:**

- Primary, Secondary and Tertiary Decomposers
- What They Are
- What They Do

## LET'S GET READY TO ROT!

Chances are, you already know plenty of saprophytic fungi.

That's because **most of the common gourmet and medicinal mushrooms people know** – from medicinal powerhouses Turkey Tail *(Trametes versicolor)* and Reishi *(Ganoderma lingzhi)* to culinary delicacies like Shiitake *(Lentinula edodes)* and Oyster mushrooms *(Pleurotus spp.)* to the mushroom of the moment, Lions Mane *(Hericium erinaceus)* – **are saprophytes**.

Saprophytic fungi work their magic by decomposing wood. Why do they do this? Not because they like cleaning up forest floors. No, it's because they're hungry!!

Remember, fungi are **heterotrophs**, meaning **they eat other organisms for energy and nutrients.**

So, how do they break down lignin, one of nature's most complex polymers?

It's all thanks to **their unique ability to navigate through and between cell walls via their fast growing, filamentous, mycelial networks and their ability to whip up chemical cocktails of external stomach acid on a whim**, that saprophytes are capable of cracking the codes of nearly all complex organic molecules.

In this way, **Saprophytic fungi are the planet's foremost experts & practitioners of recycling.** How eco-conscious of them!

**FUN(GI) FACT**

While many fungi are inedible & some can be toxic and potentially deadly, there is NO fungus that we know of that is dangerous to touch. So don't be afraid to get your hands dirty and get a feel for any fungus you come across on your forest walks! Just ask for myco-consent first, please.

There are only about **50 lethal mushrooms** in the world, compared with over **700 deadly plants** and **200 psychoactive mushrooms.**

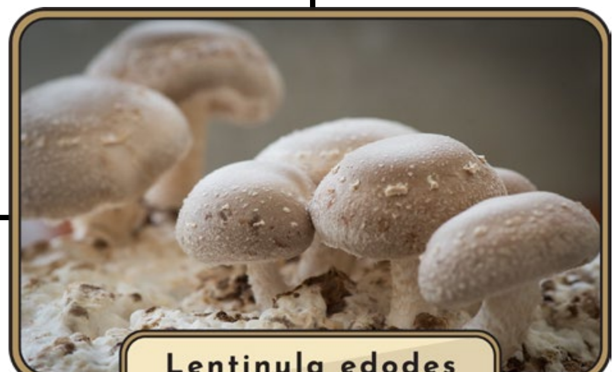
# SAPROPHYTES

MOST COMMON GOURMET + MEDICINAL MUSHROOMS

**Trametes versicolor**
(Turkey Tail)

**Ganoderma lucidum**
(Reishi)

**Pleurotus spp.**
(Oyster mushrooms)



**Lentinula edodes**
(Shiitake)

**Hericium erinaceus**
(Lions Mane)

## MUSHROOMS MUSINGS

"There are old mushroom hunters
and bold mushroom hunters,
but no old bold mushroom hunters."

"Every mushroom is edible
...for 30 minutes!"

## A ONE, A TWO, A ONE, TWO, THREE, FUNGI!

Saprophytes can be categorized into three main groups:

1. Primary decomposers
2. Secondary decomposers
3. Tertiary decomposers

## PRIMARY DECOMPOSERS: FIRST FUNGI TO THE FEAST

Primary decomposers, as their name suggests, arrive first to the dinner table.

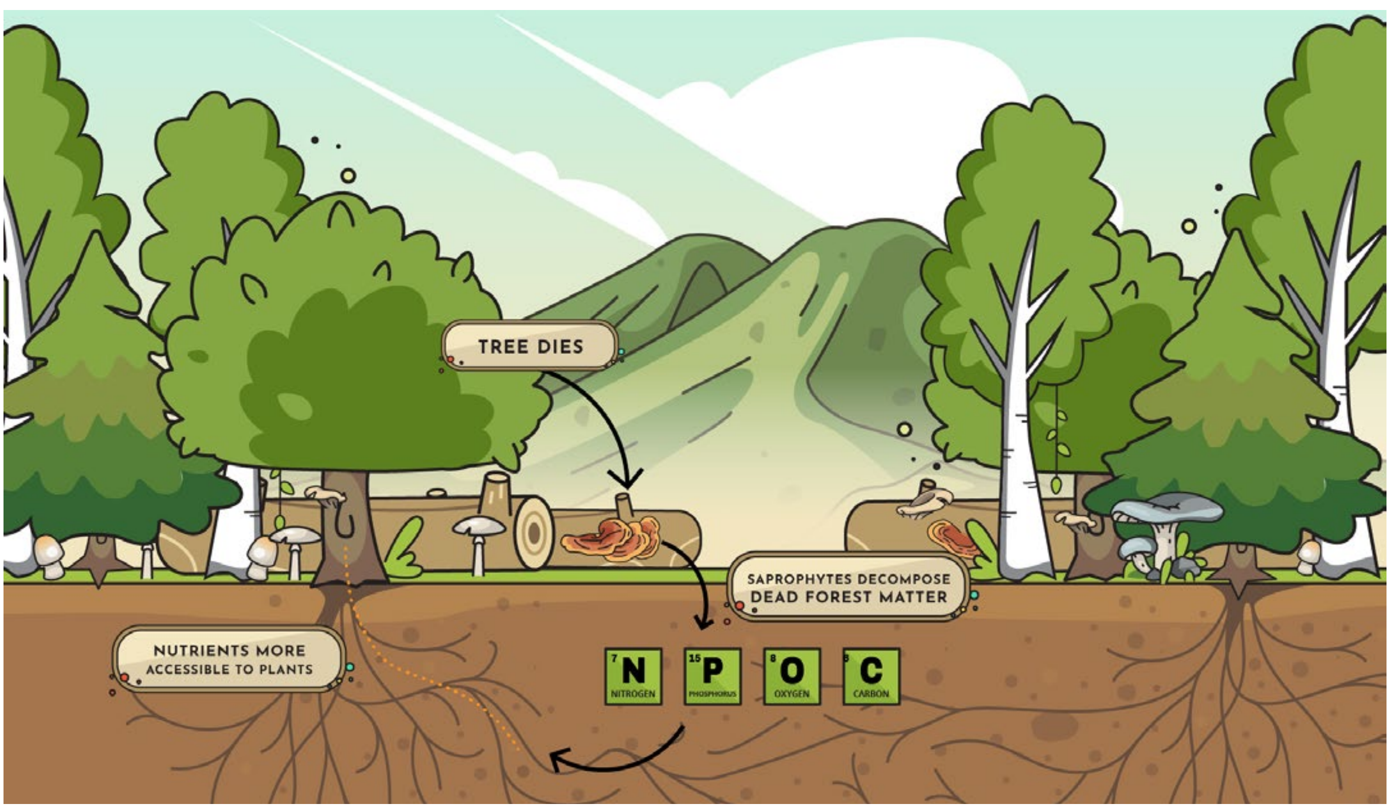
Typically fast-growing, they rapidly send out filaments of mycelium that find and attach to organic matter ready for decomposition.

Think of primary saprophytes as calling 'Shotgun!' on the dead organic matter atop the forest floor then racing to get there first.

It may come as a surprise to your refined palette but dead organic matter is considered a delicious delicacy to the saprophytes. They covet soft-tissue fruit, plants and animals so much so that they come in armed and ready to fend off competition.

**Saccharomyces cerivisiae**
(Brewer's yeast)

Lil' old Brewer's yeast *(Saccharomyces cerivisiae)*, the simple single celled fungus we know and love for its ability to produce alcohol, doesn't actually just provide sweet alcohol for us to booze upon! They use it to fight off saprophytic bacteria, who compete with the yeast for a sweet sugar supper.



# 4.2 SAPROPHYTES THE DECOMPOSERS

Have you ever lifted a fallen log and gazed at its rotting wood full of white strands? Ever grown your own Oyster *(Pleurotus spp.)* mushrooms and watched the substrate turn white with mycelium?

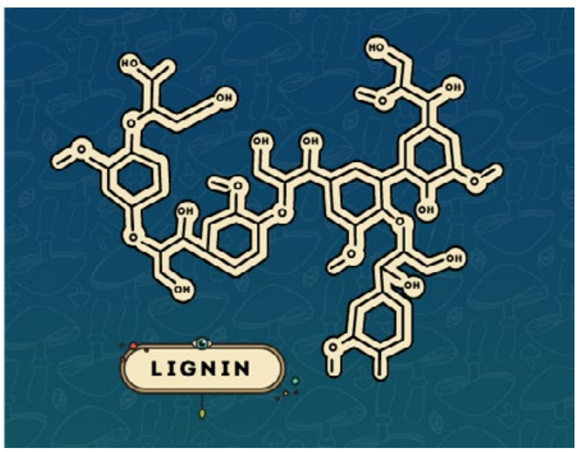
What you see is white rot fungi doing its thang!

Also known as wood rot fungi, these fungi, which belong to the phylum Basidiomycota, build healthy, carbon-rich soil because they're capable of degrading the dry matter of plants, like wood. But this wasn't always the case...

White rot fungi

Like most of us, trees prefer not to be eaten alive. So around 400 million years ago, trees developed extremely tough cell walls thanks to **a complex chemical polymer called lignin.**

Lignin is awesome. It's the reason the magnificent Californian redwoods *(Sequoia sempervirens)* & the Amazonian Kapoks *(Ceiba pentandra)* can grow into the gorgeous giants they are today.




Creating lignin was a great protectionary tactic, so much so, that **for millions of years, nothing could break down lignin.** But over millions of years, all these dead trees laying on the ground began to pile up. In fact, they piled up so much that they created a whole new substance in the earth's crust: Coal!

But then, around 300 million years ago, the formation of coal began to decrease drastically.

Why?

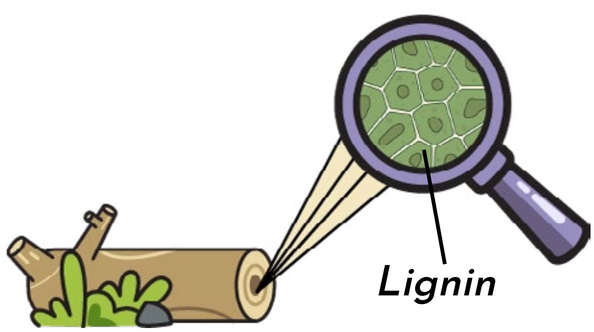
**White-rot fungi figured out how to crack the lignin code!** White-rot fungi produce enzymes (like manganese peroxidase, lignin peroxidase and laccase) to split the lignin's chemical bonds, releasing carbon dioxide into the air.

Amazingly, these enzymatic compounds have been studied extensively for some time now yet scientists still don't have a firm grasp of how this chemical mechanism works.

But in layman's terms, we know that to break down lignin, white rot fungi use strong enzymes and proteins to split the lignin's chemical bonds, thereby releasing carbon dioxide into the air.

Oh no, carbon dioxide!! They don't release that much though, right? Right?

**Actually, fungal decomposition is one of the largest sources of carbon emissions, emitting about 85 gigatons of carbon into the atmosphere every year. For comparison, in 2018, the combustion of fossil fuels by humans emitted around 10 gigatons.**




PLEUROTUS DJAMOR
(Pink oyster mushroom)
PRIMARY & SECONDARY DECOMPOSER
Corie Bidgood @corie__bee

# 4.2 SAPROPHYTES THE DECOMPOSERS

**In short, Fungi release 8.5X more $CO_2$ into the atmosphere annually than us puny humans!** But, don't start thinking we should eradicate all the fungi to deal with our excessive consumption problem.

**FUNGI RELEASE 8.5X MORE CO2 INTO THE ATMOSPHERE THAN HUMANS**

**That's because the ecological role of wood-rot fungi is hard to overstate.** Can you imagine if trees never decomposed? We'd be neck deep in dead wood at all times! In a natural forest, decaying logs and fallen branches are a crucial part of the natural environment. They provide habitat for animals and are a stable nutrient resource for fungi and plants.

They can also become what's known as a **'nurse log'** for the next generation of trees. Not only does a downed tree leave a new patch of light where the old tree once stood, allowing sun to reach the new seedlings, but **the seedlings themselves can grow directly from the fallen tree, having their water and nutrient needs met from the dying log.**

# 4.2 SAPROPHYTES THE DECOMPOSERS

In no small way, the world as we know it wouldn't exist without white-rot fungi. Nothing else can break down lignin like it...not even termites!

Besides white-rot fungi, **we also have brown-rot fungi.** If you've ever stumbled across a fallen tree and run your fingers through **crumbly, block-shaped decomposing wood,** you've probably had an encounter with brown rot fungi.

Brown rot fungi

The gourmet mushroom Chicken of the Woods *(Laetiporus sulphureus)* and the species of the genus *Fomitopsis* (e.g *Fomitopsis pinicola*, the red-belted bracket fungus) are examples of brown-rot fungi.

Though brown-rot fungi can't completely break down lignin like their white-rot sisters, they still fill an extremely important ecological niche!

Laetiporus sulphereus
(Chicken of the Woods)

**Brown-rot species make up just 6% of all the wood decomposing fungi yet they decompose 80% of the world's conifer trees.**

Conifers saw what was going down with white rot fungi and figured out how to create anti-white-rot fungal compounds inside their lignin. In fact, this compound even stays active after the tree has died!

But the brown-rot gals weren't so easy to sidestep. By producing an intense chemical reaction known as the **Chelator-Mediated Fenton reaction, brown rot fungi can break down cellulose but avoid the lignin and the antifungal compounds within it.**

This chemical reaction is nothing short of INTENSE!. It basically produces hydrogen peroxide and a host of other chemicals that react to break down the cell walls, allowing the brown-rot fungi to reach the other chemicals inside.

Such a strong reaction should in theory break down the fungus itself, too. But these fungi are clever! **By timing the release of the reaction through a two step process, the fungus is able to safely harvest the sugars from the cellulose without endangering itself.**

**CHELATOR-MEDIATED FENTON REACTION**

CREATES AN **INTENSE CHEMICAL REACTION** THAT **BREAKS DOWN CELLULOSE** BUT **AVOIDS THE LIGNIN** AND **ANTIFUNGAL COMPOUNDS** WITHIN

**Here's how I like to think about it:** white-rot fungi are like surgeons, breaking down lignin with immense precision, while brown-rot fungi are the demolition crew, blowing up everything and getting the goodies when the coast is clear.

Like the natural alchemists they are, both use chemicals in their own unique, advantageous ways!

## SOME BRIEF PROSE ON PENICILLIN

Okay, it's a bit of a tangent here, but while we're on the topic of Fungi's alchemystical powers, we'd be remiss if we didn't mention **one of the most world changing discoveries of the 20th century.**

**When Alexander Fleming discovered a mold called *Penicillium notatum*,** which killed all of his samples of the pathogenic bacteria Staphylococcus aureus that he was studying, **he officially found the world's first antibiotic.**

But that's where the story starts, not ends. *Penicillium notatum*, although effective in a petri dish, wasn't strong enough to be effective on humans consistently.

For years, scientists searched for a more potent species of *Penicillium*. Then one hot summer day in 1941, Mary Hunt, a laboratory assistant, returned to the laboratory with a cantaloupe she'd bought at a local market which was covered in a "pretty, golden mold."

This mold was about to change the fate of human history.

That "pretty golden mold" was *Penicillium chrysogeum* and it contained over **200x** the amount of penicillin found in *Penicillium notatum.*

This is the moment when the microscopic fungal warfare we talked about earlier in this lesson began to have a major influence on our own MACROSCOPIC war.

Since the beginning of human warfare, bacterial infections were the most deadly killer during armed conflict, with almost 20% of people who contracted a bacterial infection eventually succumbing to the pathogen.

That all changed with Hunt's discovery.

By the end of the WWII, the United States was producing **650 billion doses of pure** Colombian cocai...errr... we mean penicillin, per month. Death rates of bacterial infections dropped to under 1% almost overnight.

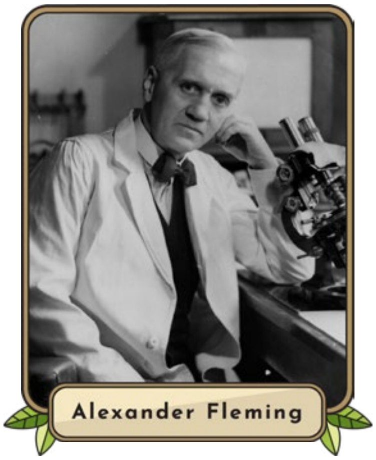


The allies had their hands on this fungal alchemical concoction while their enemies, the Japanese and German 3rd Reich, did not.

It 's no far stretch to say that this accidental discovery tilted the tides of war and shaped all of human history to follow.

*"When I woke up just after dawn on September 28, 1928, I certainly didn't plan to revolutionize all medicine by discovering the world's first antibiotic, or bacteria killer. But I guess that was exactly what I did."*

- Alexander Fleming




Always humble, that good old Mr Fleming


## LEFTOVERS: IT'S WHAT'S FOR DINNER

Okay, back to the main story, and our second character in this tale of decomposition.

Are you a fan of leftovers? Then you and the saprophytic fungi known as secondary decomposers have something in common.

Typically, secondary decomposers rely on primary decomposers to pre-digest their food for them, kind of like baby birds. Then, **working alongside other saprophytic bacteria, fungi and animals, this secondary decomposer armada (new band name?!) runs amok in the muck of animal dung, compost piles, soil, rotting wood and other organic matter,** breaking down the organic compounds and **emitting heat, water, carbon dioxide, ammonia and other gasses** along the way.

It's simple mathematics: **the more primary and secondary saprophytic organisms there are in an ecosystem, the quicker the complex organic molecules will be decomposed into simpler molecules, i.e. plant food.**

**More food leads to more plants** (which means more biodiversity and ecosystem resilience) **which then, when they die, become more food for the saprophytes to eat!**

Ahhh, the beautiful circle of life!

# 4.3 SAPROPHYTES THE DECOMPOSERS

Perhaps this is the first time you're hearing about secondary decomposers. Chances are you've seen them before, though.

Ever come across the common **"button mushroom"** *(Agaricus bisporus)* at the grocery store? This **compost loving mushroom, the most widely cultivated mushroom in the world, is a secondary decomposer.**

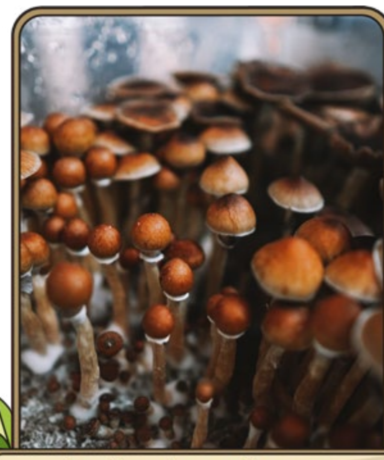
So too are the "inky caps" of the family *Coprinaceae, Stropharia ambigua*, and our favorite, *Psilocybe cubensis!* Not that you've ever seen that last one other than on Google though, right? ;)

Compared to primary decomposers, **secondary decomposers are more adept at dealing with complex assortments of microorganisms.** That's because they evolved in direct contact with microbially rich soils, forcing them to adapt and learn to develop an arsenal capable of fighting off competing bacteria and fungicidal fungi like the tricky Trichoderma.

This adaptability also means **it's much easier to cultivate secondary decomposers than primary decomposers.** Think of Button mushrooms, Oyster mushrooms *(Pleurotus spp.)*, Garden Giants *(Stropharia rugosoannulata)* and *Psilocybe cubensis.*

**Coprinopsis atramentaria**
(Inky Caps)

**Stropharia ambigua**
(The Questionable Stropharia)



**Psilocybe cubensis**
(Gold Caps, Sacred Mushroom)

**Trichoderma**

Any experienced cultivator knows the ease with which they fight off competition and the rate at which they grow. By evolving in competitive environments, they got to where they are today.

To be clear, the distinctions of primary and secondary are far from absolute. **There are some fungi that can be considered both primary AND secondary decomposers.**

One great example are Oyster mushrooms of the genus *Pleurotus*, which basically eat everything they can get their hyphae on. They could even eat this book! Or if you're reading the digital copy, the PDF! Actually, we aren't certain about the last one. We'll get back to you in a couple months.

Merlin Sheldrake

## LAST BUT NOT YEAST

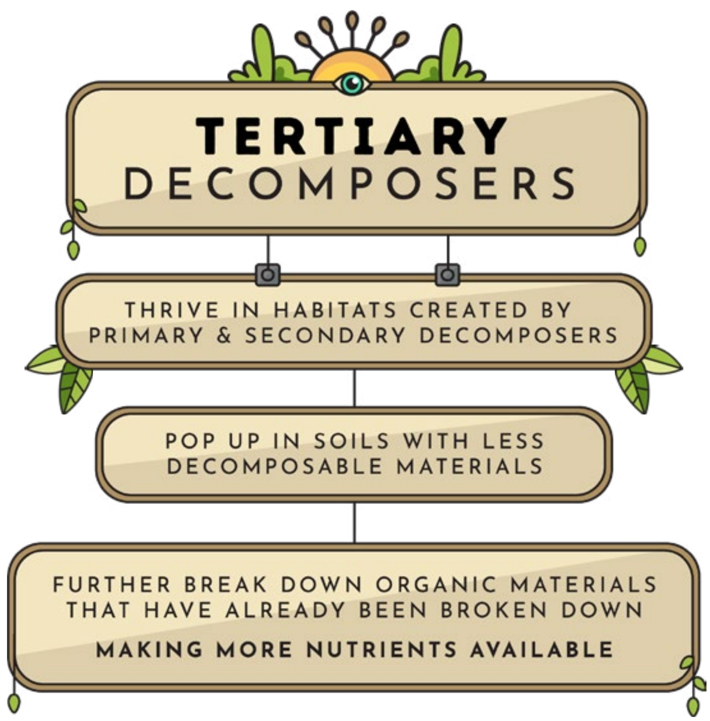
Finally, we've come to tertiary decomposers, a group of fungi that are difficult to categorize.

Arriving at the end of the meal, **these fungi thrive in habitats where primary and secondary decomposers have been feasting for years.**

**Tertiary decomposers rely on highly complex microbial environments** and are often called **"soil dwellers"** because they reside in soils with little in the way of decomposable material.

Though they're at the end of the food chain, **tertiary decomposers dig deep to break down organic matter that has already been broken down several times before.** As a result, they make even more nutrients available to even more organisms.

Tertiary decomposers include certain species of *Cenocybe, Agrocybe, Mycena, Pluteus* and *Agaricus.*




Corie Bidgood @corie__bee

## ONE ORGANISM'S DEATH IS ANOTHER ORGANISM'S DINNER

Whether first to the food line or last to lick the plate, saprophytic fungi are more than happy and hungry to slowly churn the great circle of life around for another rotation.

They're the grand recyclers and archetypal alchemists of our planet, secreting enzymes and acids to degrade and disassemble large inaccessible organic molecules into simpler forms that nourish an ecosystem's other inhabitants.

From dead plant matter, fungi recycle the carbon, hydrogen, nitrogen, phosphorus and minerals so living plants, insects, animals and other organisms can continue making a life and home for themselves and us.

An interface organism between life and death, saprophytes are a reminder that nothing is lost, only transformed.

Are you feeling transformed after this lesson?

Well don't go just yet! Leave any comments and questions you have in the discussion box.

We'll see you next time for our largest lesson to date, all about Parasitic fungi!

Mwahahaha!

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*Ophiocordyceps humbertii on wasp - Dr. João Araújo, PHD*

MODULE

5

# FUNGAL INVADERS

## PARASITIC FUNGI

Welcome to this lesson about the creepers, the crawlers, the killers, the unwanted dinner guests and stowaways...

**The Parasites!!!**

When I say the word 'parasite', what comes to mind?

A leech? A tick? Or the most hated creature in our planet's history? The mosquito!

The parasites we humans encounter are the stuff of nightmares, but parasites are about so much more than these simple macroscopic blood suckers.

And for anyone who has spent considerable time in Mesoamerica knows this...intestinal parasites, not mosquitos, seem to rule this part of the world.

The word parasite has its roots, like everything it seems, in ancient Greece. For the Greek, ***Parasitos*** **meant "one who eats at the table of another."**

Kind of like your brother-in-law that always shows up uninvited around dinner time promptly to leave when the meal is done... is by all definitions, a parasite.

A more modern definition explains parasitism as **"a close relationship between species where one organism (the parasite) lives on or inside another organism (the host), causing the host some harm while the parasite adapts structurally to this way of life."**

I can recall a few intestinal parasites that caused me some harm!

When it comes to parasitic fungi, there are countless species parasitizing plants, animals, humans and other fungi all over the world!

And even though plants and fungi have a long heritage of collaboration, coexistence and coevolution, **plants are, by far, the largest group of victims for the sinister plans of parasitic fungi.**

But as you're about to discover in this module, there is so much more to this story than first meets the eye.

# 5.2 FUNGAL INVADERS

## IN THIS MODULE, YOU'LL LEARN:

- Fungal Parasites of Plants
- Fungal Parasites of Fungi
- Fungal Parasites of Insects
- The Importance of Parasitic Fungi

## AN INSIDE JOB

Most fungal parasites attack plants and **85% of all plant diseases are caused by fungal parasites.** Poor plants!

But these parasites don't just cause mayhem for plants. The organisms that eat plants (including us humans!) are also deeply affected.

**Generally speaking, the FIVE most common kinds of fungal parasites that attack plants are:**

1. **Powdery Mildew**
2. **Blight**
3. **Rust**
4. **Heart Rot**
5. **Armillaria Root Rot**

These diseases have many different attack strategies.

**Some fungal parasites are born within the cell walls of the plant,** already at home inside their host. These fungi are the few lucky ones.

Most other fungal parasites must invade their host using **specialized adhesive spores that stick to a host's leaves or bark.** Once there, the spore then germinates and waits/searches for its point of entry.

**The entry point is usually a natural opening like, say, an air pore on a leaf/bark.** But whatever the landscape and situation, if a plant is damaged with a broken branch, a chip in the bark, or a slice in a leaf, parasitic fungi will usually find their way into the host.

Once inside, **the fungal invader begins rapidly spreading its hyphae around and throughout the victim.**

Remember the Myco-consent concept from the module on Mycorrhizal fungi? Well that's *not* happening here!

**The fungus begins to penetrate the plant's cell wall with a special microscopic battering ram known as the appressoria.** This appressoria punctures the epidermis, fancy botanical speak for the skin of the plant.

After this most definitely nonconsensual fungal penetration, the fungus weaves its hyphae into a stranglehold around the plant's cells, slowly feasting on its living host.

Of course, not all fungal parasites have this microscopic battering ram. **Obligate parasites like rusts, mildews and powdery mildews only survive on living plant tissue and need to find natural air pores on the surface of the plant** (making the cultivation of obligate fungal parasites really difficult in controlled environments).

5 MOST COMMON KINDS OF

# FUNGAL PARASITES OF PLANTS

Powdery Mildew

Blight

Rust

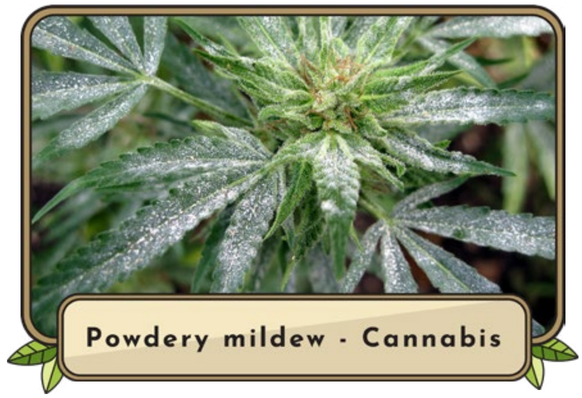
Heart Rot

Armillaria Root Rot

## CANNABIS DREAMS, POWDERY MILDEW NIGHTMARES

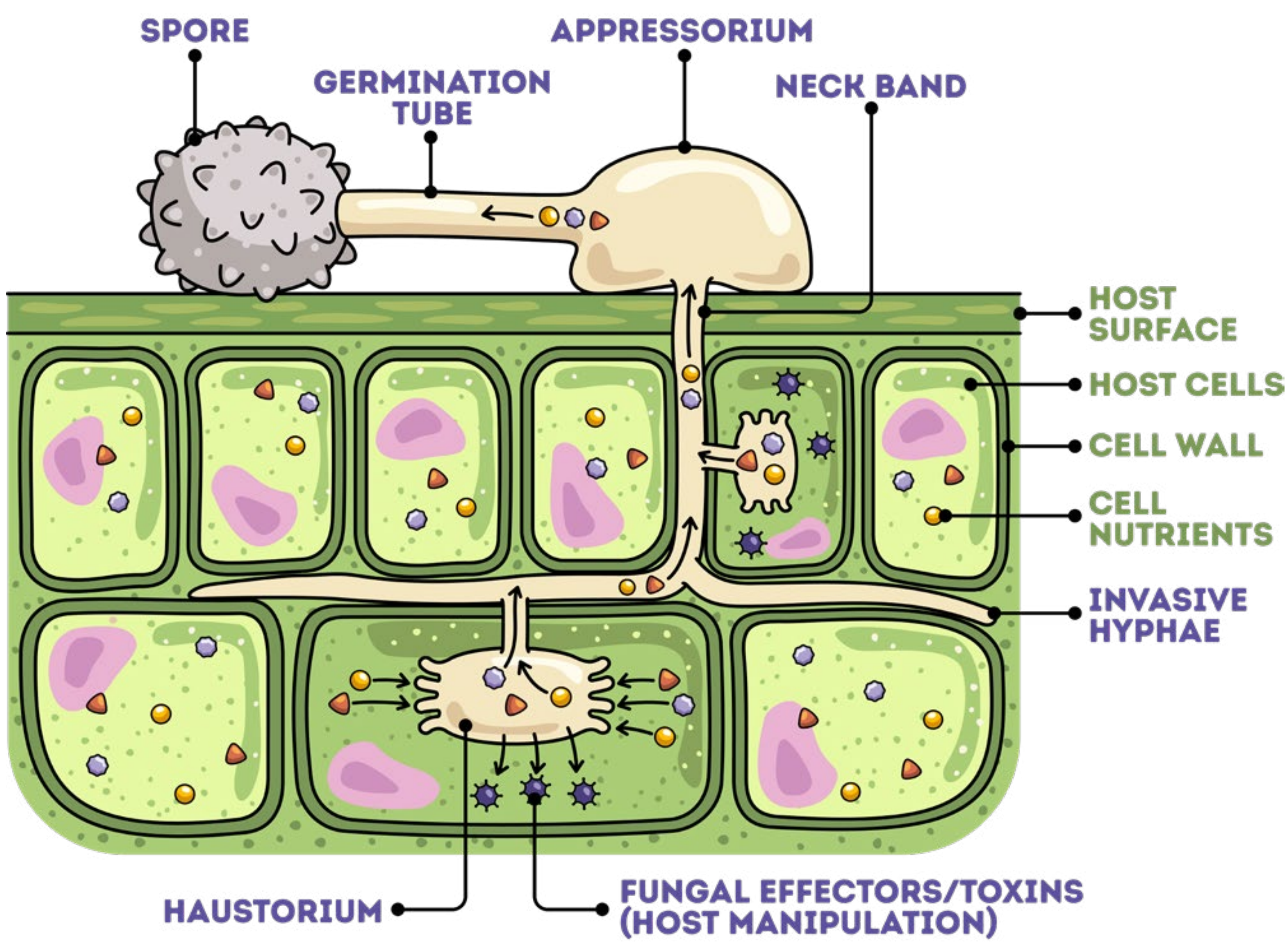
If you've ever grown cannabis, tomatoes or roses, you've probably had a nightmare or two about Powdery Mildew. For the uninitiated, **Powdery Mildew is a fungus that grows on a leaf's surface, surrounding the leaf's epidermis.** Once the epidermis is surrounded, the fungal invader then builds a death star... errrr, we mean a *haustorium*, to complete its evil plan. What the hell is a haustorium?

> **"A haustorium is a rootlike structure that grows into or around another structure to absorb water or nutrients."**




So basically, Powdery Mildew uses this haustorium death star thingy to shoot laser beams into the cells that then beam up nutrients to the main fungal organism. That's a much more fun definition, no?

The plant, with its water and nutrients zapped, then proceeds to grow slower, mutate, or finds itself unable to flower properly.



FUN(GI) FACT

**The powder that defines Powdery Mildew isn't actually the fungus.** Rather, it's **a huge collection of the fungus's spores** that spread to other plants with any slight tussle from the air.

And unlike most other fungi, **these spores don't need moisture for germination, meaning they're also highly effective in dry areas.**

That said, if there is moisture present, like the condensation that happens with the warm days and cool nights that characterize Humboldt County and other parts of California, – America's Cannabis Capital – Powdery Mildew thrives it carries out its sinister plan.

An important note: **Powdery Mildew is an umbrella term for several different species,** each of them highly specialized. In other words, **the Powdery Mildew preying on your cannabis isn't able to attack your roses,** or vice versa.

But, when the Powdery Mildew has found its favorite prey, they are a botanist's & gardener's worst nightmare, good for two things: Devouring your plants and making more Powdery Mildew.

## YOU GOTTA FIGHT THE BLIGHT!

Blight is another umbrella term for **a host of diseases that cause a plant to rapidly and completely lose its ability to photosynthesize.** Obviously, this is devastating for plant communities. Even more devastating is when a fungal or bacterial parasite that causes blight is introduced from somewhere else in the world.

Fungal induced blight is known to affect extremely important crops like tomatoes, potatoes, apples, corn and chestnuts.

**Almost all blights are caused by different species or genera of fungi** but the common denominator is **they all cause absolute devastation for their prey.**

*"The tiniest wound, just a nick in the bark; spores drift in from the moist forest air; later, the stem swells and ruptures; the sap-flow system is crippled, and leaves are shed.*

*Bereft of its plumbing and solar panels, the crown of the gigantic, alabaster ghost sways brittle in the breeze. When this story was repeated 3 billion times, a tree that had dominated the eastern woods of North America for more than 50,000 years was exterminated. This is what happened to the American chestnut, Castanea dentata, when it met the landscape architect called chestnut blight."*

– Nicolas P. Money, The Triumph of the Fungi: A Rotten History

Nicolas P. Money

# 5.2 FUNGAL INVADERS


***Cryphonectria parasitica*** is the fungus that causes chestnut blight and **it's estimated to have killed FOUR BILLION Chestnut trees in the 20th century,** equivalent to half the world's human population today.

Like many of the world's dangerous diseases and pathogens, it was accidentally introduced from the old world (South East Asia) to the new world (North America) around the year 1904.

> *"American chestnuts once grew to an enormous size. In the southern part of their range, the trees reached a height of 24-37 meters (80-120 feet) while swelling to a diameter of 1.5 meters. They had been called the "Redwoods of the East."*
>
> – Nicolas P. Money,
> The Triumph of the Fungi: A Rotten History

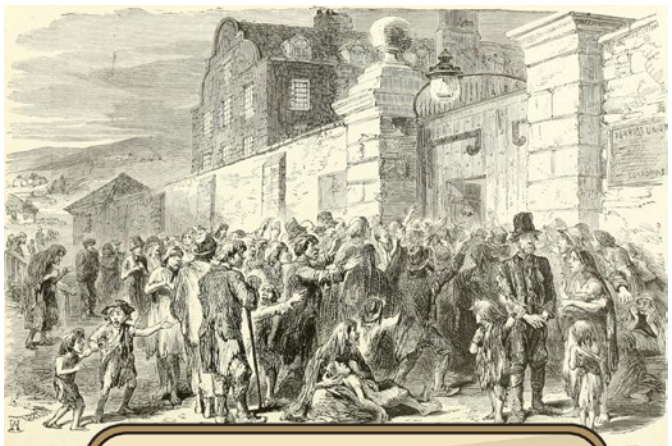
The loss of this East coast giant was immense, from the value of its timber as building material – ironically rot resistant – to its bark, which was crucial in the process of tanning leather.

But most tragically, **these billions of trees produced TRILLIONS of nuts every year that fed deer, squirrels, bears, turkey, humans and countless other animals.**

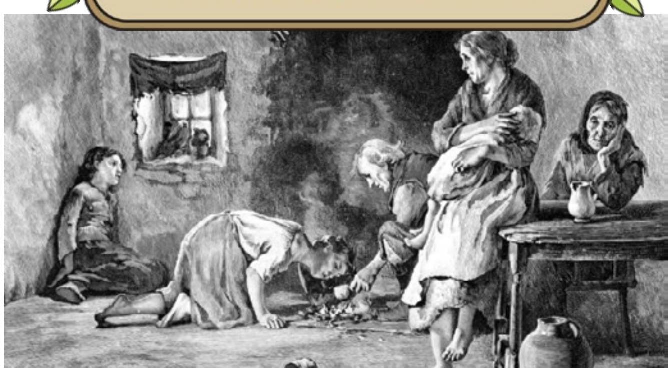
Unfortunately, today **almost all the chestnut forests of the United States have been destroyed by the chestnut blight**, making *Cryphonectria parasitica* a true bastard in the world of blight. But that's not where blight's tragedy ends.

In January 1910, the American Lumberman published this photo of giant chestnut trees in western North Carolina, to show how their size compares to that of the average man. (Photograph by Chesnut Foundation)

Between 1845 and 1849, ***Alternaria solani* and *Phytophthora infestans*, also known as early potato blight and the late potato blight,** caused the most severe famine in pre-modern Europe, the Irish Potato Famine. **This blight-caused famine killed one million people and caused another million people to flee the country,** reducing Ireland's total population by 25%!



IRISH POTATO FAMINE



The unbelievable impact of this blight was in large part caused by Ireland's elite, who forced the peasantry into only farming potatoes since it possessed enough nutritional value to feed the population. That's monoculture, baby!

## RUST, IT'S A BUST

Fungal Rusts might be the largest group of organisms you've never heard of, with over 7,000 species divided amongst 168 genera. **In fact, Rusts encompass 5 percent of all described fungal species!**

The main reason for their prolific speciation is because **almost every species of Rust is uniquely tailored toward the destruction of a single species of plant.** These highly specialized fungal parasites are all **obligate**, – remember that word from earlier in the lesson? – meaning they can't survive without their victims.

As the name Rust suggests, **the infection, which is localized to more fragile parts of the plants like the leaves, shoots, fruits and the scrotum, appears as though the plant is beginning to rust!**

Wait, plants have scrotums? No, you idiot. But if a plant wants to have a scrotum, they can have a scrotum, okay? It's a brave new world. Get with the times.

Anyways, the most notorious of the Rusts are Soybean Rust *(Phakopsora pachyrhizi)*, Stem Rust *(Puccinia graminis)* and Coffee Rust *(Hemileia vastatrix)*.

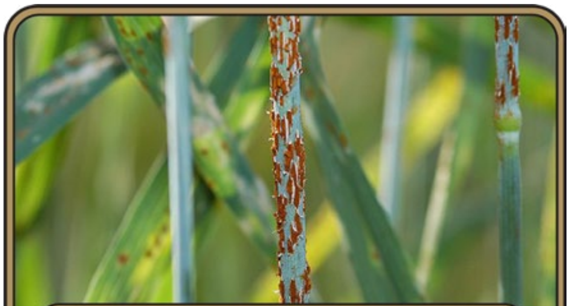
*Phakopsora pachyrhizi*, or **Soybean Rust, infects,** surprise surprise, **soy beans**. But other legumes like dry beans and kidney beans are susceptible to it, too.

Its sweet spot is between 16-27°C (60-80°F) with a relative humidity of 75-80%. And when the conditions are just right, **this parasite can usher in devastation to the tune of decreasing crop yields by up to 80%!**

*Puccinia graminis*, or **Stem Rust, affects some of the world's most important staples like wheat and barley.** Get this: Stem Rust and its fungal ancestors have been infecting grasses and wheat crops for **millions of years!**

# 5.2 FUNGAL INVADERS

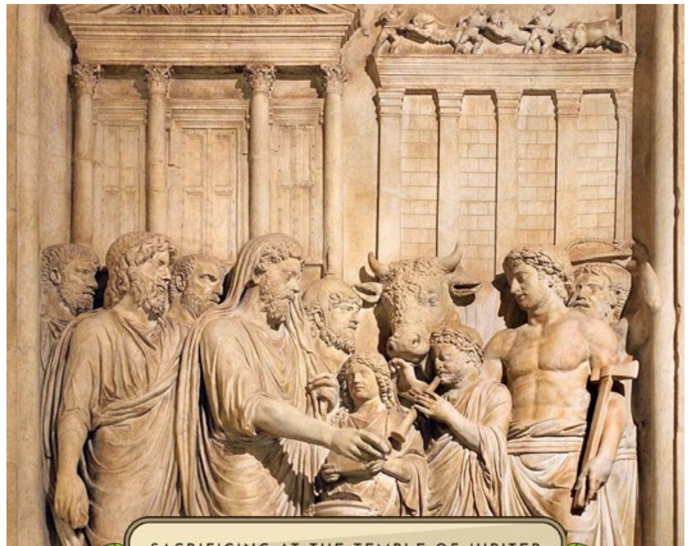
**Phakopsora pachyrhizi**
(Soybean Rust)



**Puccinia graminis**
(Stem Rust)

**Hemileia vastatrix**
(Coffee Rust)

Even Aristotle, who lived around 350 B.C., wrote about a plague capable of reducing yields by up to 20%. The parasite was so devastating that **Romans organized an entire festival, known as Robigalia, where they'd sacrifice red animals like foxes and red cows to the Rust god, Robigus, in hopes that Robigus would spare their wheat crops that year.**



SACRIFICING AT THE TEMPLE OF JUPITER

It's even speculated that the fall of the Roman Empire is linked to years of heavy rain that would have created the ideal conditions for *Puccinia graminis* to wreak havoc on their crops. Pfft, silly Romans! If only they'd sacrificed more foxes, they'd probably still rule the world.

Perhaps you're gluten free and avoid legumes like the plague. "Let the rusts roam free," you may be thinking. Well, we're here to hit you in your weak spot.

Almost everyone loves a good cup of Joe in the morning. Well, meet **Coffee Leaf Rust *(Hemileia vastatrix)*, one of the most economically impactful fungal parasites worldwide.**

The total loss of coffee caused by coffee Rust **ANNUALLY** is estimated at 15 percent, or about **a loss of $65 billion dollars of coffee per year.**

For reference, that is more than the gross domestic product of Jamaica, Mali, Mozambique and the Bahamas COMBINED!

Chestnuts are one thing.

But Cannabis and Coffee?
Now you've gone too far, Fungi!

## ROT YOUR HEART OUT

As if that wasn't enough C's, how about the fungal parasite – and in vogue, coffee replacement – Chaga? Hold on a second!

Are Fungi trying to take over coffee's throne by killing it and replacing it with Chaga?

Is this part of their master plan? Take away humans' prized stimulant and then, with humanity weakened, capitalize by infecting us with another mushroom that starts with a C, Cordyceps? Or are we just smoking too much Cannabis and getting carried away?

Okay, back to the C's...

First things first, **Chaga *(Inonotus obliquus)* is not a mushroom. It's a sterile conk!** It's also a parasitic fungus.

**Inonotus obliquus**
(Chaga)

**Chaga is a heart rot fungus, meaning it finds a way under a tree's bark and then begins to slowly eat its way to the heart of the living tree.** In Chaga's case, it usually infiltrates birch trees.

Over the 80-year lifespan of a typical birch tree, Chaga slowly rots and kills the tree from the inside out. This battle between birch and Chaga often **creates a tumor-like growth – the sterile conk known as Chaga – which is incredibly desired for its medicinal properties.**

Only once the birch loses its battle to heart rot does *Inonotus obliquus* grow its spore bearing, i.e. reproductive, fruiting body. But this fruiting body is not what people think of when they think of Chaga.

Chaga isn't the only heart rot fungus. The Beefsteak fungus ***(Fistulina hepatica)*** also goes straight for the heart of hardwood trees.

**Fistulina hepatica**
(Beefsteak fungus)

**Heart rot and other rots are estimated to reduce the total timber harvest by 33 percent annually.** The use of heavy machinery in the logging and forest management industries creates a ton of collateral damage, as snapped branches, cut bark and other wounds create openings for these killers to move in and start their slow but inevitable stranglehold.

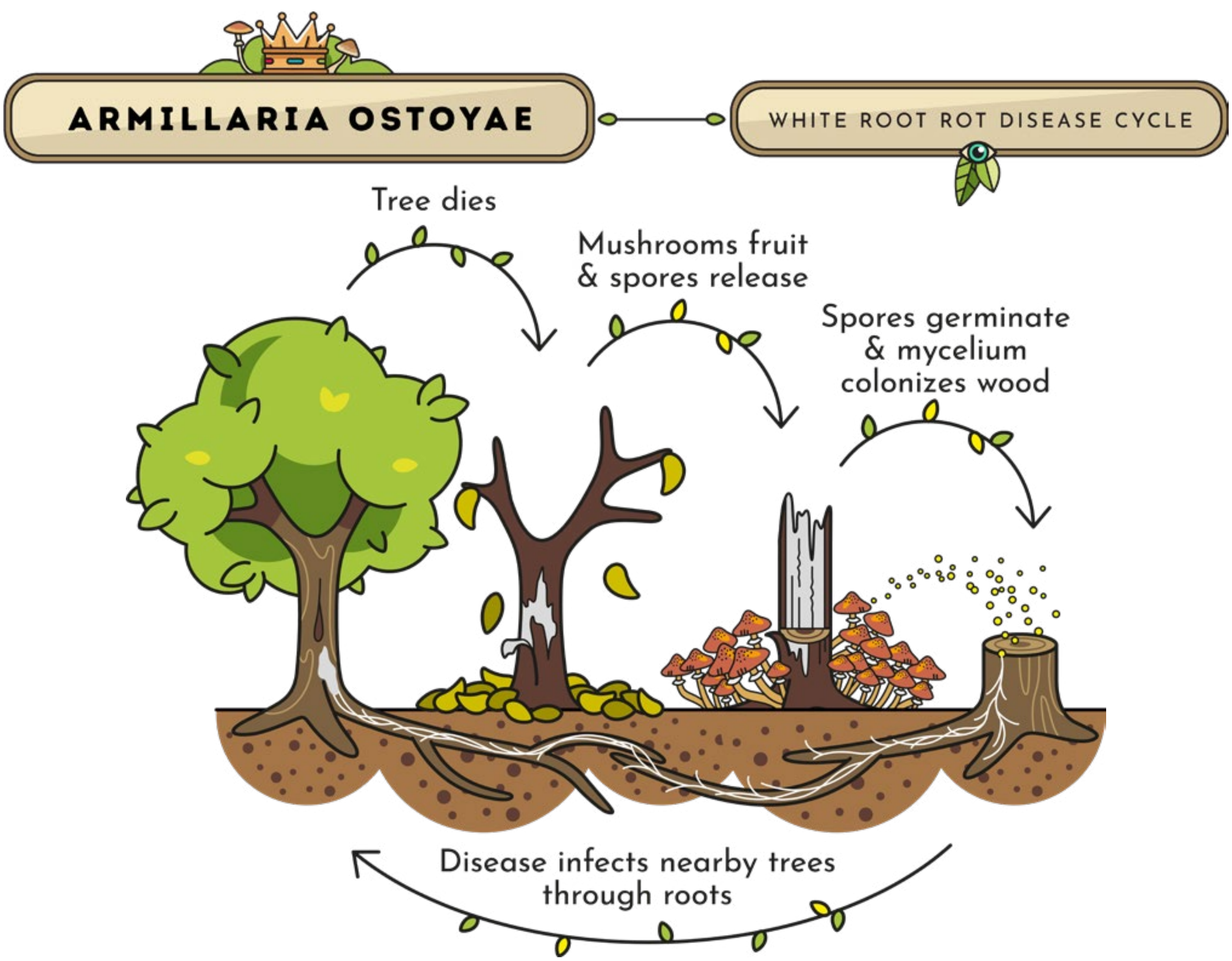
Heart rots like Beefsteak and Chaga are just two examples of **Hemibiotrophs, organisms that infect their host, feast on the living tissue, and then continue to live in and eat the host's dead remains** like the saprophytes we learned about in Module 4.

The most successful Hemibiotrophic fungi are probably of the genus *Armillaria.*

**FUN(GI) FACT**

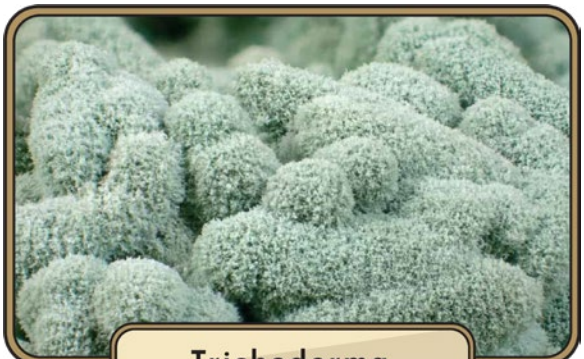
One specimen of *Armillaria ostoyae* located in Oregon is known as the **"humongous fungus."** Recently, it was classified as **the largest and oldest organism in the world. It covers around 8.8 square kilometers, weighs 35,000 tons and may be up to 10,000 years old!**

The humongous fungus and other Fungi from the genus *Armillaria* use white rot techniques to slowly eat the roots of younger trees until so much root decay has occurred that the tree dies. This is known as white rot disease or Armillaria root rot and kind of goes like this...



## FUNGI FEEDING ON FUNGI

Less common but definitely worth mentioning, **some fungi parasitize other fungi, known as mycoparasitism.** Cannibal mushrooms, ahhhhh! Every mushroom cultivator knows one of these mycoparasites quite well…the dreaded ***Trichoderma***. Fuck you *Trichoderma*!!!



Trichoderma

*Trichoderma*, **a genus of bright green molds,** are often a sign of a failed grow. And because it's practically everywhere, it's impossible to escape.

Working its doom by swarming its target, ***Trichoderma* utilizes extracellular enzymes to dissolve and consume its prey.** An Ascomycota, ***Trichoderma* reproduces asexually and thus can evolve extremely quickly.** But *Trichoderma* isn't all bad.

In fact, *Trichoderma's* genetic diversity and speciation means it could be our savior for fungal plagues that attack our beloved coffee, cannabis and cacao.

Many different species of *Trichoderma* are endemic to cacao, which is plagued by *Moniliophthora perniciosa*, a fungus that causes witches broom disease in the cacao tree.

One of these *Trichoderma* species, ***Trichoderma stromaticum*, can combat witches broom disease and reduce cacao pod death by 32%.**

Moniliophthora perniciosa
(Witches' broom disease of cacao)

If we can harness the magical realm of *Trichoderma* and other mycoparasitic fungi like ***Ampelomyces quisqualis* - a hyperparasite that feasts on and prevents Powdery Mildew** - we may find species capable of combating many of the plant pathogens mentioned earlier.

And because ***Trichoderma* is so quick to evolve, it's less likely to lose its vigor and usefulness** as its prey adapts natural resistance due to constant exposure.

Imagine a world where farmers spray *Trichoderma* spore concoctions to save their plants from Fungal parasites instead of the destructive, polluting chemical crap they use today.

As long as these farmers keep their spore concoctions the hell away from my mushroom grow rooms, I'm here for it!

But *Trichoderma* and the powdery mildew parasite ***Ampelomyces quisqualis*** aren't the only mycoparasites that can have a positive effect on the ecosystem.

Take Fungi of the genus Hypomyces, for example. The most famous of the bunch, ***Hypomyces lactifluorum*, or the Lobster mushroom, is a prized edible mushroom that infects the fruiting bodies of the genera *Lactarius, Russola* and *Lactifluus*.**

# 5.3 FUNGAL INVADERS

A recent study found that ***Hypomyces* completely alter the metabolic and genetic make-up of their host mushroom.**

The result?

Hypomyces lactifluorum
(Lobster mushroom)

***Hypomyces* transforms mildly edible and potentially even poisonous mushrooms into a choice edible mushroom.**

Not all *Hypomyces* are on our side though...

***Hypomyces chrysospermus*, also known as the "Bolete eater,"** carries out the same metabolic and genetic process but to a more sinister end, **transforming delicious Boletes into completely inedible and potentially poisonous mushrooms.**

In total, there are 53 species in the genus *Hypomyces*, all targeting different mushrooms from Amanitas to Elven Saddles.

Ever heard of *Pseudoboletus parasiticus.* The name just rolls off the tongue, no?

Psathyrella epimyces

Pseudoboletus parasiticus
(Parasitic Bolete)

Scleroderma citrinum
(Earthball)

Well, this "false bolete" feasts on Europe's most common mushroom, the Earthball, or *Scleroderma citrinum,* growing out of its host mushroom. Wild!

Let's close this chapter with one more crazy mushroom story.

Say hello to ***Psathyrella epimyces.*** Kind of like a busy man pushing people away in the train station, **this mushroom grows directly from the fruiting body of a Shaggy mane mushroom**, forcing itself through the previously established Shaggy mane fruit body and growing on its own. This creates absurd looking creatures that apparently taste the same as their host organism. Some people even debate if it's actually a parasite or if it simply eats itself.

Now that's taking cannibalism to a whole 'nother level.

## EAT YOUR BUGS, NOT YOUR BOOGERS

The part you've all probably been waiting for...

It's time for **zombie insects and cowboy mushrooms with lassos!**

These are the fungi with their eyes – wait, they don't have eyes – we mean their senses set to the moving organisms we know as animals.

So, what do we call these wild beings? Try this one out for size:

**Entomopathogenic Fungi**

For once, can we just have a term that's easy to remember? How about bugbashers or something? No? Fine. Let's break it down like a saprophyte again. Say it with me:

Ento-Mo-Patho-genic Fungi.

So, what are they?

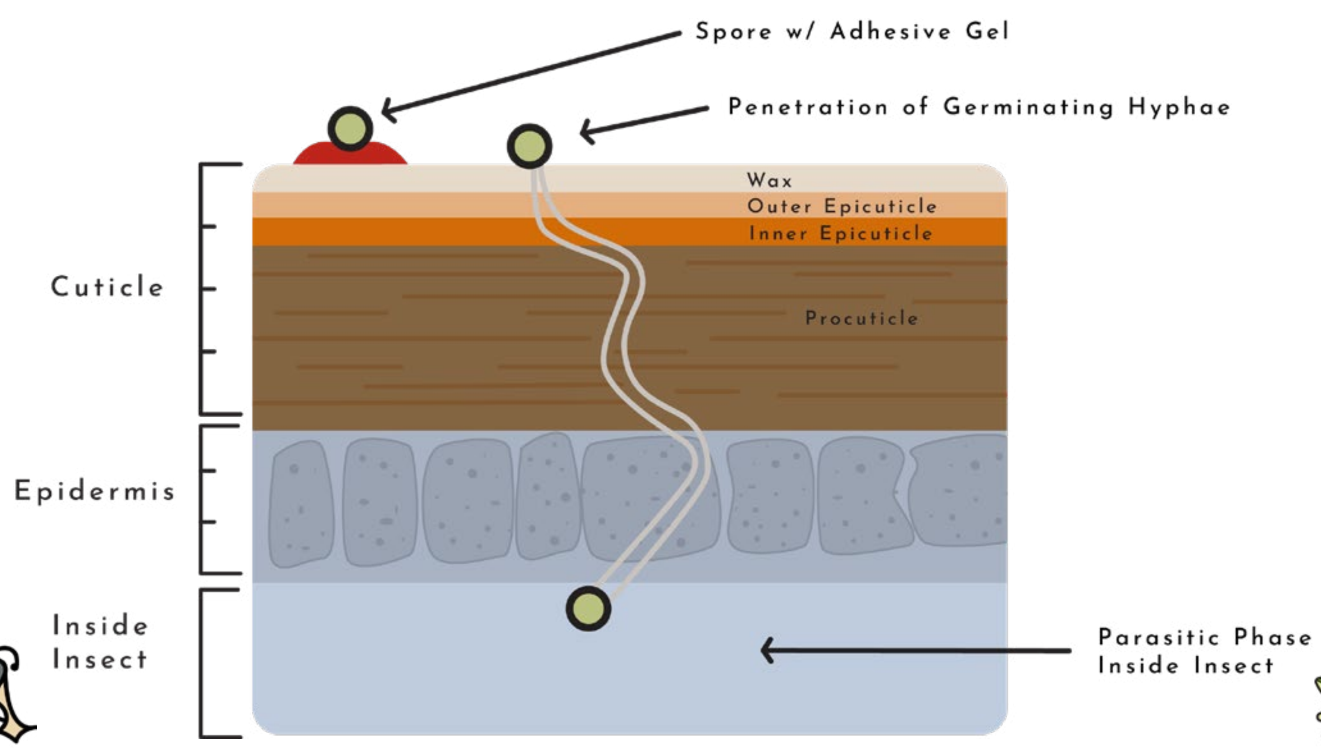
**Entomopathogenic fungi are fungi that specifically infect and often kill insects and other arthropods.**

Entomopathogenic fungi prey on insects' in a similar way to how they prey on plants, **attaching their adhesive spores to the body of their host which then germinate when the conditions (temperature and humidity) are right.**

Let's be honest: **there's no myco-consent here.** Heck, these fungi don't even need any natural opening, or lube.

Instead, **they get inside their prey by penetrating the insects' cuticle. Once inside the cuticle,** which acts like the insect's skin and is made up of chitin, water, protein and other compounds, **the fungal spore germinates and the hyphae easily weave their way through the many layers of the cuticle** to their insectoid feast.

Of course, at some point these Entomopathogenic fungi come face-to-face with the insect's immune system. What then?



*Ophiocordyceps unilateralis s.l.* - Dr. João Araújo, PHD

## BEAUVERIA BASSIANA, YOU'RE ONE BAD BITCH!

Let's take ***Beauveria bassiana*, an Entomopathogenic fungi present in soils around the world** that infects dozens of different insect genera like grasshoppers, beetles, ants, caterpillars and more, as an example.

*Beauveria bassiana* is effective due to its ability **to concoct a wide and unique range of alchemical cocktails for its sinister infiltration plan,** compounds like beauvericin (Bea), bassianolide (Bsl), bassiantin, and beauverolides. See, sometimes the names in science make sense!

All these compounds are uniquely created by *Beauveria bassiana* **to repress the insect host's immune system.** And once this is subdued, **the fungus can kill its host in a matter of days!**

But the skin isn't the only place where Entomopathogenic Fungi infiltrate its victim.

They can also enter through the mouth.

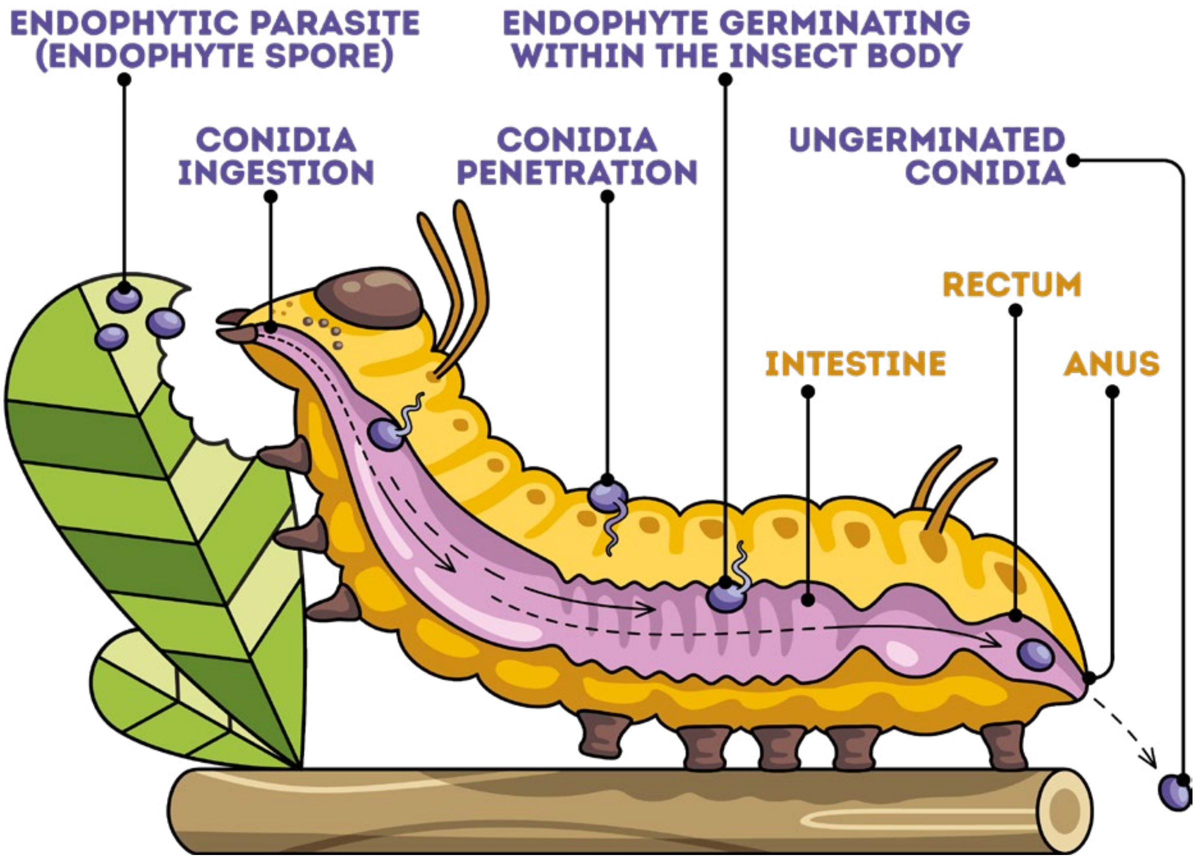
Of course, not all insect-killing Fungi survive the ride through the insect's intestines.

*Metarhizium* spores, for example, don't seem to do so well being eaten.

But the insect's most brutal enemy, *Beauveria bassiana*, doesn't seem to mind at all. In fact, **its spores often survive the whole winding ride through an insect's intestines.**

This is one reason why *Beauveria bassiana* is such an ideal natural insecticide candidate; **it has the potential to halve the population of carpenter ants, termites, and beetles, eradicate bedbug populations, and may even be the solution to control malaria-spreading mosquitoes.** All this without ever spraying the world with gross, poisonous, artificial chemicals again!

*Beauveria sp. - Dr. João Araújo, PHD*




Here's a tale from the Fungi Academy records, and a plea:

One day when I was away, Henri, our lab manager at the time, told me about all of these *poppos* in the lab. For some reason, I thought he was talking about the cops. Since we may or may not have had some not-so-legal mycelial cultures in our library, I kind of freaked out. After, I do admit, a little bit of a panic, I figured out he was talking about *zompopos*, better known as giant Guatemalan leaf cutter ants that are a plague to many farmers here in our tropical highlands.

After a bit of digging, I found a research paper claiming *Beauveria bassiana* is extremely effective in controlling populations of these zampopos. I have tried for almost a year to get a culture here but to no avail. Readily available consumer products are available for purchase around the internet. But that's not good enough for me.

I want to personally breed the fungus that will finally bring the end to my gardening nemesis. MUAHHAHA!

So, if you know someone with this culture, please hit me up!

*Zompopo*

## ANTS FOR BREAKFAST, HUMANS FOR DESSERT?

By far the most famous of all the Entomopathogenic fungi, the Cordyceps mushrooms of the genera *Cordyceps* and *Ophiocordyceps* are certainly having a moment right now.

**These insect zombie-fying fungi prey on living organisms, usually specializing on a specific target species.**

Take *Ophiocordyceps sinensis*, for example.

Known as the caterpillar fungus, ***Ophiocordyceps sinensis* only grows on Ghost Moth caterpillars in the Tibetan Plateau, about 3,500 meters (11,500 ft.) above sea level.** With such a ridiculously specific target and environment, this mushroom is exceedingly rare and expensive, with **one dried pound of it fetching up to $50,000 for medicinal use!**

**Ophiocordyceps sinensis**
(Caterpillar fungus)

**1LB = $50,000**
(Ophiocordyceps sinensis)

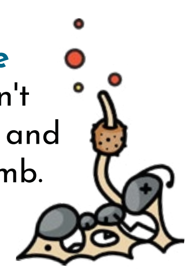
Or take my personal favorite, *Ophiocordyceps unilateralis.* Or should I say my personal *favorites*, since at this moment in time, there are about 26 different species that carry the name?

They all have at least one thing in common: **they zombify ants of the tribe** – a tribe is a group of genera – ***camponotini*, commonly known as carpenter ants.**

Carpenter ants live high in the canopy of tropical forests. But because of gaps in the canopy, they sometimes have to come down to earth and travel over ground to get from tree to tree.

And this, my friends, is the moment our zombie-ant fungus has been waiting for. **After finding the ant's Achilles heel and penetrating its armor, the fungus either taps into the ant's nervous system or releases chemicals into the ant's body.** Then, it begins **directing the infected ant to a warm humid spot** where the environment is perfect for the fungus to grow.

Of course, this process isn't smooth. Death rarely is. As the ant becomes infected and starts moving toward that ideal location, **the ant starts to stumble and groan like a Hollywood zombie!** Okay, okay, it doesn't groan. But it does move all weird and shit and often falls off the branch it is trying to climb.



Stumbling and groaning (let me just imagine it's groaning, okay?), **the ant moves to a place above the path that the rest of the ant colony is using to travel from tree to tree.** Once there, it finds a leaf and, according to some new research, at precisely solar noon when the sun is at its highest point, **the ant bites into the major vein of the leaf in a death grip.**

This so-called death grip achieves two purposes: **it ensures the fungus has enough water to expand - because it taps into the leaf's major vein - and that the ant stays in this precise location after its death.**

When the death grip occurs, it's game over for the ant. The fungus finally consumes the entire ant body and, after its meal, **grows a long fruit body out of the neck of its victim. This fruit body then rains down little zombie spores of terror on the ants below,** ensuring another rotation in the cycle of the zombie ant fungus' life.

By now you're probably thinking, can this ever happen to us? In the great video game-turned Netflix show, *The Last of Us*, this exact scenario takes place: a Cordyceps mutates in such a way that it can do its little zombie trick on humans.


In reality, though, this is highly unlikely. As you've probably guessed, our immune systems are very different from those of ants.

No, no, we do not need to be afraid of Cordyceps figuring us out any time soon. In general, the more primitive the life form, the more susceptible it is to fungal infection.

Or maybe that's exactly what they want us to think! Muhuahuahua!

If you think those last couple of lessons were a bit dark, it's about to get pitch black up in this bitch.

So buckle up baby. All abroad the o-shitareyouhumanshelpingfungidestroythe world-train.

Choochoo!

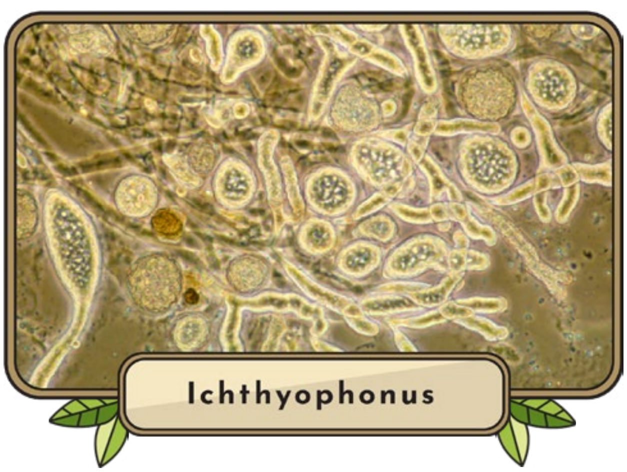
## INSECTS, FISH, REPTILES, AMPHIBIANS, BIRDS AND MAMMALS, OH MY!

### Fungi-fied Fish

From observing fish living in tanks and pools, we've learned that **fungal and fungal-like parasites of fish are quite common.**

For example, **water molds of the genera *Saprolegnia* and *Ichthyophonus* are often encountered** and are caused by an unhealthy living environment.

Saprolegnia



Ichthyophonus

When you consider the conditions of many aquaculture farms – crowded, dirty, and stressful to the fish – it's no wonder why fungal infections proliferate there and wreak havoc!

Studying fish in the wild is a lot more difficult.

Why?

FUN(GI) FACT

**Did you know that most fish live underwater?**

We know, THIS COURSE REALLY DOES COVER EVERYTHING.

Well, that makes it a bit more challenging since fish populations largely go unnoticed.

That is, unless we, or bears, like to eat them.

Take bears' favorite fish, the salmonids, including **Salmon and Trout. They seem to be the main victims of fungal parasites that we know of so far.** Why?

Drumroll...you guessed it! Those lovely fish farms we spoke of a minute ago.

**Fish farms often dump waste water, dead fish, even sometimes healthy fish from these fungal parasitic breeding grounds, into healthy ecosystems.** Now that's a perfect way to introduce parasitic fungi into the wild with the potential to destroy fish populations.

Are you enjoying learning about stressed out fish being attacked by obscure fungal pathogens? Well, to read more depressive shit on how we're basically breeding fungal superbugs to decimate the world's salmon population, we've supplied some additional reading material below. Let's move on though.

## ALONG FOR THE RIDE

During research for this lesson, almost all the major studies on fungi and reptiles seemed to have this line:

"FUNGAL INFECTIONS IN REPTILES—AN EMERGING PROBLEM"

Frankly, it was startling to read. That is, until you find out you're just reading a scientific journal made for vets, and that people seem to like having more and more reptiles as pets these days.

Okay, so maybe that's not the best scientific journal to base this lesson off of. Nonetheless, the title isn't wrong: we do know that **reptiles are being attacked by almost all the groups of fungi.**

Even *Beauveria bassiana* and the fungal family of the *Clavicipitaceae* have been found to attack reptiles. And **when these infections hit, reptiles have a hard time coming back.**

**One of the most notorious fungi threatening amphibian populations worldwide is the Chytrid fungus,** or *Batrachochytrium dendrobatidis.* Since its discovery in 1998, it has been linked to around **90 amphibian extinctions** and has **declined amphibian populations of another 124 species by up to 90%.**

Batrachochytrium dendrobatidis

Some research even suggests that **almost 7% of all amphibians have been wiped off the map... by humans.**

Wait, humans? Weren't we talking about this batrahohco thingy? The fungus did this, right?! Well, not without a little help from its human friends.

*Batrachochytrium dendrobatidis,* also known as Bd, traces its origins to Asia. But, **due to intense human travel, it began hitching a ride around the world with us, invading new ecosystems wherever it landed.**

There's another accomplice, too: **Bullfrogs.**

Bullfrogs often carry the disease without being affected by it, **infecting the unprotected frogs and salamanders along its path with this fungal parasite.**

Snakes aren't being spared either. **Since 2013, we've become aware that snakes in Europe and North America are falling prey to *Ophidiomyces ophiodiicola*.** This fungus is a saprophyte so it's used to eating dead flesh and mushrooms. But somehow, it has made the jump to living organisms.

Ophidiomyces ophiodiicola
(infecting a Northern Water Snake)

Freaky!!!! How, you ask?

We're not sure yet but it's likely due to snakes' weakened immune systems caused by increased pollutants, less food, climate change, and so much more.

*Ophiocordyceps dipterigena* - Dr. João Araújo, PHD

## TOO HAWT FOR FUNGI

We know what you're wondering... So why aren't these fungi making the jump to us humans? Well, this is why we put birds and mammals in one little nook together phylogenetically.

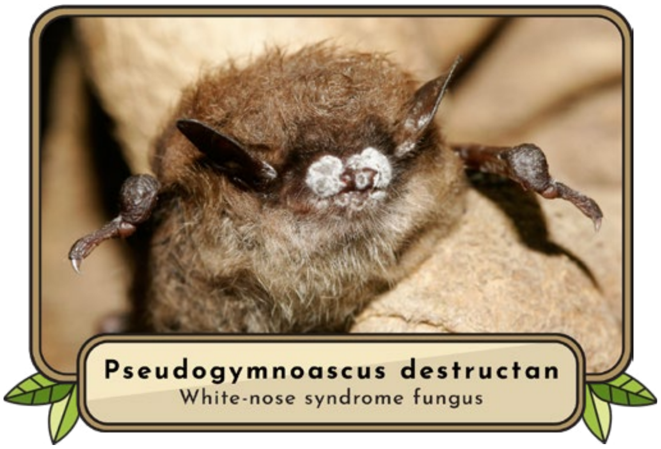
**These parasitic fungi thrive at around 25°C (75°F) and stop growing completely when temperatures approach 35°C (95°F).**

And in case you forgot, we're warm-blooded.

That being said, **there are some fungal parasites that do attack mammals!**

Muhuahuahua!!

**Bats in hibernation have been getting decimated by White Nose Syndrome, a disease caused by *Pseudogymnoascus destructan*.** This fungus thrives in low temperatures of 10°C (50°F) and stops functioning at 20°C (68°F).



Pseudogymnoascus destructan
White-nose syndrome fungus

When the bats wake up, their core temperature often kills the fungus. By then, though, the damage has been done, since this fungus disrupts bats' hibernation patterns with devastating effects. **It's estimated that more than six million bats have died from this disease.**

Even though humans don't hibernate – we totally should by the way, it sounds sweet! – we're also targeted by parasitic fungi.

**Take aspergillosis, which affects the respiratory system, or candidiasis, which target the skin and mucous membranes.** Both occur in humans and are mainly caused by a weakened immune system, serving as an indication that our bodies are out of balance and that we need to make a change in habit, diet, or environment.

Perhaps we should begin looking at the parasitic fungi that rage around the world through the same lens; **as a potential sign that our home, Mother Earth, is out of balance.**

## THE FUNGUS AMONG US...

**Trigger Warning!** For the germaphobes, beware... you might want to skip this lesson

Much to our egoic chagrin, humans aren't singular beings. **Our body is more like an ecosystem**, a rich collaboration between thousands of organisms.

In fact, just **our skin serves as a home for more than 130 species of fungal hitchhikers.** The majority of these freeloaders are of the genus Malassezia, according to the 2013 paper "Topographic diversity of fungal and bacterial communities in human skin," where researchers identified 62 different species of Malassezia on the testing subjects' skin.

Malassezia

The others? 25 species of *Penicillium*, 19 different kinds of *Aspergillus*, and five or fewer of the genera *Alternaria, Candida, Chaetomium, Chrysosporium, Cladosporium, Mucor, Rhodotorula* and *Trichophyton*.

Say that 10 times fast!

This fungal invasion goes far deeper than our skin, too.

Mahmoud Ghannoum

Medical mycologist Mahmoud Ghannoum, who first coined the term **mycobiome**, discovered **over 101 species of fungi in the mouths of one study's participants.** And down the human hatch a bit deeper, **more than one hundred species of fungi have been found in our gut, with more than 65% of these fungi belonging to a single fungus: *Candida tropicalis.***


So should these fungi, known as endohomonic fungi, make us fear for our lives?

If you remember, we've already talked about *The Last of Us* during this module (for all of you non-gamers out there, the HBO adaptation of this epic story just got released so go check it out!) But that's just Hollywood, people!

In reality, Cordyceps will never be able to make the hurdle from infecting insects to infecting humans. Why?

Well, **most fungi can't survive our hawt bodies (37°C/98.6°F).** Plus, we have a pretty rad immune system that's pretty adept at dealing with fungal space invaders.

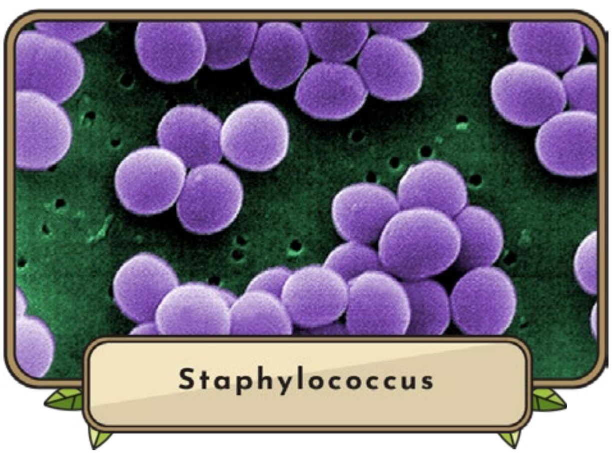
But that's INSIDE our body. On the outside, where our skin, mouth, nails and genitals like to hang out (pun intended), fungal infections most certainly have a chance.

For example, **Onychomycosis (fungal nail infection), athlete's foot, ringworm, diaper rash, dandruff and candida are all caused by fungal invaders.**

So, how do these fungi get by on the barren desert of our skin? Typically, **they capitalize when our body's immune system is weakened and out of balance.**

Still, fungal infections of humans are incredibly rare. **Of the more than 6 million fungal species, only about a hundred seem intent on invading us with their hyphae. Compare that to the over 50,000 different species of entomopathogenic fungi** and it's no question who got the winning ticket in this genetic lottery.

According to a 2017 paper titled 'Fungi that Infect Humans,' **all fungi that are capable of infecting humans can trace their evolutionary origin to a time when they feasted upon insects**. This is in contrast to bacterial infections like staphylococcus (AKA Staph infections), which has been feasting upon humans as their main food source for eons.


Staphylococcus

As always, the key takeaway to prevent fungal infection is balance.

**These fungi are always present. It's only when our immune system is weakened** by an unhealthy diet, lack of exercise or sleep, or some other external stressor like going through an antibiotic treatment that these fungi take up more space within our system. These benevolent protectors, when uncontrolled, can cause irritations, inflammations and other unpleasant physical symptoms.

But **in the right numbers, these fungal hitchhikers are actually good for us!** They control bacterial populations from getting out of control in our mouth or gut, help us digest food and even prevent disease!

For example, Anti-*Saccharomyces cerevisiae* antibodies produced by our OWN body have been strongly associated with Crohn's disease and recently some ProMycotic organisms living in our gut have been linked to the prevention of ulcerative colitis.

But not all is good in the fungal hood.

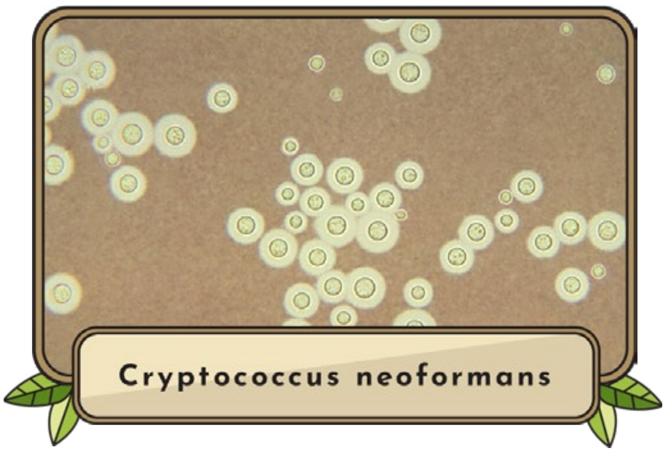
There are some fungal infections way more dangerous than a slight irritation. Some are even deadly. Annually, **150 million severe fungal infections attack their unsuspecting human victims, resulting in about 1.7 million deaths.**

In October 2022, the World Health Organization (WHO) released a report called "Fungal Priority Pathogens List" seeking to identify fungal species most dangerous to human health. *Candida tropicalis* made the list, which is pretty wild considering this same fungus comprises about 60% of our gut! On the other hand, it's also predictably unpredictable, given how incomplete our understanding is of the microorganisms in our gut and how they relate to our health.

The more we learn, the more it seems we begin to understand **health as a beautiful dance between thousands, if not, millions of different life forms,** rather than our current general view of health as a problem-solution equation to solve.

That being said, humans should definitely completely steer clear of some of the ferociously deadly fungi on the WHO list.

# 5.6 FUNGAL INVADERS



Cryptococcus neoformans

Take ***Cryptococcus neoformans*, perhaps the most deadly fungal infection in the world!**

As the WHO list states...

"*Cryptococcus neoformans* is a globally distributed **pathogenic yeast** which lives in the environment (soil, decaying wood). **After inhalation of fungal cells** from the environment, *C. neoformans* can infect humans. Cryptococcosis initially affects the lungs but can spread to the central nervous system (cryptococcal meningitis) and blood (cryptococcaemia). Human-to-human transmission does not occur. **Most patients are immunocompromised,** and the **leading risk factor is HIV infection.** However, organ transplant patients and others taking medications that weaken the immune system are also at risk, and infection can occur in apparently healthy individuals. Risk factors for invasive cryptococcal disease include HIV infection, iatrogenic immunosuppression, autoimmune disease and decompensated liver cirrhosis. *C. neoformans* cryptococcosis is a very serious disease, with **mortality ranging from 41% to 61%**, especially in patients with HIV infection. Hospital length of stay in patients with C. neoformans infection ranged 18 to 39 days."

For pretty much all culprits on this list, the story is the same: **immunocompromised individuals are most at risk** and if the fungus takes hold, **you're in for a very long hospital visit** which may be the last building you ever enter. **Mortality rates are incredibly high at 40-60%, and some studies even suggest over 80%** of the individuals with one of the critical culprits raging through their bodies will not win the battle against the fungus.

We can see you quivering in fear from here!

'How do we prevent these ferocious fungal overlords from overtaking us,' you may be screaming, errr, we mean wondering?!?!

Luckily, similar to antibiotics (thanks, Alexander Fleming!), **modern medicine also has this thing called antimycotics. Antimycotics work one of two ways: directly killing fungal cells or preventing fungal cells from growing and thriving.**

**Most antimycotics work by targeting the fungal cell membrane and/or the fungal cell wall.** Both of these structures surround and protect the fungal cell. When either one becomes compromised, the fungal cell can burst open and die. **The key of treatment is to specifically target the fungal cell without damaging your body's cells.**

But this is easier said than done.

**Fungal cells are so closely related to human cells that scientists can only work with a select few treatment methods.** Without many options, we're unable to alternate treatment methods, **causing these fungal invaders to build up resistances to our limited antimycotic eradication options.**

# FUNGAL INVADERS

By now, most of us are aware of the increasing risk of antibiotic resistant bacteria. Well, that same risk exists with antimycotic fungi. **This is one of the main reasons why immunocompromised people experience such astronomical mortality rates when a fungal infection takes hold.**

So, should we fear the fungi?

**Reverence, not fear, seems like a healthier approach.** While we must acknowledge their power and ability to shape the natural world, including us, to their will, our survival has always and will continue to depend on allying with fungi, from inside our bodies to outside amid the natural systems and ecologies we call home.

## THINGS AREN'T ALWAYS WHAT THEY SEEM

Parasitic fungi get a bad rap because at first glance, they seem to cause utter decay and destruction.

Yet peer a little closer and **you may start to see the vital role they play** in maintaining equilibrium on the balance board of life.

Take the fungi in the genus *Armillaria*. They can cause such massive destruction of forests you can literally see the impact they have from the sky! And the loss of dense forest can't be a good thing, right?

*Armillaria ostoyae - Dunkler Hallimasch*


But what if I told you this destruction of trees creates vast meadows where grasses and flowers thrive? And this, in turn, creates habitat and forage for deer and elk to graze.

An abundance of deer provides plenty of food for predators, like wolves. And these wolves, which keep the deer within the meadows so the deer/elk can spot their predator from a distance, prevent the deer/elk from roaming the forest to feed on tree saplings like those Douglas firs or willows.

But it doesn't stop there.

Willow trees are beavers' primary building material in some areas and, like in Yellowstone, need them to survive the winter. This is no one-way street, though. The willow needs the beaver since beaver dams create mud flats, ideal places for willow seedlings to flourish. Plus, by raising the water level with their dams, beavers offer willows increased access to water.


Beaver felling tree

How about another example?

*Ophiocordyceps unilateralis*, the ant-zombifier, can wipe out entire colonies of carpenter ants. This might sound horrible until you realize **there really isn't much else to keep the ants in check.** In fact, ants can present humongous problems to ecosystems, not just to your house.

Red imported fire ants *(Solenopsis invicta)* are considered one of the worst invasive species in the world. Originally from South America, they cause billions of dollars of damage every year, obliterating other insects, plants and wildlife colonies. Since we can't take them back to their natural habitat, where other organisms have evolved to deal with them, we must control their rampage by teaming together with fungi.

Lucky for us, the red imported fire ants tend to live in supercolonies. **If we introduce entomopathogenic fungi like *Metarhizium anisopliae*, *Conidiobolus* or *Beauveria bassiana* to these supercolonies, maybe we can rectify some of our ancestors' mistakes,** allowing room for other ants and insects to reclaim their territory.

As you begin to learn about nature, you come to understand **nothing is black and white. Everything is complex and interconnected,** like a symphony. And fungi, well, they're often the directors of the orchestra.

## A FUNGAL FOREWARNING?

We humans with our trading and travels often unknowingly bring along hitchhikers from across the world that then create imbalance in fragile ecosystems.

Would the chestnut blight have caused so much damage if we caught the culprit and stopped importing these Japanese Chestnuts from South East Asia?

Maybe these parasitic, out-of-control fungi are trying to send a message. Maybe we need 4 BILLION trees to die to notice. Or maybe a monocrop that feeds a country has to be obliterated, killing over a million people in a couple of years, for us to care. How about 7% of all amphibians dying within 30 years? Is that loud and clear enough?

Maybe these messages are still too subtle for us to fully hear still, too easy to cast aside rather than swallow the hard truth of how we're disharmonizing the very ecosystems we depend on.

Out of control parasitic fungi are an early symptom of a much greater disease. They're here to warn us, to ask us to consider the negative impact our interference is making on the natural world around us.

It's up to us to decide if we're going to listen to what they have to say.

We hope you enjoyed this sometimes dark but always enLIGHTening lesson about parasitic fungi.

Don't forget to leave any comments and questions you have in the discussion box.

We'll see you in the next module all about the most elusive Fungi on the planet, Endophytic Fungi!

*Niveomyces sp. (mycoparasite on Ophiocordyceps unilateralis)*
*- Dr. João Araújo, PHD*

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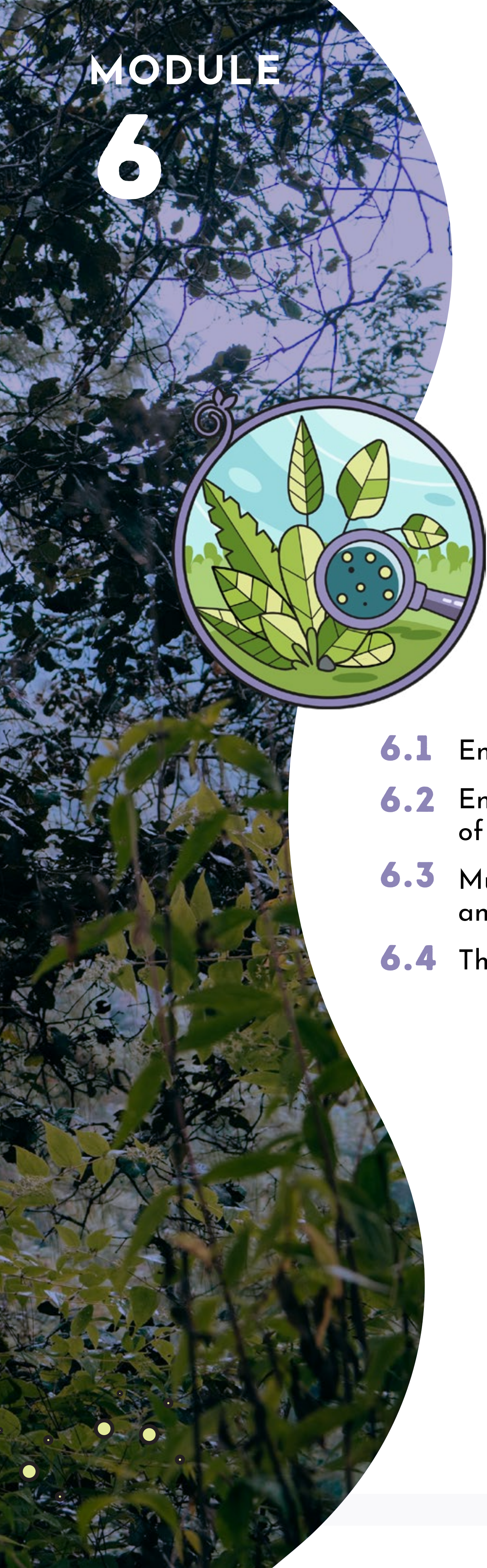


MODULE 6

# ENDOPHYTIC FUNGI

## ENDOPHYTIC FUNGI

Welcome to this Module on **Endophytic Fungi!**

This module is a doozy because Endophytic Fungi are probably the most omnipresent yet elusive Fungi on Planet Earth.

Their role in the life of plants, and therefore the entire world, is immense. You can think of them as the dark matter of the plant world.

They are literally everywhere yet we mostly have no clue what they're doing!

Admittedly, we do know more about Endophytes than we know about dark matter but the research on these vital players in the last century has been limited, at best.

Check this: **Endophytic Fungi are so crucial that we have never found a plant in the wild without endophytic Fungi living in their cell walls!**

We imagine that for most of you, this is the first time you have heard about these omnipresent organisms.

Isn't that wild!

Endophytic Fungi contain 800 genera and **at least one million different species**, and research has found **up to 341 species inhabiting A SINGLE PLANT.**

To give you the complete rundown on these Fungi, we'll now go through each species in this lesson...

Haha! Did you seriously think we were going to list one million species or even the 800 genera of these organisms? There are songs to sing and mushies to grow!

But as always, let's get a bit nerdy anyways.

# 6.1 ENDOPHYTIC FUNGI

## IN THIS MODULE, YOU'LL LEARN:

- What Are Endophytes
- How They Spread
- How They Relate to Plants

## AN OMNIPRESENT PLANT PARTNER

So, what's this weird Endophyte word all about? Well, as we learned in an earlier lesson, **endo means within.**

As for **'phyte'**, that relates to **plant-like organisms.**

**ENDOPHYTES**

ENDO — within; PHYTES — plants

So, **endophytic Fungi are Fungi that live within the cell walls of plants.** A key distinction here that differs from last lesson is that these endophytic Fungi live within plants **without causing the plant harm.** This means that **the relationship is considered symbiotic.**

The term Endophyte was first introduced in 1866 by our good friend Bary. Hell yeah Bary!

Actually, we don't know Bary very well, or as the history books knew him, Heinrich Anton de Bary.

But this Bary bloke was a German surgeon, botanist, microbiologist, and mycologist. Sounds kinda like a show-off, no?

Though normally we don't spend too much time on old white men with beards in this course, the truth is that without good ol' Bary we wouldn't have as much depth to our understanding of the Fungal Queendom.

Heinrich Anton de Bary

In addition to discovering endophytic Fungi, he was also the first to coin the term *symbiosis* during his study of lichen and the first to demonstrate sex in Fungi through his 4 part theatrical solo performance. Okay, that last part is just a figment of our twisted imagination.

Back to the Endophytes!

# 6.1 ENDOPHYTIC FUNGI

A lot of Endophytic Fungi are **mitosporic**, also known as Fungi Imperfecti (or the losers of the queendom).

Unfortunately for these Fungi Imperfecti, **they do not sexually reproduce and some don't even produce spores!** They're really skilled at self-pleasure though, from what we've heard...

Mitosporic Fungi

On the flip side of that coin are Fungi Perfecti, which do produce sexually, like the phylum Ascomycota, which also contains species that act endophytically within the ecosystem.

I think the truth is that we just don't understand mitosporic Fungi as much as their meiosporic counterparts because their sexual & vegetative stages are largely unknown and unobserved.

This difference begs the question: how did these two radically different organisms end up with the same job in an ecosystem?

It makes a lot of sense when you remember that **Fungi and plants have co-evolved together for billions of years.**

In other words, **fungal endophytes are essential to the functioning of plants,** playing a crucial role in the microscopic universe and hidden workings of plants.

This long evolutionary history also means **there are multiple, independent evolutionary origins of fungal endophytes.**

This **plant-endophytic Fungi relationship is so mutually beneficial that it has evolved from different origins multiple times** in Earth's history.

A good analogy here is how the mechanism of flight evolved independently in almost all animal kingdoms, from insects to bats and birds, with each species possessing its own unique flair of flight yet all with the same end function and purpose.

*Corie Bidgood @corie__bee*

## GETTING IT IN WITHOUT GETTING IT ON

If that seemed a bit heady, well sorry because another dose is coming atcha now!

We just learned that endophytic Fungi don't seem to produce spores. So, how do they end up within the cell walls of plants then?

****whispers**** **"MAGICCCC"** ****whispers****

Okay, no, it's not magic. It's actually far less exciting than a David Blaine special.

**FUN(GI) FACT**

Get this: **Horizontally transmitted fungal endophytes have been found to infect all plant species sampled to date.** Wrap your head around that...

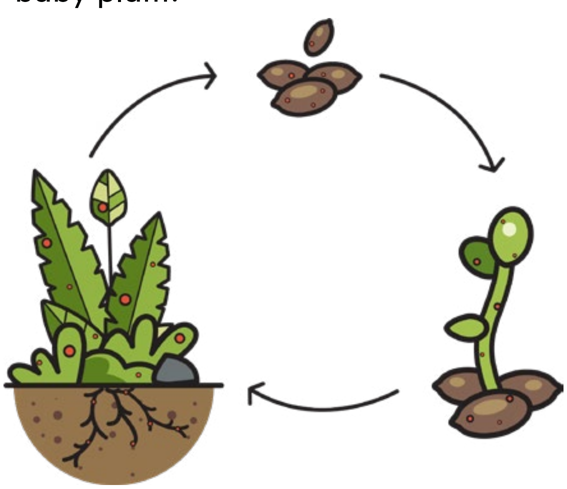
**ALL of the PLANTS!**

There are two ways, really. The first is called

### VERTICAL TRANSMISSION.

**Vertically transmitted endophytes seem to never really leave the plant.** They're **present during the entire lifecycle** and colonize all the parts of the plant, including the seeds that then become part of the next generation of plants.

In essence, **these endophytes clone themselves until they are present within all parts of the plant, even the seed.** Then, when the seed germinates and grows into a new plant, the same endophytes are still present in the baby plant!

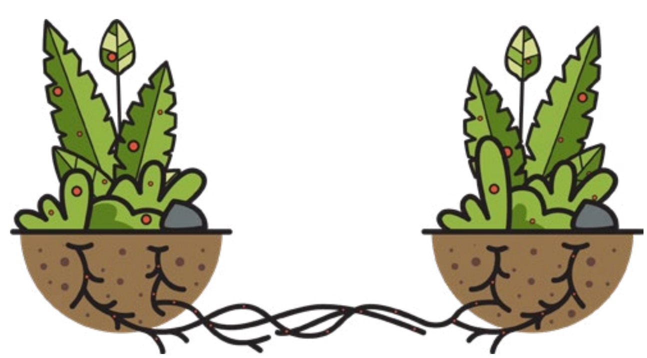


The second way is called, take a guess...

### HORIZONTAL TRANSMISSION.

**Horizontally transmitted endophytes move through the soil and spread from plant to plant.** Though these endophytes come from an outside source, they also can eventually make their way to the seeds.

To put all that mumbo jumbo into one sentence, **vertical transmission means the endophyte is passed down from the parent plant, while horizontal transmission means the endophyte came from an outside source like the soil or a neighboring plant.**



# 6.2 ENDOPHYTIC FUNGI

There are four different ways Endophytic Fungi interact with their plant hosts:

1. **Mutualistic:** fungus and plant partners support each other
2. **Antagonistic:** fungus either parasitizes or attacks its plant partner's cells
3. **Saprophytic:** you know this! If not, go back to Module 4 and brush up on it you silly psilocybe!
4. **Neutralistic:** an interaction whose nature is unknown, i.e. we don't know what role the fungus plays in the life cycle of the plant partner

Like we said earlier, there isn't a ton of research on Endophytic Fungi. But, as more and more research is published, it's starting to appear that **within the life cycle of the fungus, its relationship to the plant host can change.**

For example, the fungus can start off as impartially neutralistic, transition into a mutualistic relationship as it supports the plant, and then once the plant becomes old and ill, transition again into an paraitic role as it starts attacking the plant, then finish it all up in a saprophytic role as it feasts on the plant's dead corpse.

This relationship is generally beneficial to the plant, however, as countless studies demonstrate that **plants colonized by Endophytic Fungi experience faster growth, healthier lives and are more resilient in the face of nematodes, Fungi, pathogenic bacteria, as well as the ever increasing toll of climate change like increased drought, heavy rain and soil pH change.**

We pay homage to Endophytic Fungi for their omnipresence, versatility, and their ability to alchemize the relationships plants have with our entire ecosystem.


## ENDOPHYTES: EARTH'S PRIMORDIAL ALCHEMISTS

Fungi are so adept at creating compounds and alkaloids, some scientists claim Endophytic Fungi are responsible for almost all of the secondary metabolite production of plants.

So, it seems natural that we should try to understand how these endophytic wizard-like Fungi help support their plant friends. Remember Ergot? *Claviceps purpurea?* The Family of *Clavicipitaceae?*

*Holy shit, this word! Do I really have to say this thing all the time? From now on you are known as Clavis!*

Okay. So, our endophytic fungal friends Clavis are pretty well studied for their alchemical abilities, especially their ability to create secondary metabolites.

Secondary metabolites, if you didn't know, are **metabolites produced within a plant that are not directly involved in the normal growth, development, or reproduction of the plant.**

**Lately, a lot of research has begun to suggest that most if not all of these secondary metabolites are actually the by-product of Endophytic Fungi.**

Endophytic Fungi can have several different motivations to create these compounds, like:

1. To get absolutely fucked up yewwwwww!!
2. To fight off other microorganisms inhabiting the same plant
3. To fight off organisms trying to attack the host plant
4. To support the plant host in its resilience against abiotic (non-living) stressors

## ENDOPHYTIC? MORE LIKE ENDOLITIC

Wait, this isn't just a joke in the script?
To be fair, Endophytic Fungi are probably not getting fucked up. But nobody knows, so we might as well use our imagination. They are, after all, responsible for producing **psilocybin, psilocin, beaosyctin and alcohol.**

Ergot fungus
(growing on wheat)

Then consider the fact that **LSD (AKA acid) is derived from Ergot**—a fungus that grows on rye and other grasses like wheat— and recent studies have found that **most, if not all of the LSA in morning glory is produced by endophytic Fungi.**

Ipomoea purpurea
(Morning Glory)

But don't take it from me. Take it from Dr. James White, one of the world's experts in Endophytic Fungi (whose work most of the material in this module is sourced), who said the following:

> ***"With plant alkaloids, I suspect the endophyte***...*Most known plant defensive molecules are not primary gene products, but are the end products of complex biosynthetic pathways."*

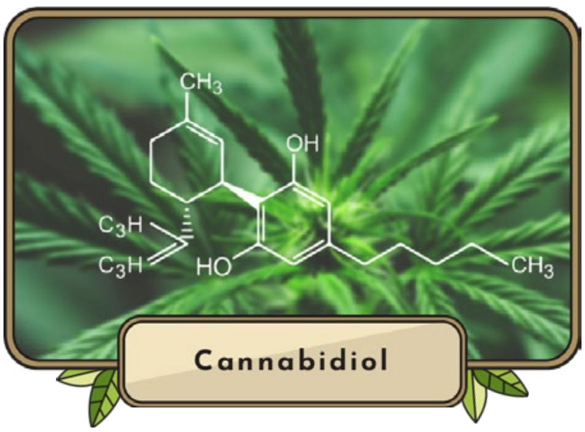
Dr. James White

# 6.3 ENDOPHYTIC FUNGI

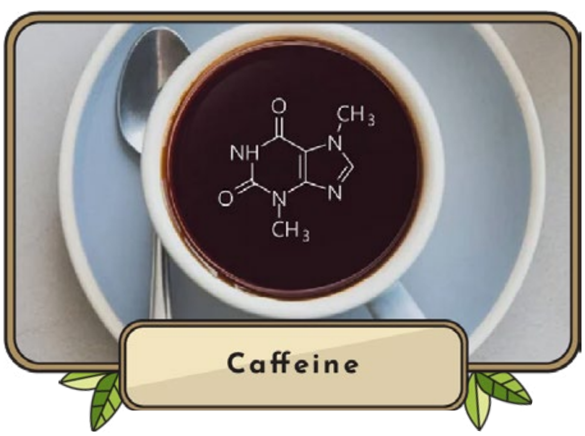
**Perhaps the secondary metabolites produced in plants actually have a fungal factory producing them.** Many scientists are starting to argue in support of this theory.

And guess what? We love some of our favorite plants because of their secondary metabolites, including compounds like Cannabidiol and Caffeine.

It's very possible that our favorite substances have secretly been produced by the hidden alchemists of the natural world, Endophytic Fungi!




Cannabidiol




Caffeine

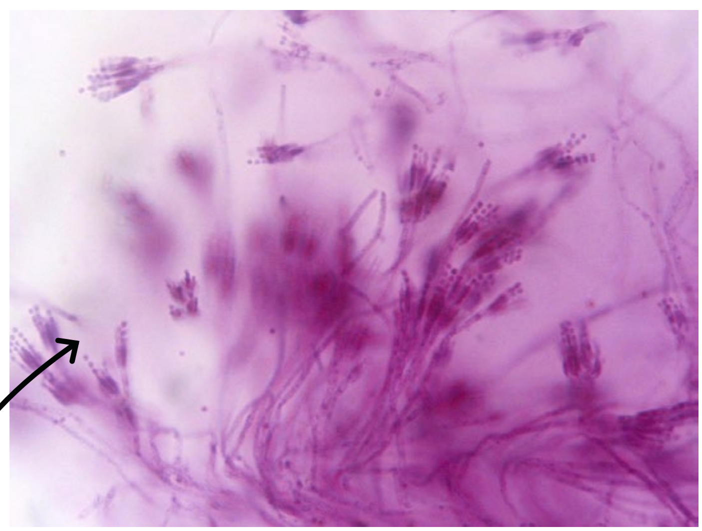
## THIS PLANT(ET) AIN'T BIG ENOUGH FOR THE TWO OF US

For endophytes, **the host plant is their world and their home.** And much like humans, endophytes protect and fight for territory within their domain.

To this end, **they use tools very similar to those used by saprophytic Fungi** in their fight for food:

Biochemical warfare.

Secondary metabolites created by endophytic Fungi can be used to fight off other Endophytic Fungi and bacteria living within the host plant's cells. Several studies in vitro (AKA on a petri dish) have found that **fungal and bacterial endophytes grown together both produce enzymes that show toxicity towards their endophytic neighbor.**



Suffice to say, it's not all rainbows and butterflies under the microscopic plant roof.

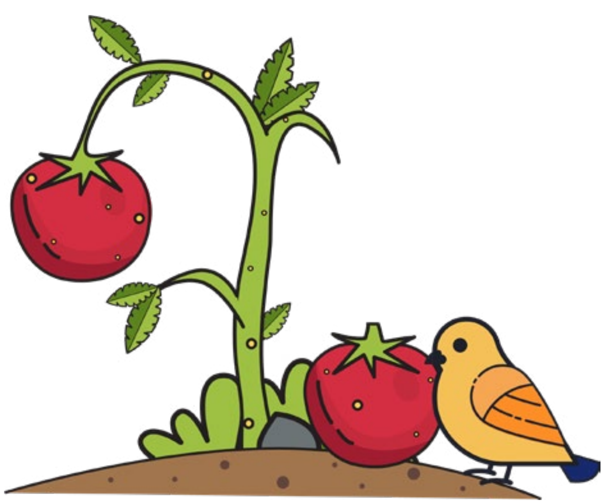
The most famous endophyte genus belongs to ***Penicillium,*** well known as the first antibiotic ever discovered and for saving millions of people's lives since that discovery in 1928 by Alexander Flemming.

But wait, aren't *Penicillium* molds and aren't molds saprophytes? Yes! But Fungi are adaptive as hell and will create their own success.

Think like a fungus for a second. You are Penicillium, hanging out in a healthy plant. The plant lets you do your thing. You help it out. It helps you out.

If your home is in a fruitmaking plant, say a tomato, and the tomato drops, boom, you have a head start on all the other saprophytes. How? Because you're already in the fruit!

And if you've made your way into the seeds and the fruit gets eaten, you'll be part of the birth of the next generation.



But now let's imagine that instead of a healthy plant bearing fruit, the plant's immune system is compromised. Well now you're in danger, too. So maybe you want to start attacking your host.

Why?

Because it's not in the endophytes best interest to try to support an unhealthy, dying host.

**Some scientists believe certain endophytes have such a profound understanding of their hosts that they might even know how long the plant will live.** They've come to this conclusion after observing that the longer the lifespan of the plant, the more protective the secondary metabolites the endophyte seems to make.

Whether short lived or long lived, at some point the host will die and Endophytic Fungi like *Penicillium*, since they are present, active and ready to eat the recently deceased delicious plant matter, will have a head start.

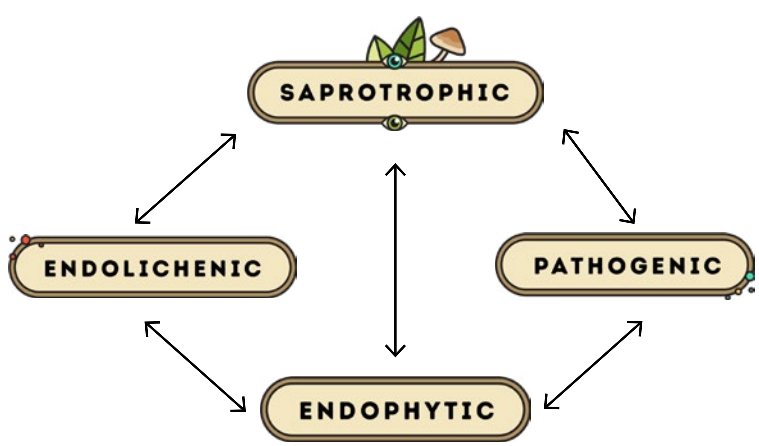
Now that's thinking ahead!

In the game of life and death, Fungi seem to be leagues ahead of any other organism.

When you start thinking like a fungus, it makes a lot of sense to shift between the different relationships of neutralistic, mutualistic, antagonistic and saprotrophic throughout the life cycle of the plant.

And this adaptiveness seems to be a winning strategy. ***Penicillium* and other Fungi that move between endophytic and saprotrophic, like those of the genus *Xylaria,* are found in huge numbers everywhere in the world!**

By protecting the plant during its lifecycle and supplying in-house antibiotics like Penicillium does for its hosts, **Endophytic Fungi help the plant to grow to maturation.** This, in turn, means more food for fungi like *Penicillium*, which transforms into a saprotroph when their host plant dies, or a longer life for those endophytes that keep it simple and never change.




## GET THE FUNG(I) OFF ME!

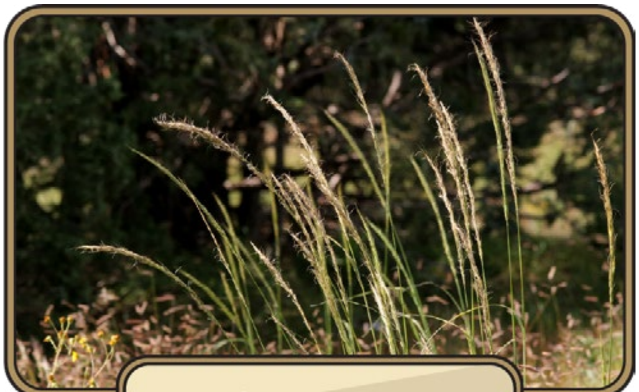
The most well studied of these microscopic alchemists are the Endophytic Fungi known as Clavicepealean, or as we like to call them, Clavis. Clavis is really really good at producing alkaloids known as mycotoxins.

These mycotoxins protect the host plant from potential invaders like:

- Insects
- Mammals
- Nematodes
- Other Fungi!

The **most famous mycotoxin may be the ergot alkaloids found in *Claviceps purpurea,*** which are toxic to most mammals and insects. By creating these mycotoxins while living within the plant, Clavis ensures that its host isn't consumed by grazers like horses, cattle or humans!

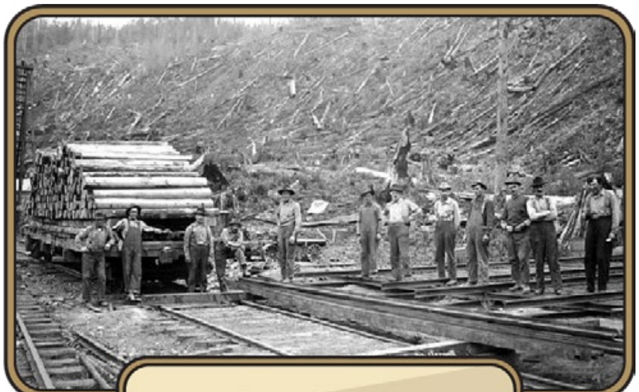
**"Sleepy" or "drunken grass"** is also caused by a fungus that belongs to the Clavis group via the production of ergot alkaloids by *Epichloë coenophiala*. As the name suggests, **this alkaloid turns animals who graze on the grass into very sleepy animals.**



Sleepy grass

"Sleepy grass" had an impact on the relationship between Native Americans and Colonizing Europeans since Native Americans had a more profound understanding of their land and knew exactly where the sleepy grass grew. As a result, they utilized this knowledge for offensive and defensive purposes.

Legend has it that five railroad workers from New Mexico were killed by Native Americans in 1854 after the railroad workers allowed their horses to graze on "sleepy grass" the night before an ambush. The next morning, under attack, the workers jumped on their horses to escape only to find that their horses were frozen in place. Without the chance for a getaway, the workers met a quick demise.



Railroad workers

Of course, the fungus and its host probably didn't create these alkaloids to help Native Americans fight the colonizers. Rather, it was likely **to cause grazing animals to think twice before munching on grass with a similar smell or taste as the grass that had knocked it out before**. Just like most other wild things, grass and their microscopic endophytic hitchhikers aren't too fond of being eaten.

But these ergot compounds don't just attack horses and other mammals. In fact, **most Endophytic Fungi belonging to Clavis primarily produce compounds to repel insects.**

**Clavis probably evolved from an entomopathogenic ancestor** and figured out that since their prey mainly eat plants, they might as well ambush them from within their food. Now that's fung-ing genius!

Over time, they likely evolved into plant symbionts, and as we have seen with ergot or claviceps purpurea, even plant pathogens.

This isn't a new relationship, either. **Scientists recently found grass preserved in Amber dating back about 100 million years that was colonized with a fungus very similar to the Clavis we know today.**

Grass preserved in Amber
Colonized with a fungus • 100mil yrs old

Aside from creating alkaloids to simply prevent the endophyte and its host from being eaten, **in some cases it appears the endophyte actually receives a reward from its plant partner.** And just like in Mycorrhizal connections, **the plant sometimes lends its sugar to the endophyte which can then be used to create more insect-repelling alkaloids.**

There are some really hectic calculations in the scientific literature that assess the cost-benefit for the plant. But we'll keep it simple here:

***Not being eaten = More leaves***

***More leaves = More photosynthesis***

***More photosynthesis = More sugar***

***More sugar = More nutrients***

***More nutrients = Better health***

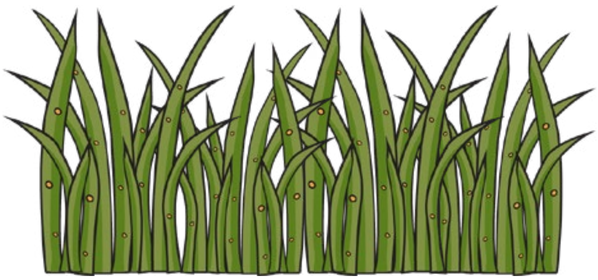
But better health for the plant isn't just a result of avoiding being eaten. Like a built-in vitamin factory, **the endophyte can also sometimes produce compounds that help improve the vigor of its host.**

## AN ENDOPHYTIC SOLUTION TO END OUR CHEMICAL ROMANCE

By supplying compounds to plants that increase the growth of their root hairs, **Clavis can increase a plant partner's resistance to drought.**

For example, tall fescue grass inhabited by *E. coenophiala,* an endophyte, has a greater potential for growth in the presence of low soil moisture levels, making the grass more drought resistant than if it was grown without this endophyte.

In some cases, **Clavis can even enhance the plant's ability to rid itself of toxic compounds** in its own cells by increasing the sweat rate through its pores, known as exudation.



Really, all across the board scientists have found that **plants that work with endophytic fungi show greater resistance to abiotic stressors like pH, ultraviolet radiation, drought, and pollution.**

In our current food production system, we often opt for the chemical approach, which we're learning is causing destruction to our soil and potentially poisoning our food.

But these hidden endophytic alchemists may harness the secrets to save the **soil and crops** and improve human health.

The more technology evolves, the more opportunities we'll have to face our problems with natural solutions. Currently, most pesticides used across the world are artificial and pollute our environment. By teaming up with Endophytic Fungi, we may find solutions to agricultural issues with much less collateral damage.

Aside from their omnipresence, endophytes from the genus *Penicillium* are responsible for some 280 compounds exhibiting **antimicrobial, anticancer, antiviral, antioxidant, anti-inflammatory, antiparasitic, immunosuppressant, antidiabetic, anti-obesity, antifibrotic, neuroprotective, and insecticidal effects.**

***And that's just one genus!***

**Taxus brevifolia**
(Pacific yew tree)

Axol (paclitaxol), a complex diterpene alkaloid produced by endophyte *Metarhizium anisopliae* in the bark of the Pacific Yew tree, is one of the most promising natural anticancer drugs developed to date.

**Nothapodytes foetida**
(Small evergreen tree)

Camptothecin, an endophyte in the small evergreen tree *Nothapodytes foetida*, is known to have cytotoxic and antifungal properties.

We could keep throwing out weird names with wild effects but you probably get the point we've been making all lesson: **Endophytic Fungi are the hidden alchemists of the natural world.**

Remember, these concoctions and alkaloids aren't just good for humans. **They're vital in the support of plants, can act as biocatalysts, plant growth promoters, phytoremediators and enzyme producers.**

In short, we know that teaming up with endophytes can give us:

- **Healthier plants**
- **Larger fruits**
- **Faster growth**
- **Increased resiliency in the face of pathogens**
- **More nutrients**

All this without using pesticides or fertilizers that kill healthy soil!

**What's the one thing preventing us from exploring the immeasurably vast potential of Endophytic Fungi?**

**Funding for research** to find and isolate the most potent endophytic allies, and to develop products that can get these fungal allies into farmer's hands.

**The research and development to produce just one genetically modified (GMOs) organism is around $138 million USD.** And currently, there are hundreds if not thousands of these attempts at producing GMO crops happening around the world.

Imagine what we could achieve if we instead invested that money into the study of Endophytic Fungi.

So, why aren't we? For that answer, history buff Jasper needs to come out for a moment.

One of the contemporary theories on how human history is shaped is known as the "trends and forces theory." In a nutshell, **it argues that ideas that catch on and influence a large part of the decision making population are what shape the trajectory of human history.**

Right now, the trend and the force are GMOs. Billions of dollars are going towards this trend because it fits within the framework of capitalism. An organization spends a lot of money developing a new plant so they can have a patent and make more money.

Working with systems that already exist in nature, like endophytes, is a lot harder to patent and recoup your investment money from.

In other words, we know these natural solutions exist but our current system isn't built for them; it's built for creating GMO crops that, for example, STOP producing seeds so farmers have to buy the seeds from Monsanto.

But fret not. Knowledge is power!

And with this module, we hopefully shed some light and cultivated some excitement in you about these hidden alchemists of the natural world:

## ENDOPHYTIC FUNGI!

Tell your friends, family, hell, anyone with a listening ear about them! That's how we shape the future. You never know what intellectual spore might land in the right ear, germinate, and grow into the new trend.

Thank you so much for staying with us through this heady module. It was incredibly difficult but oh so fun to tell a vibrant, engaging story on these vital organisms.

Of course, we've only just scratched the surface. If you're thirsting for more, take a look at our resources below for more reading material.

And don't forget to leave any comments and questions you have in the discussion box.

We'll catch you in the next module, one we're sure you're really going to *like...*

**The Symbiotic Lives of Lichen!**

# 6.5 REFERENCES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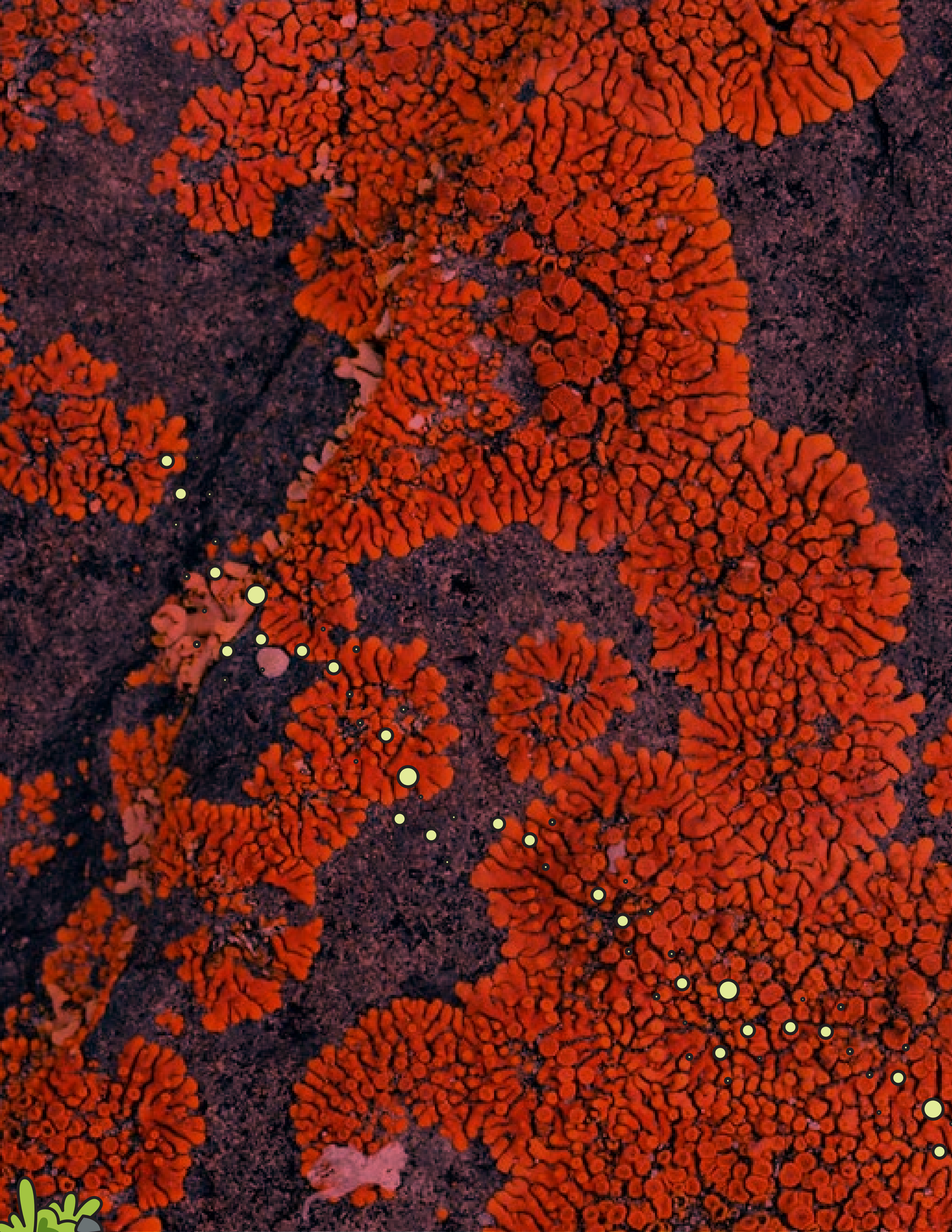


MODULE

7

# THE SYMBIOTIC LIVES OF LICHEN

**Xanthoria elegans**
(Elegant sunburst lichen)

**Letharia vulpina**
(Wolf lichen)

**Igneoplaca ignea**

## THE SYMBIOTIC LIVES OF LICHEN

How do you like your lichen?

Bright orange like ***Xanthoria elegans****?*

Neon green like the Wolf lichen *(**Letharia vulpina**)?*

Fire red like ***Igneoplaca ignea****?*

Well, however you like your lichen, we're glad you're here.

Though you've heard a bit about Lichen already in this course, they're just so damn cool that we decided we need to spend an entire module diving into them.

What's so awesome about them?

For one, **Lichens are the ultimate representation of the interconnectedness of nature.** The Photobiont, Mycobiont or the Endolichenic fungi (yea, that's a real term) can't survive without each other as life partners.

This codependency makes it incredibly hard to study Lichens in vitro (petri dishes), meaning **they've been shrouded in relative mystery for a long time**. Plus, their favorite habitats – places like rocks, tundras and other barren areas – aren't the best locations for producing high-quality fossils.

As a result, Lichens have been largely overlooked by science. **Yet Lichen have played an enormous role in the evolution of our planet.**

This starts to make sense when you consider that **they've been hanging out on Planet Earth for up to 635 million years,** which is not coincidentally around the same time when marine life first made the leap to terrestrial life.

Plus, did we mention yet that **Lichens are *extremophiles,* meaning they can survive in extreme conditions most other organisms cannot?**

One of the toughest lichens on the planet is the bright orange lichen we mentioned earlier, *Xanthoria elegans.* Not only is it beautiful; it's also really hard to kill. In fact, **more than 71% of *Xanthoria elegans* specimens tested in the freezing cold and scorching heat, UV radiation-laden vacuum of space survived for more than 1.5 years, bare naked!**

That's not all, either.

# 7.1 THE SYMBIOTIC LIVES OF LICHEN

*Xanthoria elegans* can also survive a pressure of at least 50 Gigapascal, which means **it can survive asteroid impacts so strong they actually shoot up parts of the earth's crust into space!**

This resiliency is one of the leading arguments behind the **Panspermia theory,** the idea that **life on earth originated from outer space** and maybe even was caused by some rogue lichen flying through space for eons until it hit our fertile planet and knocked her up, serving as the catalyst for all the life we see around us today.

Have we got you really liking lichens now? We thought so. But we're not done yet.

Fast forward to today, and **Lichens are estimated to cover up to 8% of the total landmass on Earth!**

**Rhizocarpon geographicum**
(Map lichen)

**The oldest known organism on this earth is a lichen,** known as the Map lichen *(Rhizocarpon geographicum)*. Scientists dated a single specimen of this lichen species to about **8,600 years old!**

Alright, to recap, **lichen can survive in space on their own, may be the seed that started life on earth, helped marine life jump to land life 600+ million years ago, and seemingly live forever.**

But we're not done yet. **Lichen can thrive off of nothing but sunlight and condensated air humidity,** and like the endophytes we learned about last module, **lichens also have alchemical superpowers capable of dissolving rocks.** Wait, what?

That's right, lichen can create compounds like **oxalic acid,** which effectively dissolves minerals straight from rocks.

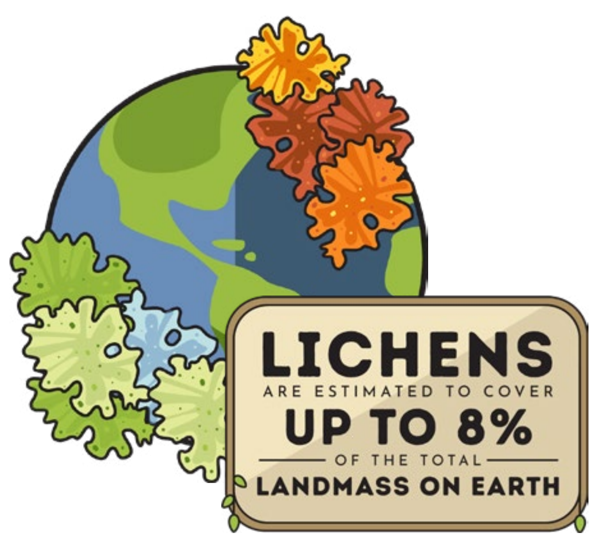
By now, you're probably thinking lichen is practically indestructible. Yet you'd be wrong.

In reality, **lichen can be quite a sensitive little organism.**

For example, **the presence of lichen is often used as an indicator for good air quality**. This is because lichen are adept at absorbing pollutants like heavy metals and carbon from the air (scientists have been working with lichen to biomonitor air pollution in Europe for over 20 years!). But this also means that when pollutants get too high, lichens simply die.

This hasn't prevented the speciation of lichens, however, with **around 20,000 species of lichenized organisms** currently known and likely thousands yet to be discovered!

Nor has it affected their spread. **Lichens can be found almost everywhere in the world, from the polar region to tropical rainforests, to deserts, and even in freshwater lakes and rivers!**




XANTHORIA PARIETINA
LICHEN
HAVE OCCUPIED
PLANET EARTH
FOR UP TO
635 MILLION
YEARS

# 7.2 THE SYMBIOTIC LIVES OF LICHEN

Now is a good time to pick the bits of brain from your mind explosion off the ground and put yourself back together again.

Consider this module a love letter to lichen and a tumble down the unfathomably deep rabbit hole—almost as deep as the fungal rabbit hole itself—of lichenology.

Apologies in advance if we missed some of your favorite lichen learnings (if we did, write to us and let us know so we can continue the learning!)

We can only get so liquored up on lichen in one module.

### IN THIS MODULE, YOU'LL LEARN:

- What are Lichens?
- How Lichen Grows
- The Possibilities of Panspermia and Lithopanspermia

## THE MANY LAYERS OF LICHEN

When you look at a lichen, you're actually looking at multiple life forms merged into one of nature's finest collaborations.

**A lichen is an ancient fusion of a Mycobiont, Photobiont, and a special and integral player, an Endolichenic Fungi,** which only recently was discovered to be the third vital player in this game of lichen life.

Not surprisingly, little is known about these microscopic players (esp. Endolichenic Fungi).

One reason: **lichens are incredibly hard to study in vitro due to their impressively slow growth rate, often only around 1 millimeter per year!**

But let's get the official definition here to start understanding these Fungal Federation centers.

*"A lichen is* ***a composite organism that emerges from algae or cyanobacteria living among the filaments (hyphae) of the fungi in a mutually beneficial symbiotic relationship.*** *The fungi benefit from the carbohydrates produced by the algae or cyanobacteria via photosynthesis."*

So we have the **fungus,**
AKA the **Mycobiont.**

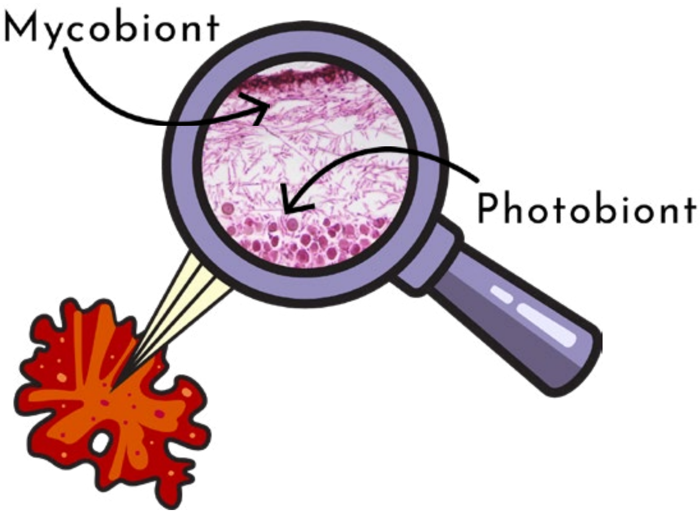
We have the **algae or cyanobacteria**,
AKA the **Photobiont.**

And we have the invisible fungal players,
AKA the **Endolichenic Fungi.**

**The body of the lichen**, where these three players reaside, **is known as the thallus.**

**About 95% of the thallus is the mycobiont.**

## 7.2 THE SYMBIOTIC LIVES OF LICHEN




The clearly dominant abundance of fungal matter in the lichen's body mass caused some scientists to claim the Fungi are simply farming, or even 'enslaving', the photobiont.

But this is not the case.

Although clearly dwarfed by the mycobiont in mass, the photobiont has just as much say in the whole thallus-formation ordeal. After all, 600 million years is plenty of time for the photobiont to figure out how to optimize its photosynthetic output, which in turn serves the whole Lichen organism.

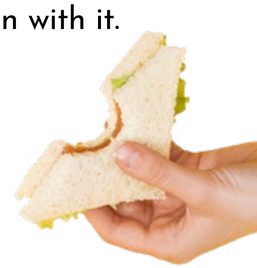
Since lichens' bodies are composed of up to 95% fungi, what sets them apart from other fungi? Really, it comes down to **lichens' ability to survive ridiculously harsh conditions.**

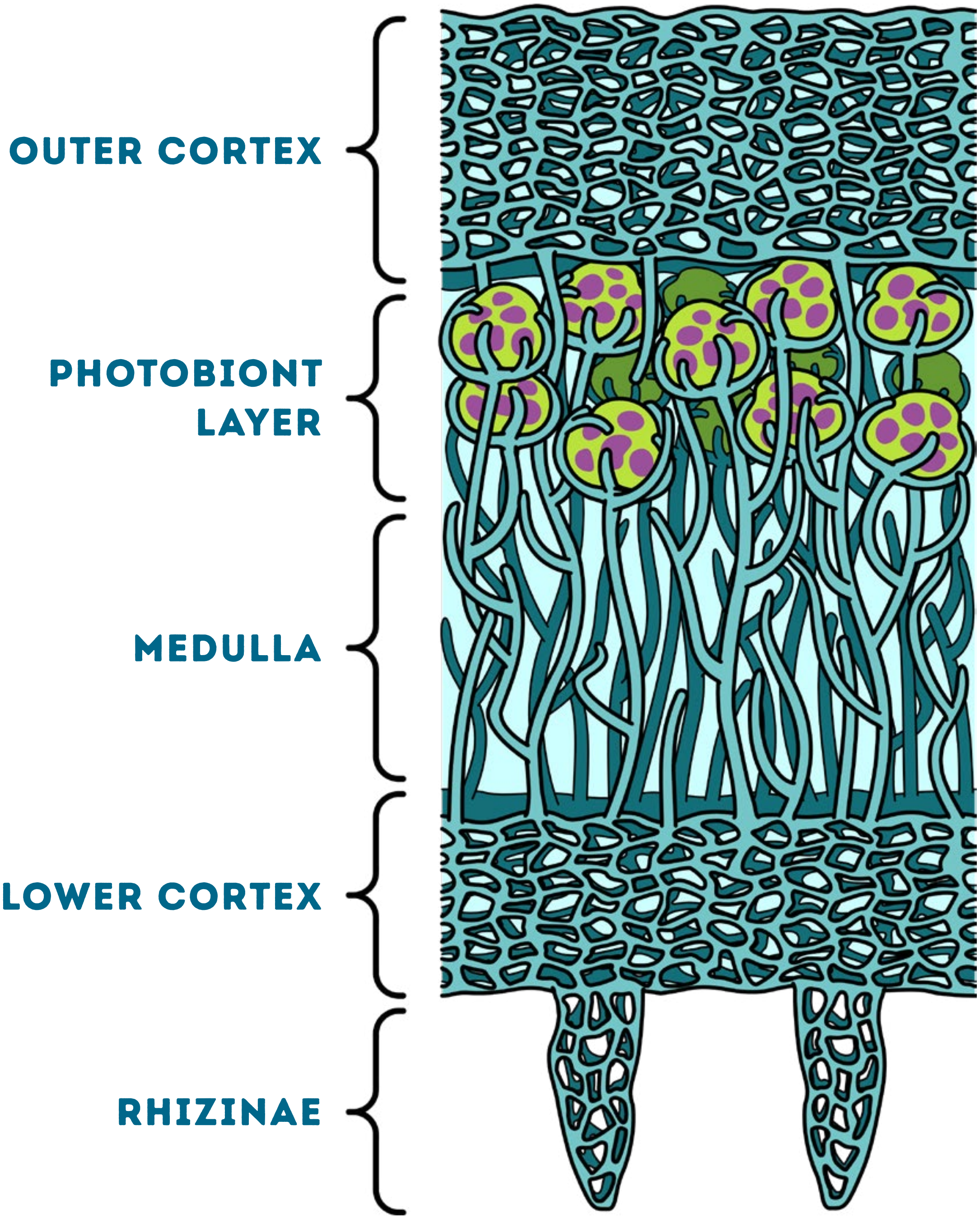
Most fungi live in the soil or within decaying matter, only daring to survive the conditions of Earth's surface for brief periods when it's time to reproduce via the production of fruiting bodies.

But lichens are able to withstand conditions WAY more harsh than just our earth's surface, via the **four carefully constructed layers that make up the thallus:**

1. The **OUTER CORTEX,** composed of **layers of tightly packed hyphae (mycobiont)** that contain pigments and **acts like a solar filter.**
2. The **PHOTOBIONT LAYER, where the algae or cyanobacteria lives** and the magic of **photosynthesis happens.**
3. The **MEDULLA,** composed of **a layer of hydrophobic, interwoven, fluffy hyphae (mycobiont)** that **can store an incredible amount of water and air.**
4. The **LOWER CORTEX,** almost identical in structure to the outer cortex (mycobiont) but with **the extra task of creating adhesive rhizines to keep the lichen affixed to its home.**

Think of lichens as a beautiful symbiotic sandwich, with the best parts in the middle. Of course, it wouldn't be a sandwich without the bread, nor a lichen without the cortexes. A weird analogy, I guess, but let's eat, I mean, run with it.






LICHEN STRUCTURE

Since the mycobiont constitutes most of the body of the lichen, **science identifies and classifies the different species of lichen based on the genetics of the mycobiont.**

**Over 98% of all lichen belong to the Ascomycota phylum,** with lichens comprising 42% of the entire Ascomycota phylum.

A bit dated but still relevant 2001 paper titled "Major fungal lineages are derived from lichen symbiotic ancestors" claims that **one-fifth of all known fungal species lichenize,** that **lichens have evolved on at least 5 different occasions,** and that some major lineages like *Aspergillus* and *Penicillium* have a lichenized origin story.

But let's not get carried away with solely focusing on the fungal part of lichens; **almost 90% of known lichens rely on the help of algae to sustain themselves.**

These lichens that team up with algae are known as **chlorolichens**, named after green algae belonging to the chlorophytes. Of these chlorolichens, **about 20% of all lichens work together with a single-celled alga genus known as *Trebouxia.***

As we learned in previous modules, **creating one's own food in the natural world is known as autotrophy**, or self nourishment.

It's pretty interesting that algae are self-sustaining autotrophs that can also support the growth of lichens.


But algae aren't the only autotrophs helping to form our favorite fungal federation stations. **Cyanobacteria serve as photobionts in about 8% of lichens.** These lichens are known as **Cyanolichens**. Finally, some names you might actually remember!!


Cyanolichen

Cyanolichens are unique because **they're capable of capturing nitrogen from the air** (AKA nitrogen-fixing), **which helps increase their photosynthetic output and growth rate.** You can identify them by their characteristic black-gray color!

Hundreds of different species of algae and cyanobacteria have been identified as photobionts for lichen but so far, none of the photobionts studied have been shown to survive only with their mycobiont.

**In other words, algae and cyanobacteria can survive outside of the lichen relationship while the mycobiont cannot.**

And get this: **one algae species can function as a photobiont for over a hundred different species of lichen!**

**1/5** OF ALL KNOWN **FUNGAL SPECIES LICHENIZE**

# THE SYMBIOTIC LIVES OF LICHEN

Corie Bidgood @corie__bee

Now you're probably starting to understand why scientists think the mycobiont is "farming" the photobiont. Without it, the mycobiont wouldn't even exist.

Under this perspective, the fungus started farming photobionts by building a greenhouse (the outer and lower cortex) that was just too hard to resist for the algae. So the algae moved in and found protection from drought and the harsh rays of the deadly laser Sun. Once comfortably nested in the greenhouse, there was no escape and the mycobiont began to capitalize on the photosynthetic sugars of the photobiont.

But when we approach Lichens as an **ecosystem,** this idea of fungi-farmed algae flies out the window pretty fast.

We already mentioned how **the photobiont is just as responsible for the structure of the fungal space station as the mycobiont.** Well what if we told you that **the photobiont is also ingeniously using the mycobiont for capturing water from the air via crystallization?**

In fresh water, single-celled algae encounter tons of competition or predation by plankton. But by living in the greenhouse garden club of the lichen-sphere, the algae find their own haven of tranquility.

Tripartite lichen

And the tripartite lichen, well, they're the royalty of this tranquil haven.

Tripartite lichen contain both cyanobacteria and algae. The cyanobacteria are capable of nitrogen fixing straight from the air, which as we already learned, increases algae growth and photosynthesis.

But what about chlorolichen? How do they obtain their nitrogen?

Though plants can obtain nitrogen from the soil, they can't from rocks. But have no fear, the mycobiont is here!

By secreting organic acids like oxalic acid, **the mycobiont can extract nitrogen and other minerals, supplying the photobiont/algae with that oh-so-important nitrogen.**

**This mineral mining also has another wildly important result:** it speeds up the erosion process of rocks, thereby **creating more soil.**

**MYCOBIONT**
**EXTRACTS NUTRIENTS**
FROM
**MINERAL SURFACE**
BY SECRETING
**OXALIC ACID**

Alright, alright, alright, so we now understand the functions of the cortex and the photobiont pretty well. But what about this medusa thing?

Uhg, it's the medulla, idiot.

Ok smartass, what's this medulla about?

As we defined earlier, **the medulla is a layer of hydrophobic, interwoven, fluffy hyphae that can store an incredible amount of water and air.**

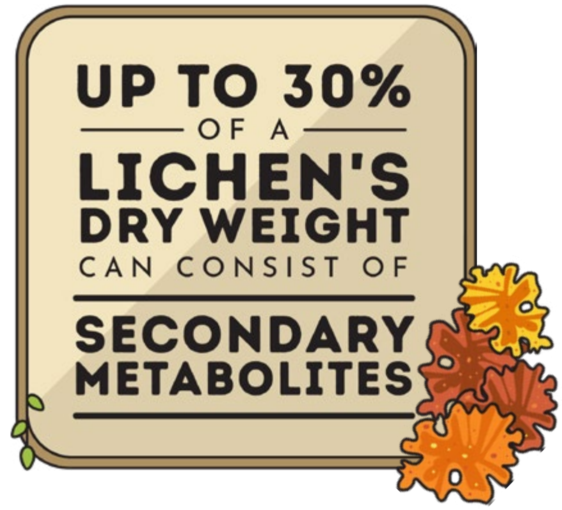

Fog
(QFDEEM images)

Recent Quick-freeze deep-etch electron microscopy (QFDEEM) images *(WTF was that?)* have shown that the medullary space is filled with an etch-resistant liquid phase that scientists call fog. Okay, we didn't just lose you. We lost ourselves, too.

Save us, sandwich metaphor!

If the lichen is a sandwich, the bread is the upper and lower cortex, the medulla is a thick layer of strawberry jam, and the photobiont is a layer of chocolate sprinkles.

Chocolate sprinkles on bread is totally how we roll in the Netherlands, hagelslag op je hoofd jonge!




Ok, back to the sandwich analogy:

This layer of strawberry jam, **the medulla, or fog, is a liquid phase that holds high concentrations of both water and oxygen.** It also **acts as the substrate for the mycobiont's hyphae to grow throughout and do that benevolent alchemical thang producing secondary metabolites like oxalic acid** and so much more.

We can't really stress the importance of these secondary metabolites enough: **Lichens are so good at producing them that up to 30% of a lichen's dry weight can consist of them.**

And these metabolites aren't just good for the lichen. They're also good for us.

**Of the 800 or so secondary metabolites we've studied in lichens**, they've demonstrated **antimicrobial, antioxidant, antiviral, anticancer, antigenotoxic, anti-inflammatory** and many other pharmacologically active properties.

This alchemical lab in the medulla fog reflects its environment, with the chemistry it produces reflecting what's occurring in the big bad world outside the cortex's safe shell. For example, the intensity of the environment's UV radiation will dictate whether more or less pigment needs to be created in the cortex to protect the photobiont.

Finally, this medulla fog is where the lichen fungal federation star center really shines as the epicenter of organic symbiotic life. Within this layer, a stunning diversity of bacteria, endolichenic fungi and yeast can be found. It's worth noting that these hugely understudied Endolichenic fungi seem to generally be related to Endophytic fungi we learned about last module. And like Endophytic fungi, Endolichenic fungi are slowly being understood as the hidden alchemists of the lichen-sphere.

So, are you liking the lichen yet?

We hope so. Now, let's dive into all the different shapes these alien life centers can embody.

## IT'S MORPHIN' TIME!

As intimidating as the word **Morphology** may sound, it's actually just a fancy name for **the physical form of an organism.**

As we learned earlier, **lichens are believed to have evolved independently from each other on multiple different occasions.** It's no surprise then that there are such radically different looking lichens!

**The three most common lichen growth forms (i.e. lichen morphologies) are:**

1. **CRUSTOSE**
2. **FOLIOSE**
3. **FRUTICOSE**

While these are the three most common, there are tons of other ways for lichens to weave their shapes. **Here are some of our favorites.**

- **BYSSOID,** named after the Greek word Byssos, meaning **"linen cloth of very fine threads,"** includes lichens that look like linen (say that *"lichens that look like linen"* 10x fast)

- **CLADONIFORM LICHENS** are some of the coolest lichens out there. Our favorite is *Cladonia pyxidata,* or the **Pixie cup lichen.**

- **FILAMENTOUS LICHENS,** as the name suggests, are filamentous. What a great word, filamentous. Anyways, **filamentous lichens** with all their frollicking filaments **are actually woven by the algal partner (photobiont) instead of the mycobiont.**

Another one of my top 20 words in English is represented in the lichen growth forms:

- **GELATINOUS LICHEN**. Commonly known as the jelly lichen lax a cortex, **this lichen exposes the cyanobacteria photobiont to the outside world, giving it its gelatinous nature.**

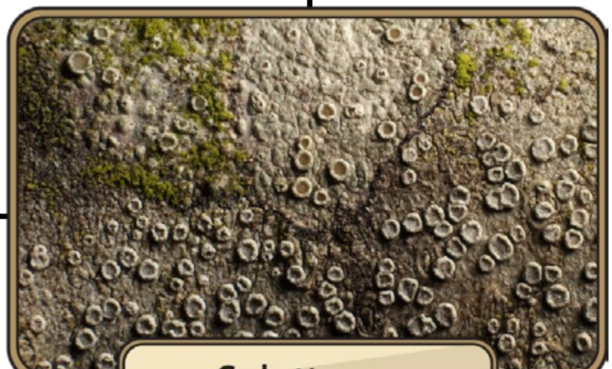
- **LEPROSE LICHEN,** just like gelatinous lichen, also figured out ways to survive **without the cortex.** It's also, strangely enough, **hydrophobic!** To stay hydrated, **this lichen acquires all its water from the humidity in the air.** This lichen is also sometimes completely covered by **soredia, a structure that lichens create to reproduce asexually.** This means that **Leprose lichen only needs a slight chunk of its main body to break off to start an entirely new lichen.**

## SOME OF OUR FAVOURITE
# LICHEN GROWTH FORMS

Byssoid

Cladoniform

Filamentous



Gelatinous

Leprose

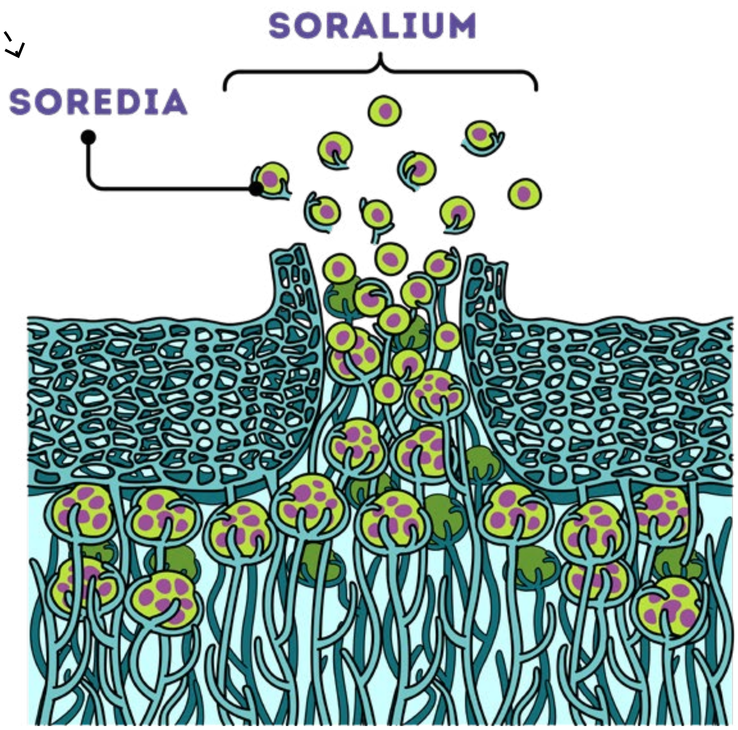
**Soredia are little balls of fungal hyphae that wrap around the photobiont.**

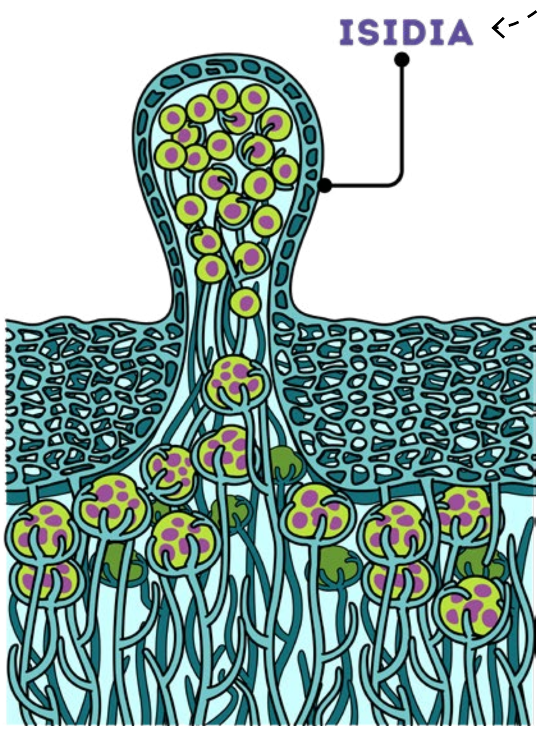
Think of them as the expedition crew of the fungal federation center we call lichens. Once released from the cortex, Soredia have all the tools at their disposal to start a whole new colony wherever they land as long as the conditions are lichen-licious.

**Isidia** have the same basic principle, but their structure is a little different. While Soredia are little balls,

**Isidia are little clubs, warts, scales or branches.**

In case it helps you remember, you can compare the Soredia and Isidia to the two main fungal groups in Dikarya, Ascomycota and the Basidiomycota. **The Sacks (Ascomycota) and the Pins (Basidiomycota) vs. the Balls (Soredia) and the Clubs (Isidia).**

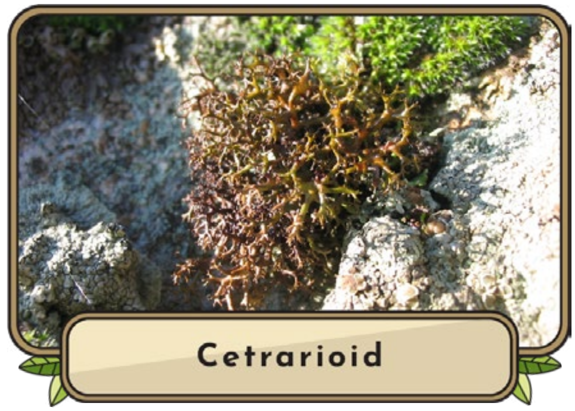


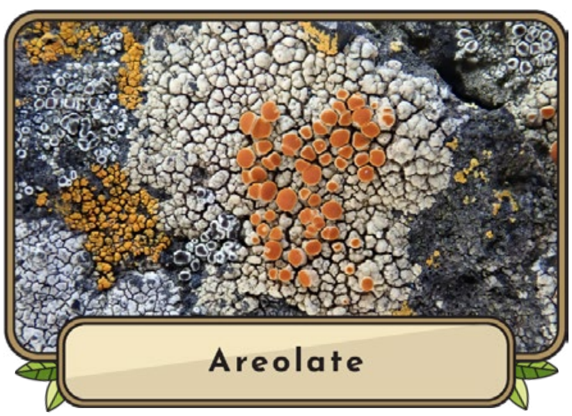



# 7.3 THE SYMBIOTIC LIVES OF LICHEN

Some lichenologists go so far as to create subgroups of morphologies which we won't go into but are just incredibly fun to pronounce so we'll just put them here for your pronunciation pleasure.

- Areolate
- Alectorioid
- Astrothelioid
- Catapyrenioid
- Cetrarioid
- Hypogymnioid
- Parmelioid
- Usneoid
- Squamulose
- Placodioid


Cetrarioid


Areolate


Alectorioid

Alright, now that we've touched on the weird and wild and wondrous, let's focus on the three most common lichen morphologies, ones that you've, whether you know it or not, probably had an interaction with in the past.

## CRUSTOSE LICHEN

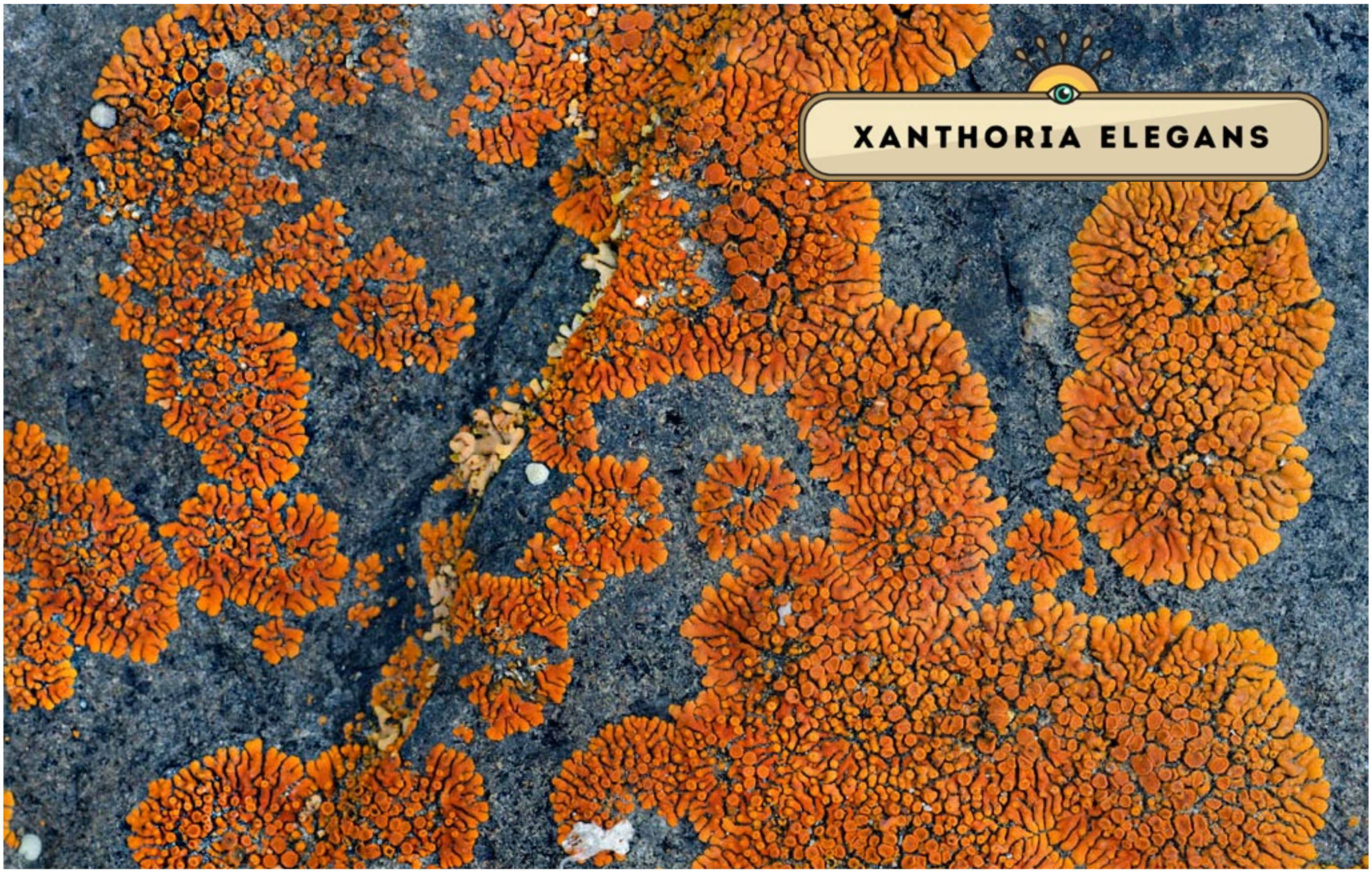
Let's venture down to Bikini Bottom for some nautical nonsense and start with the Krusty Krab, errr, we mean, Crustose lichen. Or as we like to call them: The Krusty Boiss

**Crustose lichen are some hardy sons of bitches, adhering so strongly to their substrate that it's impossible to separate them from their substrate without destroying them.**

But this kind of clinging comes in handy when you're trying to go to space!

Remember that Lichen that survived in space for 1.5 years?

***Xanthoria elegans*** **is a classic example of a Crustose lichen:** hardy, tenacious, and extremely slow growing. ***Xanthoria elegans*** **only grows 0.5mm per year!** And that's during the first 100 years of its life; it slows down even more after the first century.




**"The surface of Crustose lichens is characterized by branching cracks that periodically close in response to climatic variations such as alternate wetting and drying regimes."**

Ready for another trip down memory lane from about 20 minutes ago? Remember *Rhizocarpon geographicum*, the lichen thought to be over 8,600 years old? You guessed it… *Rhizocarpon geographicum* is an old crusty son of a bitch too.

The truth is Crustose lichen aren't just tenacious. They've also been incredibly important in creating life as we know it, **responsible for transforming all the dull rock covering our young planet into juicy soil** for the rest of life to flourish. Sure, it might have taken them millions, maybe even billions of years, but they got the job done (sound like your contractor?)

Although Crustose lichen's most important job may have already been fulfilled, that doesn't mean they're finished working their magic.

According to a paper published in 2010, Crustose lichen dominates an area in Southern China filled with soluble rocks like limestone and gypsum. Researchers claim **Crustose lichen covers up to 30% of all the rocks in exposed conditions and up to an incredible 70% in covered parts** of this location in South China.

As we witness time and again in the wild world of fungi, helping others always helps out the fungus in the long run. Crustose lichen seem to do better surrounded by trees, trees that wouldn't have the soil to dig their roots into without the work done by our crusty friends eons ago.

## FOLIOSE LICHEN

Next up we have **Foliose Lichen, AKA the Leafy Boys, AKA Rolly Polly Foilly.**

Compared to their crusty counterparts, the leaf-like **Foliose Lichen grow like weeds at a blistering Usain Bolt speed of 27mm per year!**

But these bad boy biker lichens, with all their "Ride Fast, Die Young" style, **only live for about 45 years before heading up to lichen heaven.**

They're also not nearly as inseparable from their substrate as Crustose lichen. These Foliose frolickers like to call branches, rocks, buildings, and your old rusty car home, **spreading into and attaching onto their home with tiny root like structures called Rhizines.**

Because they're chunkier and easier to peel from their home, Foliose lichen is a choice edible for tons of grazers, and at times, even (desperate) humans!

### FUN(GI) FACT

***Umbilicaria esculenta***
*(AKA the Iwatake lichen AKA Rock tripe)*
**is considered a delicacy** in Japan & Korea. **It's also medicinal, with recent studies finding that it contains polysaccharides that can inhibit the replication of HIV.**

**Umbilicaria esculenta**
(Iwatake lichen or Rock tripe)

Just like Crustose lichen, Foliose Lichen also play an important role in the erosion of rocks and creation of soil. Aside from producing oxalic acid, **Foliose lichen also penetrate tiny crevasses in rocks with their rhizines, speeding up the erosion process significantly.**

But these fast Foliose lichen are also little softies, at least when it comes to sulfur oxide, a chemical compound present in the fumes of burning fossil fuels and the chemical you probably associate with the sweet smell of a recently extinguished match. Unfortunately, **sulfur oxide reacts with the chlorophyll present in the photobiont of this lichen, eventually causing the Foliose lichen to starve.**

This is why you don't see these or other vibrant lichens in densely packed cities.

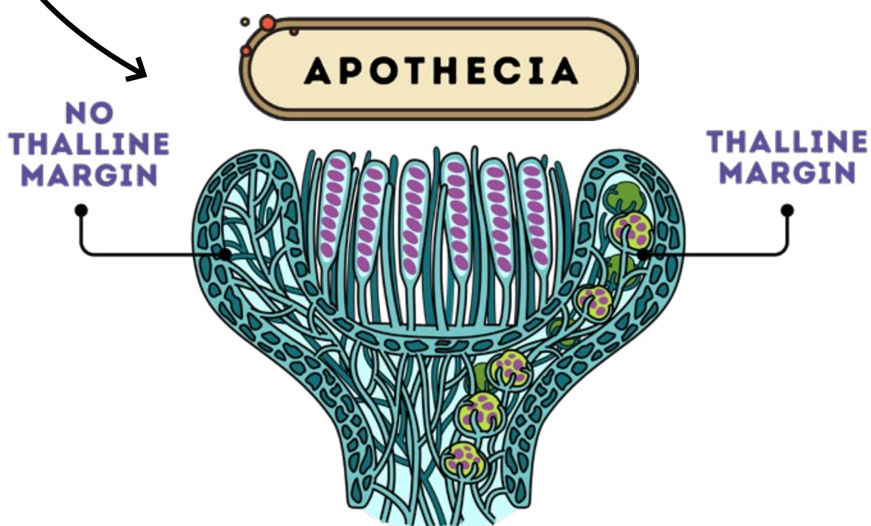
But they are abundant in lush, thriving ecosystems like in the Guatemalan Highlands of the Fungi Academy HQ!

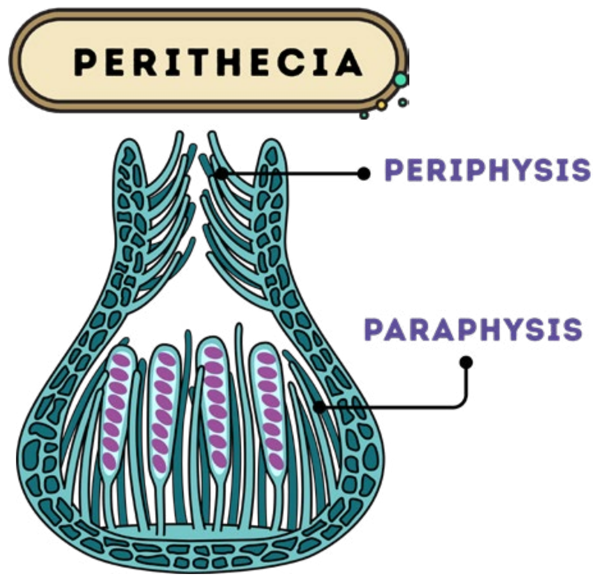
# 7.3 THE SYMBIOTIC LIVES OF LICHEN

See the tiny cups of the common green shield lichen *(Flavoparmelia spp.)* in the graphic below? They are known as the **Apothecia and are the sexual reproductive organs of most lichen.**

But Lichens are no dummies. They know that diversity is the surest way to evolutionary success. So some have chosen to produce **Perithecia** instead, which looks like this!

In the center of these **Perithecia**, you can see **little sacks filled with spores,** unique to the Ascomycota. But **these structures aren't unique to the Foliose lichen.** In fact, almost all the sexual production of lichens takes this form, including the Shrubby boys, which are up next!




Corie Bidgood @corie__bee

## FRUTICOSE LICHEN

**Fruticose lichen have a beardy, shrubby, bushy or coral-like morphology and grow at similar hyper-speed rates as the Foliose lichen** (27mm per year).

**To make the triplet complete, we got the Shrubby Boisss**

Like Crustose lichens, Fruticose lichens are also pretty tenacious, able to withstand incredibly cold temperatures and long swaths of time without water or even humidity.

**Fruticose lichen differentiate themselves from other lichens in two distinct ways:**

1. The photobiont layer grows in all directions
2. Only a tiny part of the cortex actually connects to the substrate, similar to the way a plant stem connects to the soil, making Fruticose lichen less adhesive than other lichens.

But this lack of adhesion makes Fruticose lichens perfect for interacting with the largest network on this planet: the human network.

In Lichens and People, Sylvia Duran Sharnoff notes how at least 50% of lichen have antibiotic compounds.

For example, the **Wolf lichen**, *Letharia vulpina*, **was used to poison wolves** (hence the name!) and for dyes.

Wolf lichen

**Tree moss**, or *Pseudevernia furfuracea*, **was used for embalming, preserving bread and was even incorporated into perfume!**

And herbalists might know the name **Usnea, a powerful medicine** that, as you probably guessed, is also a Fruticose lichen.

Pseudevernia furfuracea
(Tree moss lichen)

**Lichen are abundant.**
Remember, up to 8% of the total earth landmass is covered by them.

**Lichen are powerful allies.**
Life as we know it probably wouldn't be possible without lichen.

Lichen are the ultimate superhero team of single celled organisms that photosynthesize (photobiont) and a hardy, flexible alchemist (mycobiont) of the natural world.

Which brings us to our last puzzle piece to this lichen module:

SPACEEEEEE!!

## CALL ME DADDY?

Space is pretty intense, to put it lightly.

Temperatures can be scorching or freezing. Ultraviolet and cosmic radiation is everywhere. Come to think of it, radiation is basically the only thing present in the vacuum of space.

Yet, some organisms can survive the vacuum of space. The microscopic animal known as the **Tardigrade is able to survive a journey to space for 11 days** and still be alive and kicking after landing back on Earth.

Just FYI, here, you can't do that. Without a spacesuit, all the air would get sucked out of your body and you'd pass out in 15 seconds and be dead in 90.

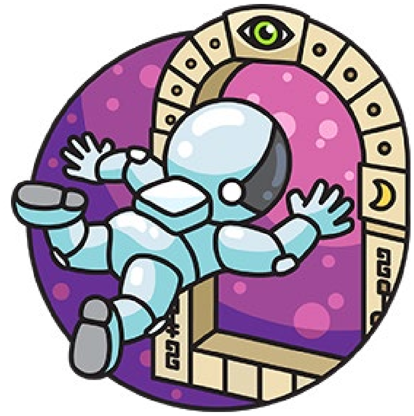
But, Tardigrades got nothing on some of the organisms that LIFE has exposed to these extreme conditions. **LIFE is the Lichen and Fungi Experiment on the International Space Station,** and mostly what they do is put things in space and see how long they can survive.

We've mentioned it a few times already, but one of the toughest lichens we know of is *Xanthoria elegans*.

And like we noted in the opener, more than **71% of specimens of this lichen species survived for more than 1.5 years bare naked in space.** Plus, *Xanthoria elegans* is **able to survive a pressure of at least 50 Gigapascal** which means **this super strong being can survive the first and second phases of the interplanetary transfer process!**

Why are we all of a sudden talking about space and interplanetary mumbo-jumbo?

Because this evidence suggests **life might not have originated on Earth at all.**



Our planet might just be a substrate inoculated by the fungi!

**This concept is called Panspermia.** Panspermia has many different philosophical approaches.


One of these theories is known as Lithopanspermia. **Lithopanspermia proposes that extremophile life forms like lichens could survive being blasted into space after their home planet was slammed with an asteroid, causing part of the crust to be shot into space after the collision.**

# 7.4 THE SYMBIOTIC LIVES OF LICHEN

After such a cataclysmic event, the fungus and its spores would find themselves flying through space on the most low-tech of space ships: a simple rock we know as an asteroid.

Of course, this asteroid could hit a planet in its solar system. But given enough velocity, it could potentially escape the orbit of its sun and roam its galaxy until one day....


It hits a young planet like Earth that's just waiting for life to flourish.

It's probably unlikely even the hardy *Xanthoria elegans* would survive such a long trip. But its spores just might.

Fungal, algal and bacterial spores are nearly indestructible. These microscopic little safes filled with DNA can easily survive space, so much so that the International Space Station is actually facing a mold problem.

But simply surviving radiation isn't enough to be an interstellar or intergalactic space traveler. You also need to simply survive for a long, long time. But fungi have that covered, too. The oldest viable spores found on Earth are 250 million years old. Let me repeat that: **the oldest spores that were successfully germinated here on earth were a staggering 250 MILLION YEARS OLD.**

So it's not too far a stretch of the imagination to envision spores sitting on a rock floating through space for infinity until they hit a planet ready to harbor life with a BAM!


Now let's imagine that the planet was Earth in its youth when it was little more than a pale blue dot of water and rock. And picture that the very first organism on Earth was in fact an alien lichen from another solar system.

Given enough time, say a couple of billion years, it's not hard to see these Lichen hitchhikers and algae shaking themselves loose from the safe haven of the licho-sphere and evolving into the first primitive animals and plants.

It's also not hard to picture the mycobiont eventually figuring out how to live on its own as it began the journey of becoming the great grandfather of all the fungal friends we are here familiarizing ourselves with.


**With recent suggestions that incredibly abundant genera like *Aspergillus* and *Penicillium* might have a lichenized origin story, this idea might be far more than just a fun thought experiment.**

And of course, let's not forget Endolichenic Fungi. Although we didn't dive very deep into these mysterious dwellers of the medulla, they wouldn't have been forgotten in this ride to earth.

In short,

**Lichen have all the tools within themselves to kickstart a thriving ecosystem on any suitable planet.**

Truthfully, we'll probably never find out the origin of life on Earth. That is, unless one day we're able to ask the lichen themselves.

That pretty much wraps up this literature on Lichens. So, one more time, are you liking the lichen yet?

Before you dive into the next module all about Fungi in the Food Chain, don't forget to leave any comments and questions you have in the discussion box.

We'll catch you next time!

Corie Bidgood @corie__bee

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MODULE

8

# FUNGI AS FOOD

# 8.1 FUNGI AS FOOD

## FUNGI AS FOOD!

We have spent the majority of this course focusing on the things our fungal friends like to eat.

But in this module, we'll explore **the crucial role fungi play as food for humans, other animals, plants and bacteria.**

Put simply, fungi are on the menu!

So get out your napkin, tuck it into your collar and join us as we learn all about **Fungivores (any organism that eats fungi as its primary food source), Mycophagy (the act of eating mushrooms or fungi)** and all sort of other weird fungi food shit!

### IN THIS MODULE, YOU'LL LEARN:

- Plants & Animals that Eat Fungi
- Plants and Animals that Cultivate Fungi
- A Brief History of Fungal Cultivation

## PLANT PIRATES, YARRR!

What better way to start this course off than with the weirdest one of the bunch....

Plants feasting on fungi!

Despite what you learned in grade school, **not all plants are autotrophs capable of producing their own sweet sugar from the sun.** But, don't consider these plants as lazy freeloaders. Think of them as **a showcase of the ancient heritage of mycorrhizal fungi, as plants that went all in on their relationship with Fungi** and completely lost all ability to photosynthesize in the process!

**FUNGIVORE**

ADJ. AN ORGANISM THAT EATS FUNGI AS THEIR PRIMARY FOOD SOURCE

**Monotropa uniflora**
(Ghost Pipe)

**Monotropes like the Ghost Pipe** *(Monotropa uniflora)* are probably the most famous example. Ghost pipes feast on their fungal allies via the mycorrhizal network and do this without giving much in return. **This parasitic relationship is known as Myco-heterotrophy.**

To be fair, some plants only partially lost their chlorophyll and ability to photosynthesize. But Ghost Pipes said ***"Fuck it, let's ride to death my fungal friend!"*** Or something like that. As a result, they sprout from the ground after their fungal-fed feast and display flamboyant (bright pink-purple) or nonexistent colors (white to clear) through their entire life cycle.

Besides the eye-striking *Monotropes*, there are the *Triuridaceae*, *Cryptothallus spp.* and some species of Orchids which have also said *"Bye Felicia"* to their chlorophyll and now spend their time sucking sweet nutrients from Mycorrhizal networks.

Triuridaceae

Cryptothallus

**230 SPECIES OF MYCO-HETEROTROPHIC PLANTS ON EARTH**

In total, **about 230 species of myco-heterotrophic plants roam the Earth to our knowledge, and some evidence suggests they have evolved independently from each other at least five different times,** with five different plant genera deciding *"It's a mycorrhizal pirate's life for me."*

So, how do they go about this looting?

**Myco-heterotrophic plants tap into the mycorrhizal networks to take sugars and nutrients that the fungi receive from other plants.**

Theoretically, you could argue these plants actually just parasitize other plants using the mycorrhizal networks as their pirate ship, with the parasitized plants as the metaphorical sad lot of merchants being looted.

The lives of these pirate plants is still very much a mystery to us. For example, we don't know how they circumvent the standard mycorrhizal tax, so to speak, and we can only speculate how the plant is taking the sugars from the network.

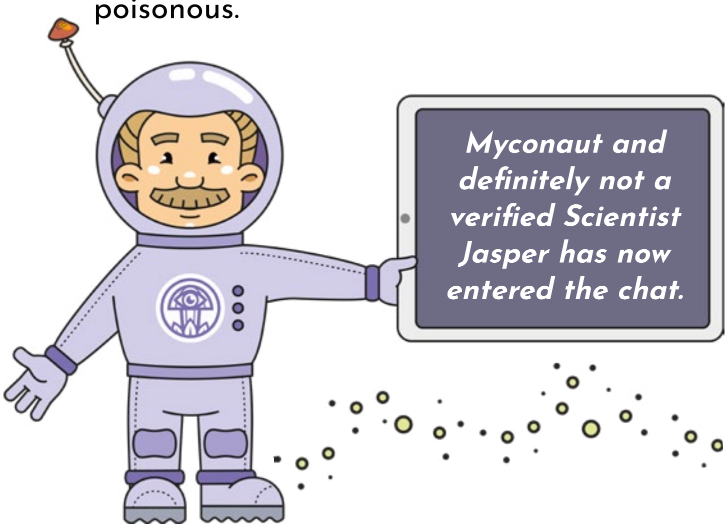
But all in all, we think it's pretty awesome that these colorful and colorless plant pirates exist. They're almost as much fun to encounter in the forest as mushrooms. Almost (shhh, the fungi are listening).

## DID SOMEBODY SAY SQUIRREL BREAD?

We can't discuss fungi as food without mentioning mushrooms. The fleshy spore-bearing fruiting bodies of certain Fungi belonging to the subqueendom Dikarya are just screaming to be eaten, aren't they?

These delicious and nutritious seasonal gifts play an incredibly vital role in the survival of certain animals across all kingdoms.

But if you're a mycophobe – afraid of fungi – you might be wondering why some are so poisonous.




*The fungus decides which animal it wants to be eaten by.* A little out there? Let's explain.

**Amanita phalloides**
(Death Cap)

Take ***Amanita phalloides*** **AKA the "death cap mushroom," the most notoriously deadly poisonous mushroom on the planet.**

This mushroom has been used as a tool for political assassinations for millenia, most infamously when it was used to kill **Roman emperor Claudius**. Yes, Claudius got capped by a 'shroom.

While half a cap can kill a grown man in an awful way **(the lethal dose is only 0.1mg/kg of body weight)**, in one of nature's hilarious ironies, this deadly mushroom is apparently also delicious.

> Please don't go out and eat this mushroom, it is called the Death Cap after all!!!!!!

**Amatoxins, phallotoxins and virotoxins are responsible for the Death Cap's deadliness.**

And unlike many ingested poisons, these compounds cannot be destroyed by heat without destroying the mushroom beyond edibility. In other words, cooking this poisonous SOB ain't gonna save you, darling.

# 8.2 FUNGI AS FOOD

Okay, back to the fungi as food bit.

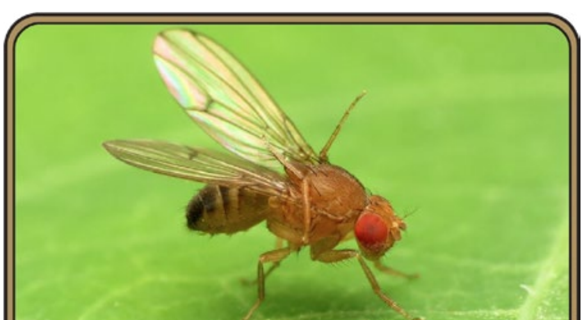
While we now understand that even a little bite of the Death Cap can be lethal for humans and other mammals, **a common naked garden slug known as *Agriolimax agrestis* easily feasts on this deadly mushroom without any ill effect.**

Fruit flies also seem to be unaffected by the amatoxins and **Deer have even (anecdotally!!) been spotted eating *Amanita bisporigera*, also known as the Destroying Angel,** without any adverse effects.

See, even killer mushrooms want to be eaten! And if you believe all organisms are somewhat conscious, it's not too far of a stretch to believe that somewhere in the evolutionary line of these fungi, they found that their spores spread far further with one animal than another... perhaps.

Okay, back to the verified science part...

Agriolimax agrestis
(Garden slug)

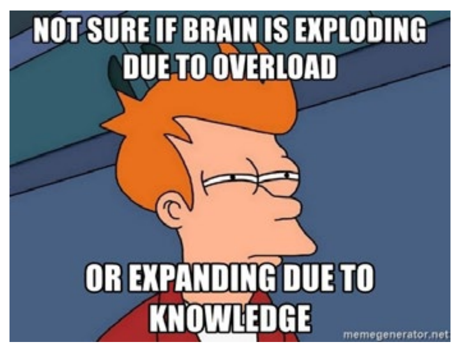


Drosophila melanogaster
(Fruit fly)

Amanita bisporigera
(the Destroying Angel)

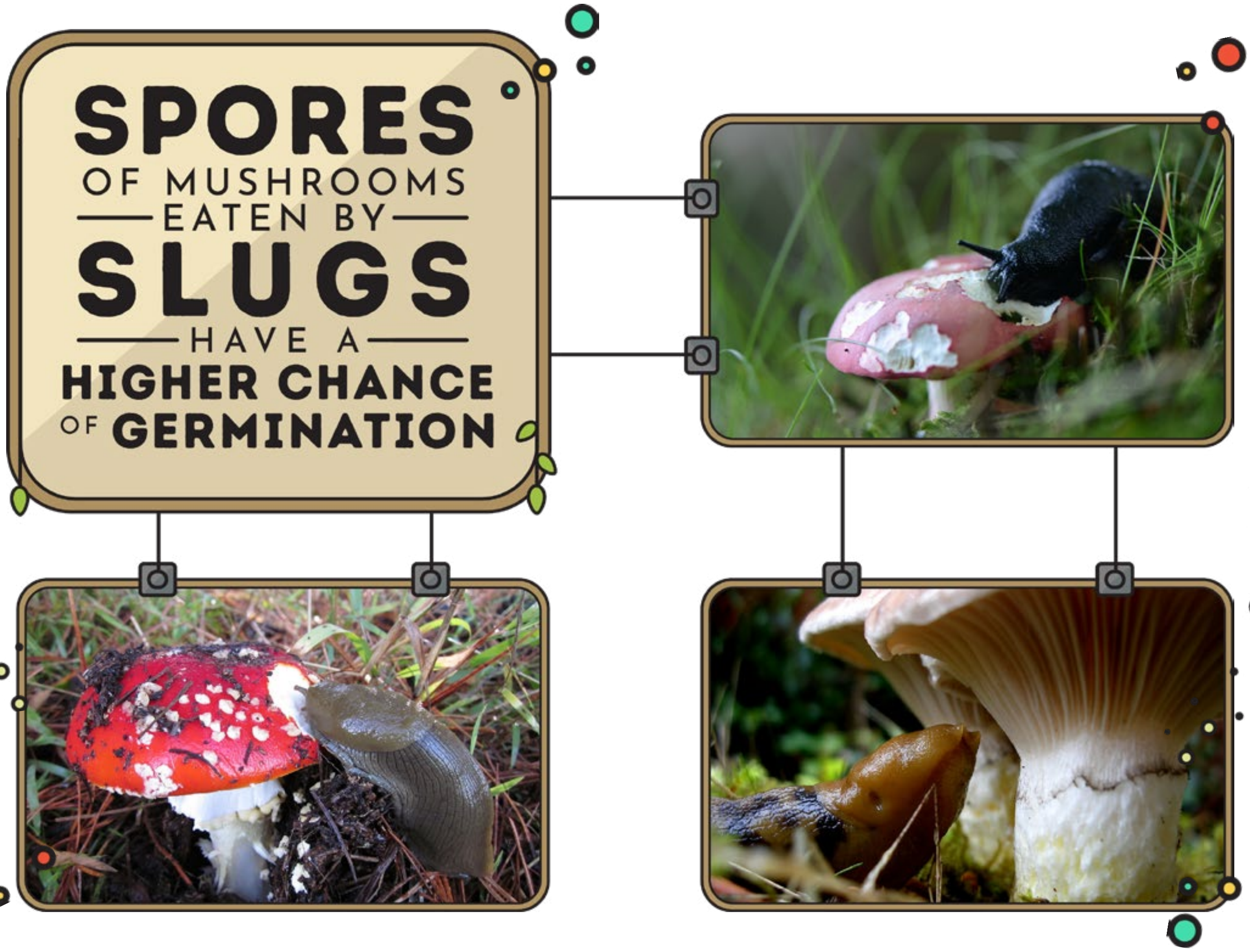
Like we learned in the last lesson, spores are really tough. They can easily survive the digestive tract of animals.

Now get this: **spores can also survive the digestive tract of the animals that have consumed the animals that have consumed the mushroom!**




Considering the fact that predators like wolves and owls often cover far larger areas than their prey, that's good news for mushrooms like *Boletus edulis*, AKA Eekhoorntjesbrood. **Yes, the common name for Porcini mushrooms in Dutch translates into Squirrel bread.**

Before we end this chapter, we need to highlight the most intricate animal-mushroom relationships on the planet.




## SLUGS EAT SHROOMS, NOT DRUGS

Any novice mushroom forager knows slugs love mushrooms. Arrive at your favorite fungi honey hole a day late and you'll often find that slugs are already helping themselves to a second plate of the fungal feast you'd planned on harvesting for dinner.

Although slugs seem to be especially fond of classic cap and stem mushrooms, this doesn't stop them from feasting on softer polypores like *Ganoderma tsugae*, though generally, they stay away from harder polypores like Artist's Conk *(Ganoderma applanatum)* or the Tinder Fungus *(Fomes fomentarius).*

**Slugs seem to be resilient to a plethora of different species that are poisonous to us and many other animals.** Some researchers postulate it's due to the enzymes slugs produce in their guts. In reality, we simply don't know how they survive consuming certain deadly specimens.

Though we often think animals instinctively know what to eat and what to avoid, slugs have been observed chomping down on the wrong mushroom from time to time. A researcher in 1907 noted a bunch of slugs greedily eating a common stinkhorn mushroom *(Phallus impudicus)*, before suddenly dying shortly thereafter.

Slugs offer another example of the fabulous cooperative abilities of Fungi, even when they're eaten alive! Similar to when fruits are consumed by animals, **the spores of mushrooms eaten by slugs have a higher chance of germination,** according to research published in February 2022.

## THE DAY AN APE SAW GOD

**All 22 species of primates, including humans, munch on mushrooms and fungi.** On average, this mushroom munching and fungi feasting accounts for about **5% of their diets.**

As for humans, **there are currently 2,006 species of mushrooms safe for human consumption,** according to a paper from February 2021. We are incredibly mycophagous and seem to be embracing that side of ourselves more and more.

This, my friends, seems like a great time to briefly mention **the Stoned Ape theory**, no?

When the climate changed and our ancestors, who were most likely swamp or forest dwellers, were forced into an environment resembling a savanna, *(check out the aquatic ape theory if you want to know more about this potential origin),* it's likely that these primates were suddenly forced to try some new foods.

The savanna, dominated by grazing mammals like giraffes, elephants, rhinos, and wildebeest, makes for a lot of dung. And all this dung makes a perfect home for the largest psychedelic mushroom, ***Psilocybe cubensis***.

As the story goes, **primates began to eat *Psilocybe cubensis* mushrooms, started having some brain-stimulating experiences, and this is why our ancestor's brains, in a 3 million year period, almost quadrupled**


*The Stoned Ape Theory - Jim Figora*

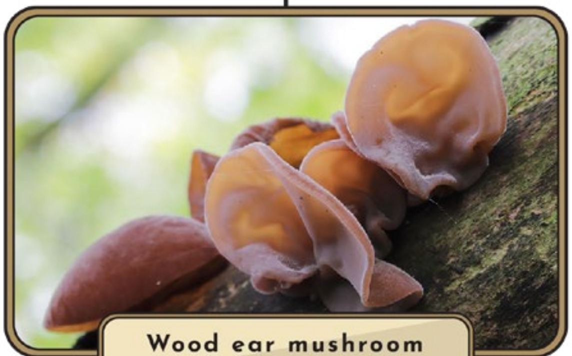
**the size its predecessors had attained over the previous 60 million years of primate evolution.** The rest, like language and culture and all the other rungs on the ladder toward modern civilization, is history.

And there are some primates that take their love for mushrooms to a whole 'nother level.

**The Goeldi's monkey** *(Callimico goeldii)*, a small South American primate living in the Amazon, **devotes up to 63% of its feeding time to the consumption of fungi.** Its favorite snack is the **Wood ear mushroom** belonging to the genus *Auricularia*. Man do they love these mushrooms! A single Goeldi's monkey can consume up to 6kg of these mushrooms annually.

**Callimico goeldii**
(Goeldi's monkey)

CONSUMES **UP TO 6KG** OF WOOD EAR MUSHROOMS ANNUALLY



**Wood ear mushroom**
genus Auricularia

*Geegee, the designer of this workbook munching away on some fresh mushies*

**Humans**

CONSUME **2KG OF MUSHIES** EVERY YEAR ON AVERAGE

That may not seem like a lot to you, but Goeldi's monkeys only weigh between 400 and 800 grams! For comparison, **a person weighing 70kg (154 pounds) would need to eat close to 1,000 kgs (or 2,200 pounds) of mushrooms in a year (the equivalent of about 6 pounds of mushrooms PER DAY) to match the Goeldi's monkey's pound for pound fungal feasting.** We've got some work to do: according to a study from 2001, the average U.S. citizen consumes about 2 kgs of mushrooms annually.

Mushrooms are vital in the lives of many organisms. They provide a significant amount of essential nutrients to populations of hogs, reindeer, bears and squirrels before winter.

The mushrooms with the largest impact on these animal populations are almost exclusively Ectomycorrhizae, mushrooms like *Boletes, Suillus, Amanitas* and Truffles.

**For Ectomycorrhizae to thrive, we need to take care of our old growth forests so they can take care of the animals residing within them.**

Some animals, though, have found that farming fungi is a more stable solution.

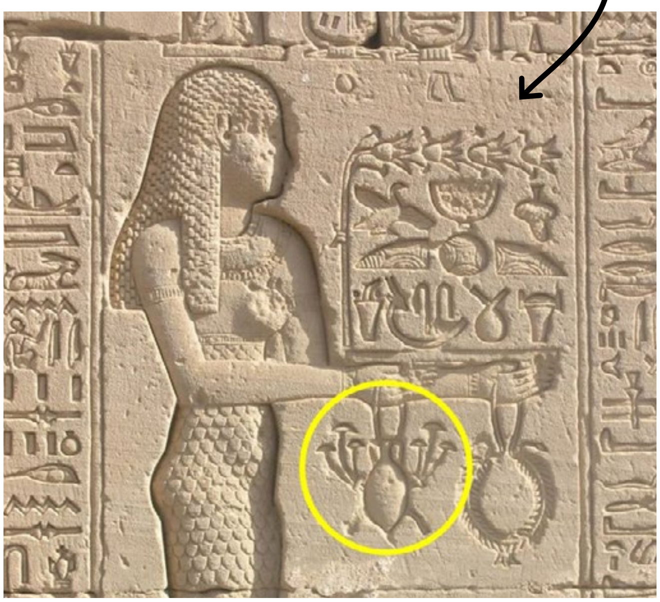

*Pademelon Eating Mushroom - Sabrina Setaro (Flickr)*

## HUMANS DON'T DOMESTICATE FUNGI, FUNGI DOMESTICATE HUMANS

Now to Fungi Academy's bread and butter: Growing mushrooms! We at Fungi Academy truly believe mushroom cultivation is the perfect blend of art and science.

It's also a doorway into an ancient way of relating to fungi, one that has been practiced for thousands of years.

Take a look at this **hieroglyph in the Temple of Hathor** in Egypt, **dated to 2250 B.C.**



The quasi-handbags at the bottom right of this image are obviously **portraying some form of mushroom cultivation, either from a vase or burlap sack.**

Anyone who has been growing mushrooms for long enough knows you can grab some substrate, for example cow dung, that currently has mushrooms fruiting from it, add some more un-inoculated substrate in, for example, a vase or burlap sack, and expect mushrooms to eventually fruit with a fairly high success rate. It seems likely that the brightest minds of the peak of the Egyptian empire figured this out too, no?

Nonetheless, **the common narrative is that it was the Japanese who were the first to unlock the secret codes of mushroom cultivation. For about 1,800 years the Chinese and Japanese have been growing shiitake mushrooms on logs** with the same principle that we hypothesize the ancient Egyptians used.

To grow shiitake mushrooms back then, these ancient east Asian mushroom cultivators simply placed logs that had shiitake (*Lentinula edodes* or the Oak Mushroom) growing out of them next to logs that didn't. Then, with a fairly decent success rate, spores from the fruiting logs of Shiitake would inoculate the fresh logs and over time would start fruiting this beloved, delicious mushroom.

# 8.3 FUNGI AS FOOD

This technique eventually became more refined by opening the bark with a hammer, soaking the logs to instigate fruiting, and at times even hitting the logs to imitate the shock of a falling tree.

These days the Japanese are still some of the most ingenious mushroom growers. Recently, they've developed new techniques like shocking their substrate with electrodes to imitate lightning hitting the substrate. This practice is inspired by the traditional tale that lightning strikes are a harbinger for mushrooms and it seems to be causing increases in yields!

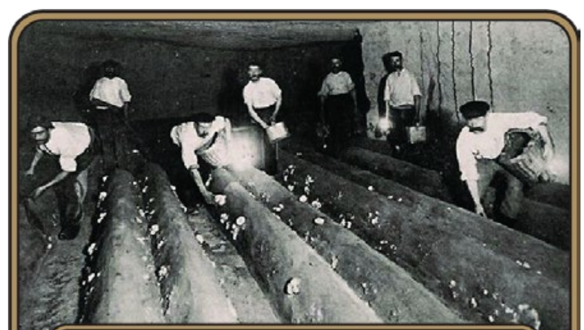
Of course, this is just *mushroom cultivation*. Our species have consumed mushrooms for eons. **The very first evidence we have of humans consuming mushrooms is almost 20,000 years old.** The Red Lady of El Miron are the skeletal remains of what seems to have been a matriarch in northern Spain. When her remains were unearthed and analyzed, tons of Amanita and Bolete spores were discovered on and in her teeth.

Okay, back to farming fungi...

Europeans started cultivating mushrooms about 1,400 years after the Japanese. **In the 1600s, French farmers started growing a lot of Champignons,** also known as Cremini, Portobello, White Button mushrooms, or *Agaricus bisporus.*

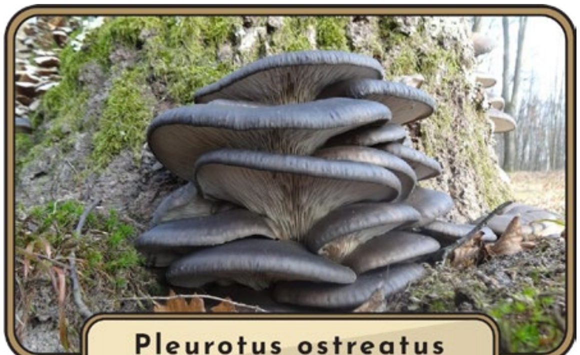
Yes, **the large portobello and the tiny button mushrooms you've undoubtedly seen in the supermarket are all the same species of mushrooms just at different stages of growth**.

About 160 years later, the French figured out that these Champignons also really enjoyed growing underground, which catalyzed the catacomb cultivation style still fairly relevant today.



Catacomb Champignon Cultivation

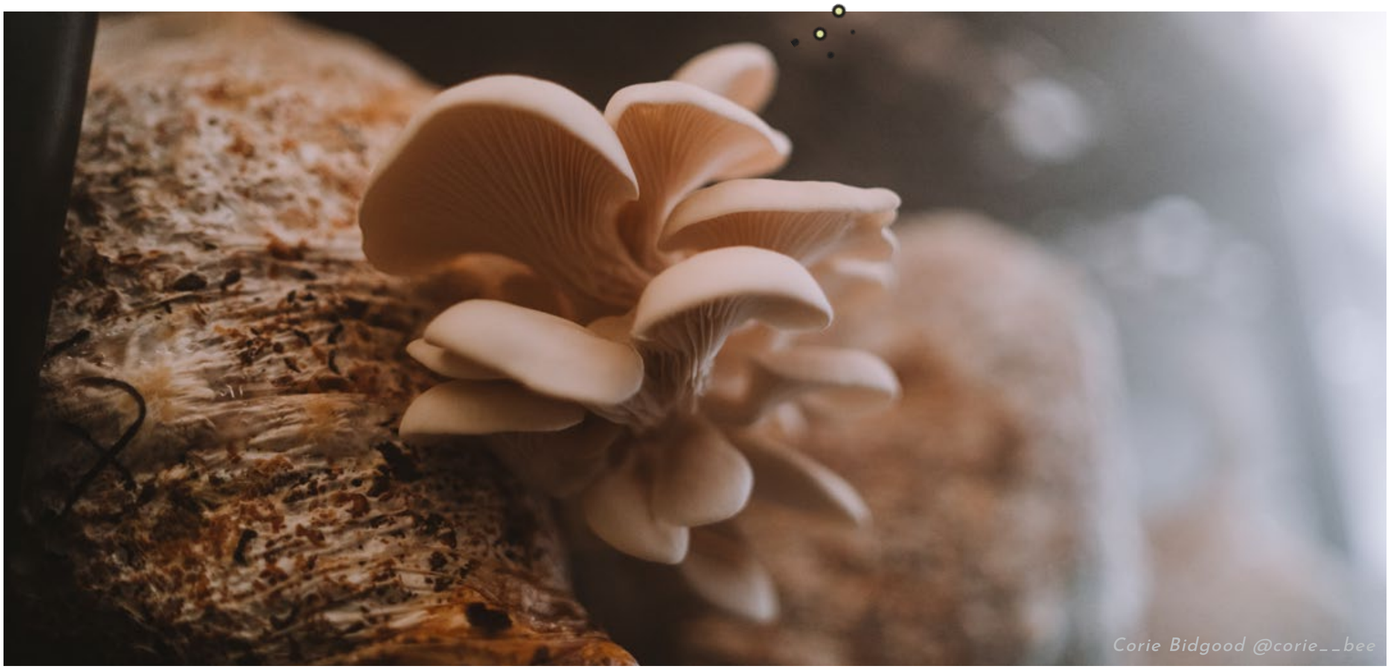
# 8.3 FUNGI AS FOOD



**Pleurotus ostreatus**
Growing on wood stump

Next, the Germans arrived at the party when they were **the first to successfully cultivate Oyster mushrooms of the genus *Pleurotus* on logs and wood stumps in 1917.** It wasn't until **1951 that we first saw today's common cultivation method of growing Oyster mushrooms on wood chips in bags.**

This woodchip in bag method paved the way for modern mushroom cultivation, which made its way west in the 70's. **Currently, there are about 30 species of mushrooms grown for food worldwide,** not counting the psychoactive species of *Psilocybe* and *Panaeolus* which would rack up the total to nearly 40 different species widely cultivated.




**1917**
1ST SUCCESSFULLY CULTIVATED OYSTERS IN GERMANY

**1951**
1ST MODERN CULTIVATION OF OYSTERS ON WOODCHIP BAGS

# 8.3 FUNGI AS FOOD

The secrets of Morel cultivation have recently been cracked by the Chinese and the Danish Morel Project but other beloved Ecto-Mycorrhizae like truffles, chanterelles and boletes are still a mystery to cultivators. That being said, if you have patience and plant their host trees before inoculating the roots with your desired mushroom-producing mycorrhizae fungi, you might experience some success....eventually.

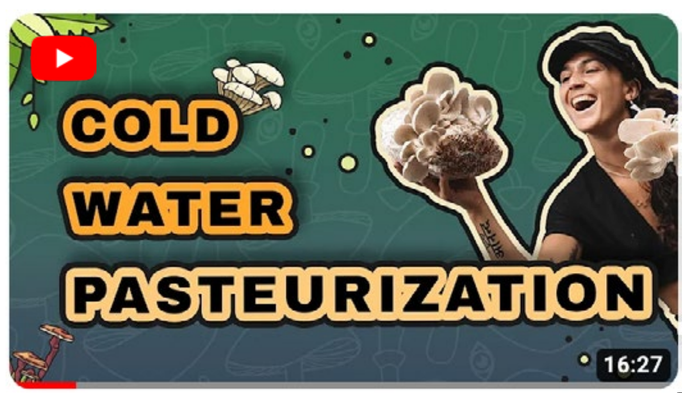
According to Fortune Business Insights, the annual global mushroom production was 15.25 million tons in 2021 and is projected to grow to a whopping 24.05 million tons in 2028.

For all of you metric illiterates out there, **15.25 million tons is about 30.5 BILLION pounds of mushrooms that humans grow every year!** Over half of that astronomical number consists of Button mushroom production.

But, what truly fascinates me is the **Oyster Mushrooms** of the genus *Pleurotus*. Compared to *Agaricus* mushrooms, Oyster mushrooms are much easier to grow and seem like the perfect candidate for the one mushroom that EVERYONE can grow wherever they are.


Oyster mushrooms can grow on an incredible variety of substrates including wood chips, corn cobs, coffee, soybean husks, wheat stalks, straw, lemon grass, all types of cane, even jeans and toilet paper! They are voracious, fast-growing, nutritious and they provide generous yields even without supplementation of the substrate.

**But the best part is that you don't need any fancy equipment to prepare the substrate for them to grow from. By simply increasing the pH of the substrate with Lime, or calcium hydroxide, you can grow pounds and pounds of Oysters.** We have a whole video on our YouTube channel on the cold water lime pasteurization if you want to know more.




This easy, forgiving process has been the catalyst for people from all continents to grow their own mushrooms at home without the need for hardly any funding while using agricultural waste like corn cobs or spent coffee grain.

## CUTTING LEAVES TO FEED THE FUNGAL BEAST

What if we told you humans aren't the only beings roaming this pale blue dot with the ability to weave fungal mycelium to their will?

Here in Central America and in other parts of the Americas, you will sometimes see a joyous parade of ants carrying green flags. Of course, these "flags" are leaves meticulously cut by the leafcutter ants, and they don't bring these little bits of leaves home to decorate for Bob's birthday party, nor do they eat the leaves.

**The leaves they carry are the substrate for their very own fungal farm!**

Today, **there are about 250 species of ants belonging to the tribe of Attini, also known as the Fungus-Farming ants.** And they've been farming fungi for A LOT longer than us puny humans.

Joyous green flag parade
(Leafcutter ants)

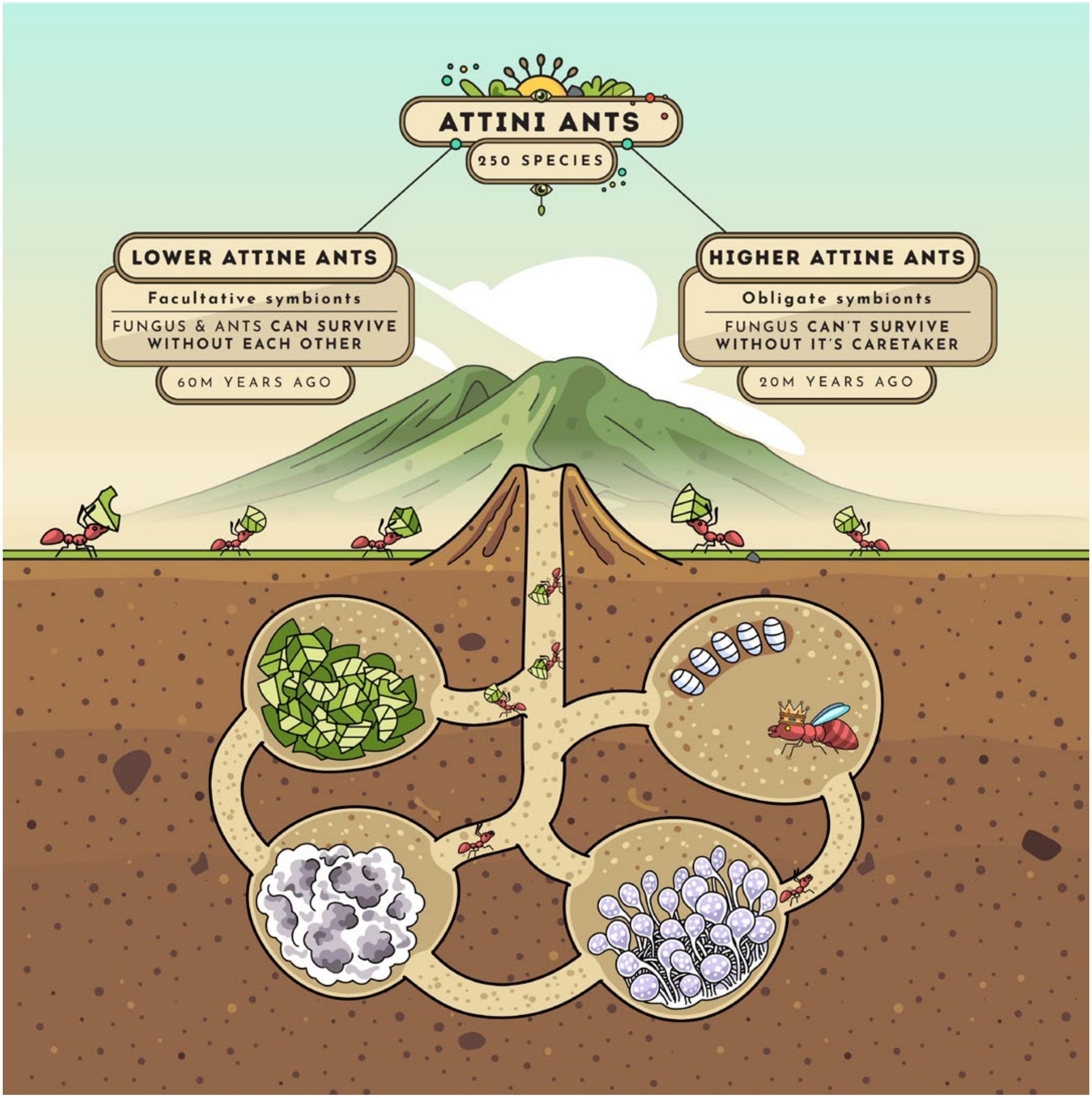
Leafcutter ant
Atta spp. & Acromyrmex spp.

One type of ants, known as the **lower Attine ants**, evolved about 60 million years ago. They are **facultative symbionts, meaning that neither the fungus nor the ant need each other to survive.** These ants pretty much just stored their food for too long, had it turn moldy, then figured out they could still eat the moldy food without any issue.

Then there are the higher Attine ants. These ants are like the aristocrats of fungi-farming ants. **Without them, the fungus they farm wouldn't survive, which if you remember from Module 5, is the definition of Obligate symbiosis.**

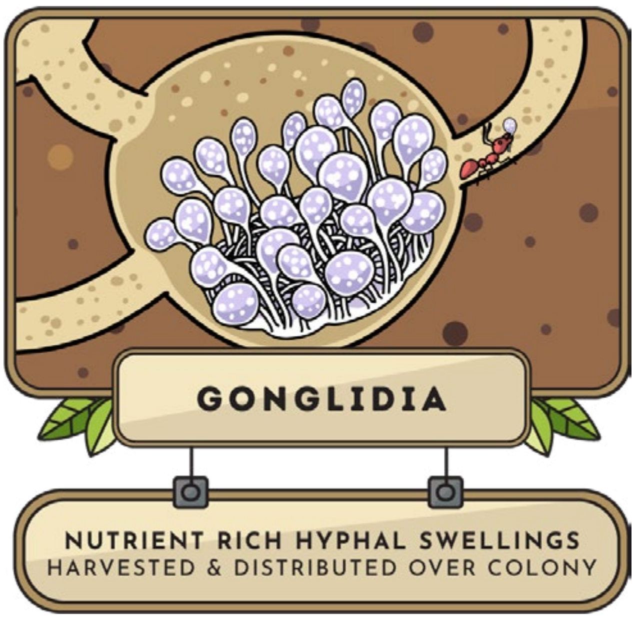
These ants, which seem to have **perfected the art of mushroom cultivation about 20 million years ago,** cultivate a species of fungus known as *Leucoagaricus gongylophorusis.* Haha! That might be the weirdest and wildest name in this entire course, and a great spelling bee test word.

Fungus-farming ants


ATTINI ANTS
250 SPECIES
LOWER ATTINE ANTS
Facultative symbionts
FUNGUS & ANTS CAN SURVIVE WITHOUT EACH OTHER
60M YEARS AGO
HIGHER ATTINE ANTS
Obligate symbionts
FUNGUS CAN'T SURVIVE WITHOUT IT'S CARETAKER
20M YEARS AGO

# 8.4 FUNGI AS FOOD

Anyways, like we just mentioned, *Leucoagaricus gongylophorusis* is **unable to survive without the ants, who feed it a steady diet of leaves. In return, *Leucoagaricus* produces gonglidia,** *(seriously, does it all have to be this hard to pronounce?),* **a nutrient rich hyphal swelling** not seen anywhere else in the fungal queendom. **These swellings are harvested by the ants and distributed all over the ant colony to be eaten.**




But this relationship, evolved over millions and millions of years, goes much deeper.

Recent studies have found that these Leafcutter ants attract a bacteria known as Pseudonocardia on their exoskeleton. This bacteria acts as a repellent against mycoparasitic microfungi like *Escovopsis* that could devastate their carefully curated fungal farm.

And on the cuticles, or pincers, of the ants, scientists have found Phialophora, or black yeast, which is believed to help *Leucoagaricus gongylophorusis* digest the leaves faster.

Now for the real kicker...

Just like in the cultivation of other mushrooms, a good cultivar or strain is immensely valuable and a vital part of the growing operation.

Leafcutter ants know this, of course. Young queens about to depart the colony to start their own farming operation often take a tissue sample of the colony's mother culture with them.

**Genetic analysis has found that these ants have been farming the same lineage of fungal culture FOR OVER 23 MILLION YEARS!**

These ants have been successfully growing food for millions and millions of years without impacting their ecosystem and without the need to create unbalancing aggressive agrochemicals. One might say that they are the original inventors of permaculture.

You thought we were done??? Oh no, my fungal friend, we've got another doozy for you!

## TERMITES: THE OG OF MUSHROOM CULTIVATION

Very much like leafcutter ants, termites have been farming the aptly named Termitomyces for millions of years. And these termites, they're onto something:

**Termitomyces is the largest fleshy mushroom fruiting body in the world!**

Termitomyces reticulatus

The main difference here is that while **leafcutter ants are fungus farmers, termites are mushroom farmers.** First, they feed the fungus dead plant matter until tiny fruiting bodies start to farm. Then, the termites harvest these baby mushrooms and divide them amongst the colony.

But the termites don't just eat these juicy fruiting bodies. In this farming process, the fungus's asexual spores prey on the hungry termites, ensuring another generation of mushrooms.

Similar to the higher attine ants, **the termites and fungi they farm are obligate symbionts, meaning neither the fungus nor the termites can survive without their counterpart.**

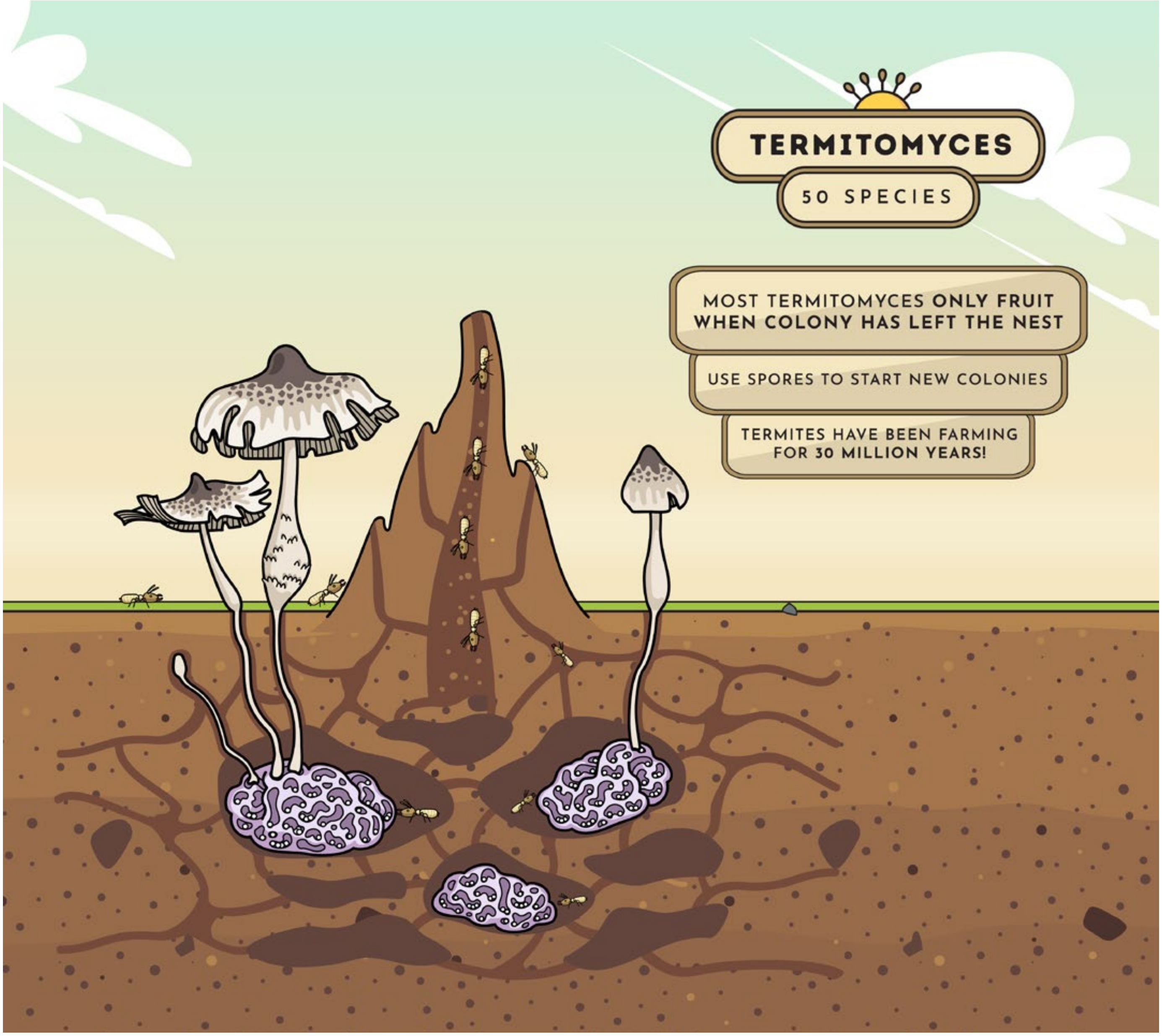
And just like leafcutter ants, these termites need to tend to their garden. The pathogen Pseudoxylaria persistently tries to attack the termite's crop, causing the termites to weed it out and remove it from the colony entirely.

Just like with *Leucoagaricus gongylophorusis*, most species of Termitomyces only grow their massive mushroom fruiting bodies after the colony has left the nest. But the termites then use the spores released by the massive mature fruiting bodies to start new colonies.

Not that they are in much of a rush; **the termite colony can survive for decades on a single asexually grown culture.**

As for the length of this relationship, it's pretty damn long, too. **Termites found in Africa and Asia have been doing this for at least 30 million years** and today we find over 50 species of Termitomyces spread around the subtropics of the old world.

To sum it all up, ants and termites, not the Egyptians, Japanese, or Chinese, are the true OG mushroom cultivators.



Corie Bidgood @corie__bee

## IT'S THE HUMBLE HUMANS HOUR

Humans think we're hot shit with our pride and joy of 12,000 or so years of agriculture. But in that short time, what we've also done is devastated heaps of fertile ground all over the planet.

It's time we learn from these permaculture masters of the insect kingdom.

We aren't tied or enslaved to our destructive ways of food production.

We can work in symbiosis with the organisms around us to create an abundance of food, water and shelter for the humans and all the creatures, critters and crustaceans around us.

A better future is possible!

Speaking of the future, our next (and last!) module is all about the Future of Fungi!

I can't believe we're almost at the end of this fungal adventure.

Don't forget to leave any comments and questions you have in the discussion box!

We'll see you in the future!

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# 8.5 REFERENCES

MODULE

9

# THE FUTURE IS FUNGI

# 9.1 THE FUTURE IS FUNGI

## IN THIS MODULE, YOU'LL LEARN ABOUT HOW FUNGI CAN:

- Refigure Our Food
- Remediate Our Mess
- Revolutionize Our Creations

We've made it to the FINAL module of this course!

We've been on quite a journey, from the micro all the way up to the macro.

We dove into the inner cellular membrane of plants, spent hours exploring obscure obligate fungal expressions, linked up with the roots of trees, teleported back in time to trace the history of fungal evolution, and feasted on the myriad ways fungi feed the world.

Now here we are, nearly at the end of this mind-bending tale yet with literally millions of untold stories of fungi and the ways they shape the luscious life we see all around us.

The bane of educators is this: **We can never tell the full story.**

All of us, through our lives, only get chapters from the grand story of life, our own book of understanding.

But before getting too sentimental or mytho-myco-poetic, there's still a vital story to be told, a crucial chapter to uncover.

Let us end with the start of a new chapter yet to unfold...

**THE FUTURE IS FUNGI!!!**

## A BLAST FROM THE PAST

Before we can understand the future, we must first understand our past.

Most of us western Europeans and their descendants have been raised in a **myco-phobic culture, meaning our culture in general is afraid of fungi, rot and mold.**

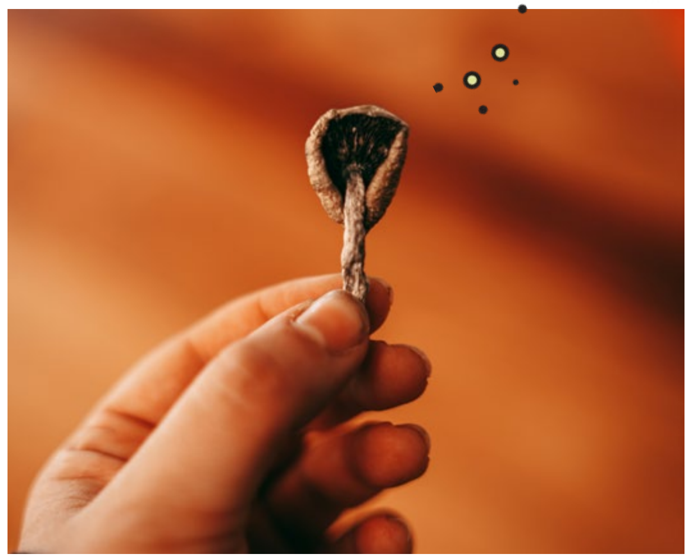
However, this hasn't always been the case! For thousands of years, human cultures have had some sort of relation to the Fungi within their ecosystems.

We could go as far back as Terrence McKenna's Stoned Ape Theory to argue how human evolution may be inextricably linked with Fungi, but that's a story for another day.

Nonetheless, it's not far-fetched to claim our ancestors were masters of their unique ecosystems all over the world, capable of figuring out and passing down what mushrooms were delicious treats and which ones were deadly poisons.

Yet their genius went much further than merely figuring out what they could and couldn't eat. Obviously, we can't really eat the bark of trees yet we've still found incredible use for this abundant resource.

Heck, even the Inuit and other native peoples spending most of their time amid ice understood the importance of certain lichens as crucial foods for their reindeer.



**Yes, our ancestors knew that Fungi was so much more than just food.**

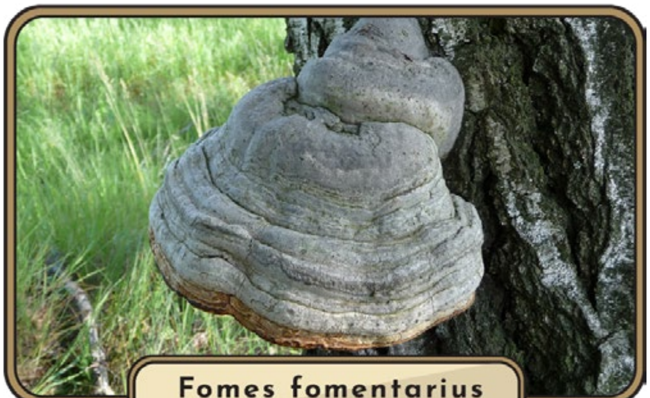
**Since time immemorial, humans have used Fungi as medicine, fire starter, building material, sacrament and undoubtedly much more.**


Ötzi the Iceman, who lived 5,000 years ago and was found frozen and preserved in ice in the Alps between Austria and Italy in the early 1990s, provides a perfect example. Found almost fully intact, **Ötzi was famously (at least in the mycosphere) found with two different species of mushrooms on his right hip.**

If you want to know more about Ötzi, there's a great history on fire podcast dedicated to this legendary ancient figure.

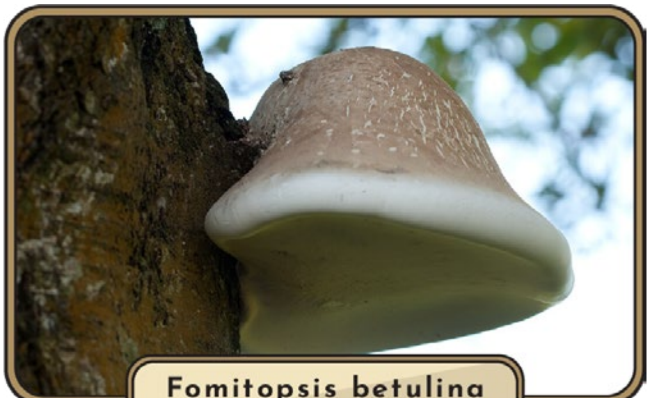
Back to the mushrooms.

The first fungus found on his hip, ***Fomes fomentarius*** **(also known as the tinder conk, hoof fungus or the amadou), can be used as a fire starter.** It's also capable of keeping a burning ember alive during the day so you have a quick, easy way to light the next night's fire. And when cured in a particular fashion, it can also be tanned into an incredible fungal leather, used to make hats or shoes.



Fomes fomentarius
(Tinder conk)

The second mushroom was the **Birch Polypore, or *Fomitopsis betulina*.** An incredibly abundant mushroom in Europe's Birch forests, the Birch polypore possesses an incredible number of novel medicinal compounds including **agaric acid, which is extremely effective in treating whipworm, a parasite that had infected the gut of Ötzi.**



Fomitopsis betulina
(Birch polypore)

We see these human-fungal interactions all over the world throughout history. But let's not turn this into an Ethnomycology course just yet. The point is, **we've been relating to fungi for our entire history, just like with plants.**

Some people would call this recent spike in interest of Fungi in the western world the "Shroomboom" but it's more like a Renaissance, or revival, of our old ways.

Of course, the recent surge of interest is no doubt connected to the growing global interest in psychedelics. But it's also rooted in the deep human desire to take better care of our ecosystems and planet so that seven generations from now humans can live with the same abundance and ease we do today.

**Plastic pollution, destructive agriculture, shimshod construction and fast fashion have proven themselves unsustainable.** These, plus a plethora of other human induced issues, are shaping the 21st century.

**But what if we told you that, for many of these human caused problems, there might be a fungal solution?**

In this final module of the Fungal Ecology course, we are diving into **the wondrous potential fungi possess to help humanity find better balance within our ecosystem.**

## REFIGURING OUR FOOD

Food: humans need it, bond over it, link their culture and heritage to it, and increasingly define themselves by what types they eat.

In the history of humanity, we've never had more food, yet most of us have only ventured into the hunting grounds of the aisles of your local market or supermarket for it.

So disconnected from food's source, most of us treat it with an astonishing amount of disrespect, from the hard work to the valuable natural resources it takes to create this abundance.

Take the United States, for example. **It's estimated that up to 40% of all food produced in the U.S. ends up in a landfill.** Now, you might be thinking to yourself, didn't we learn that because of saprophytes, nothing in nature is lost, only returned to the soil for the plants to eat?

In an ideal world, yes. In reality, though, **95% of discarded food in the U.S. ends up in toxic landfills where all that juicy nutrition is wasted as it's mixed with heavy metals, petrochemicals and microplastics.**

It's no surprise that we don't see thriving ecosystems sprout from our landfills, even though **landfills are composed of up to 20% compostable organic matter.**

The U.S isn't alone in its incredible waste of food. **Globally, it's estimated 33% of all food produced ends up being wasted.** Put another way, **we could feed another 2 billion people without producing more food if we just cut out most (but not all!) of the food waste.**

**95% OF FOOD WASTE IN THE U.S. ENDS UP IN TOXIC LANDFILLS**

Wasting food is one thing, but wasting food that's produced using agriculture's current preferred growing methods is a whole other crime.

Our love for monocrops and agrochemicals has all but devastated our soil and the micro and mycobiota that call soil home.

Funnily enough, Climate Town and Fungi Academy seemed to be connected through the Morphogenic Field and finished videos on this topic within the same week! [We highly recommend checking out his video too!]


**Pesticides, fungicides, insecticides and synthetic fertilizers might have increased our agricultural yields by up to 300%, but they've also poisoned our food, sterilized our soil and eradicated crucial components to this grand dance like native flora and essential pollinators like bees.**

With weakened plants and nearly dead soil, the delicate balance is completely out of whack, making our agricultural system utterly reliant on using even more of these destructive pesticides, fungicides, insecticides and synthetic fertilizers to keep up.

All that effort and damage, and what plants are we growing?

According to the United Nations Food and Agriculture report, **the four crops we spend the most energy on are sugarcane, maize, cereal grains and rice.**

Of these plants, **we only use about 20% of the biomass these plants produce** either for our own food or the food for the animals we keep.

So, what's happening to the remaining 80% of that biomass, known as agricultural waste or agricultural byproduct?

Unfortunately, most of it is either burned or, just like our other food waste, ends up in an overpacked landfill.

**Tens of thousands of billions(!!) of kilograms of agricultural waste are produced annually worldwide**, but in reality it's not inherently "waste."

**Most of the world's agricultural waste consists of cellulose, hemicellulose & lignin.**

By now, you should know what organism loves to feast on these compounds and organic polymers....Fungi!

The champion of the mushrooms, an incredibly versatile genus that hasn't gotten enough light during this course, Oyster mushrooms of the genus *Pleurotus*, have now entered the chat.

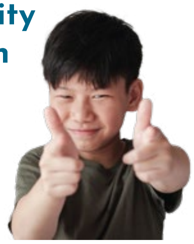
When cultivated, **Oyster mushrooms can produce a biological efficiency from 100% all the way up to 200%!**

In layman's terms, this means that **if you give the mycelium of Oyster mushrooms one kilogram of food plus some water, you can receive up to two kilograms of mushrooms in return!**

Oyster mushrooms aren't only generous. They're also the least picky eater on the planet, completely content munching on the waste products of our staple crops.

**Straw and other stems like corn stalks and the billions upon billions of rice stalks being produced each year are some of Oyster mushrooms' favorite foods.** Wheat bran, corn cobs, soy husks and even cacao shells are also happily consumed by Oyster mushrooms.

Let's pretend that half of the tens of thousands of billions of kilograms of agricultural waste we produce annually are suitable for Oyster mushrooms. With a biological efficiency of 100%, this means that **we have the ability to produce an absolutely incredible ten trillion kilograms, or about 20 trillion pounds, (that's 20,000,000,000,000 pounds, baby) of Oyster mushrooms every year without cutting more trees or planting more crops.**



The substrate for this boon is already right there, waiting for us to simply not throw it away.

And of course, it's not like we're limited to agricultural waste. There are plenty of other useful resources that go straight to the garbage dump.

Take coffee, for example. I love coffee, Corie behind the lens loves coffee, Sam editing this workbook loves coffee, most of the damn world loves coffee.

Annually, **we produce a staggering 18 billion kilograms of nitrogen rich coffee grounds. And most of that goes, you guessed it, right into the landfill.**

But you know who else likes coffee?

Oyster mushrooms!

Plenty of companies all over the world have seized upon the opportunity to close the coffee waste loop and create delicious nutritious food from the waste created by humanity's caffeine addiction.

Rotterzwam, based out of Rotterdam in the Netherlands, **picks up used coffee grounds from casinos and hotels every night and mixes it with their substrate to produce Oyster mushrooms.** Since the brewing of coffee actually pasteurizes the coffee grounds, they don't need to spend any more energy preparing the coffee grounds for mycelial inoculation. Mixed with straw or other agricultural waste, the coffee grounds are rapidly consumed by the Oyster mushroom mycelium to produce nutrient rich food within a couple of weeks!

**Oyster Mushrooms contain high amounts of protein as well as many vitamins, minerals and beneficial polysaccharides, making them an ideal substitute for our meat heavy diets.**

We're not saying Oyster mushrooms will ever fully replace our craving for meat. But it could help stop or severely slow **the largest crime being committed these days in food production: The factory farming of animals.**

Factory farms are a breeding ground for antibiotic-resistant bacteria, have a massive impact on our ecosystems, are incredible consumers of crops and drinking water, AND cause an immense amount of animal suffering in the world.

If we set our sights on the tens of thousands of billions of kilograms of Oyster mushrooms we could hypothetically grow for basically free, we could definitely inch closer to the end of factory farming as we know it today.

When it ends, our descendants will definitely look back on us and ask themselves:

"They were doing WHAT to these animals?"

But this story isn't over yet. The food that we offer the Oyster mushroom for its meal doesn't disappear after the mushrooms fruit. So, what happens to all that straw, coffee, or whatever other waste product we're using? Back to the landfill, right?

Wrong!

**Get this: once Oyster mycelium has eaten its substrate and produced mushrooms, the nutrient profile of the substrate actually increases.**

**According to a 2004 paper, *Pleurotus* species are able to fix nitrogen from the atmosphere by producing neurotoxins to hunt for nematodes, tiny soil dwelling worms that feed Oyster mushrooms' nitrogen cravings.** Known as the cowboys of the mushroom world (by us at the Fungi Academy, at least), Oyster mycelium uses hyphal lassoos to trap and consume nematodes and suck them dry for that sweet, sweet nitrogen.

# 9.2 THE FUTURE IS FUNGI

Corie Bidgood @corie__bee

**What we're saying is that Oyster mushrooms and other mushrooms within the genus *Pleurotus* can actually increase the amount of nitrogen in their substrate AFTER producing tasty Oyster mushrooms.**

This was verified by the incredible work of Dr. David M. Beyer from Penn State University. He and his team measured **the nitrogen in freshly spent Oyster mushroom substrate blocks and found levels between 1.42 and 2.05 percent. But, after leaving the spent blocks for 16 months without adding any additional food, the amount of nitrogen and many other phytonutrients like phosphorus actually INCREASED!**

In fact, the nitrogen levels rose all the way up to 2.7 percent after being left untouched for 16 months, a higher total nitrogen percentage than what's even found in spent coffee grounds.

Nitrogen depletion in our soils is one of the biggest challenges farmers face today, hence the absurd amount of synthetic fertilizers used in large-scale agriculture. According to the UN Food and Agriculture Organization, **we use about 100 billion kilograms of synthetic nitrogen fertilizer globally per YEAR.** Aside from the horrific impact the production and use of these fertilizers have on our ecosystems, the other huge issue is that only a small portion actually reaches the crops we use them for.

Now consider the alternative approach we're talking about, i.e. transforming locally produced waste into delicious mushrooms for human consumption, then using the spent mycelial blocks as organic fertilizer and compost! Do you see the potential, people?!

Of course, simply adding nutrients to our soil is only one piece of the puzzle.

Thanks to the incredible work of Erik Verbruggen, Marcel G. A. van der Heijden, Matthias C. Rillig and E. Toby Kiers, we know that **the successful introduction of arbuscular mycorrhizal fungi into our soils can increase**

**crop yields, create improved soil structure, and suppress plant disease.** With healthier soils and healthier plants, we may be able to wean agriculture off its incredible addiction to pesticides and other invasive agrochemicals.

This is why we need to protect our soils.

Currently, the monoculture-focused agricultural industry isn't interested in protecting soil life. We till and burn away soil life in the sun, sterilize it with agrochemicals, kill crucial microorganisms like arbuscular mycorrhizae and grow crops that suck the soil dry of nutrients and water.

Just by moving away from our monoculture-focused agriculture, which not only destroys the soil but also makes our crops more susceptible to disease and plague, we can already make an incredible impact.

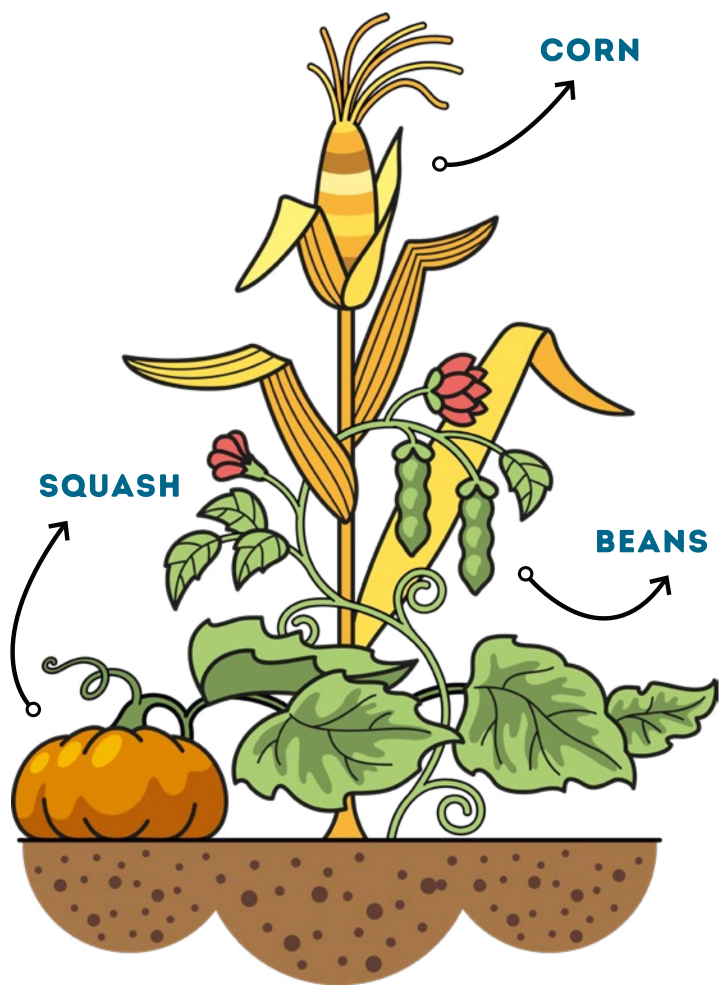
**But by combining crops in one field, we can actually increase yield while simultaneously protecting soil life and keeping crops healthier.**

The three sisters of corn, beans and squash, so eloquently detailed in Robin Wall Kimmerer's fantastic book Braiding Sweetgrass, might be the most popular example of companion planting.

The corn shoots up, creating a vertical line for the beans to trellis (i.e. grow vertically onto). The beans fix nitrogen from the atmosphere and put it into the soil to feed itself and the other plants and soil microbes.
And the squash, with its large broad leaves, protects the soil from the pounding heat of the sun and helps retain moisture on hot dry days.

Talk about an ancient agricultural practice that holds up to this day!

Now, imagine a future where we understand which endophytic fungi help increase the health, resilience and growth of these crops. **We could create natural supercrops by working with and stimulating the growth of the endophytic fungi already present in these plants.**



# 9.2 THE FUTURE IS FUNGI

But wait, there's always mush, mush more.

Fungi offer plenty of other promising species to help you get more bang from your buck in your garden while protecting the soil from the deadly laser we call the sun.

The most famous of these garden companions is ***Stropharia rugosoannulata*, AKA the Garden Giant, AKA Wine caps.**

In the wild, you may sometimes come across

**Stropharia rugosoannulata**
(Garden giants)

this mushroom as it pops out of wood chip or straw mulch piles in certain parts of Europe and eastern North America. But it truly shines when you intentionally inoculate your mulch with these giant mushrooms.

**Cultivating Garden Giants in your mulch and garden has been shown to consistently increase organic matter and bioavailable phosphorus in soil.** They're also linked to an increase in Acidobacteria, often considered a sign of healthy soil ecosystems.

Put simply, gardening with Garden Giants will increase the chances that your other crops turn into giants, too.

And lest we forget, working with this mushroom also produces an incredibly delicious and prolific wine colored mushroom.

Now that's permaculture!

The writing is on the wall: **our current food production systems aren't sustainable. We're destroying the earth's lungs, i.e. rainforests, to feed our livestock. We're poisoning once fertile soils into oblivion to grow nutrient deficient crops. Along the way, we're using ridiculous amounts of water while polluting the remaining fresh water reserves we have.**

Some solutions, not without their challenges, are right in front of us. **By working together with fungi to turn our waste into food and by helping fungi do what they've been doing since time immemorial, we can recreate healthy, vibrant soil and crops, thereby creating sustainable agriculture that feeds humanity, livestock and the trillions of other life forms that call this Earth home, too.**

Of course, we also have to clean up the giant mess we've created before the more beautiful world our hearts know is possible can come to fruition.

How?

You already know...by teaming up with Fungi, of course!


## REMEDIATING OUR MESS

Humanity has achieved some unbelievable progress in the past few hundred years. Unfortunately, it came with a cost. Large parts of the world are now polluted, trashed and toxified as a "side effect" of this unyielding march forward.

One of the worst pollutants we've brought to the earth's surface is oil.

Currently, the world runs on oil. It fuels the military industrial complex, power plants, produces plastic (well get to that later) and other single use consumer goods, and goes into the 1.4 billion cars currently in operation since, you know, we all really NEED to have our own private vehicle. Cycling fanatic, Dutch Patriot side-note: do you really want to know why cars suck? Check out the youtube channel, Not Just Bikes.

And the big problem is we suck at handling oil.

Problems with offshore drilling, bursted pipelines and oil tankers that collide and spill their entire cargo into the ocean are just some of the common failures our current oil production and distribution systems experience.

**Since 1970, it's estimated that over 10 million tonnes (or 2.6 billion gallons) of oil have been spilled in our oceans.** On land in the U.S. alone, there have been around 40,000 separate oil spill incidents.

Oil spill on land

Pelican covered in oil

We don't need to explain the damage these oil spills cause, do we? The image of birds covered in oil and unable to fly is forever etched into the minds of many already.

Then there's smoking. Smoking not only causes millions of premature deaths per year. It also pollutes our coasts worse than practically anything else.

According to a report by the Ocean Conservancy, **cigarette butts accounted for approximately one-third of all collected litter during coastal cleanups in 2019.**

In fact, **cigarette butts are estimated to be the most disposed item in the world, with some researchers estimating that we throw away more than one billion butts EVERY DAY!** Unlike Kim Kardashian, these butts are infamous for all the wrong reasons.

Cigarette butts are made with cellulose acetate, a bioplastic known to have incredibly toxic qualities. Mistaken for food by animals or broken down by microorganisms, the toxic qualities of cellulose acetate are then released into our ecosystems.

But our ocean's worst pollutant is probably its most recent...plastic.

Humans love plastic and there are solid reasons for that: it's sterile, versatile, hard yet pliable. In many ways, plastic is an incredible invention worth celebrating. That is, if we dispose of it correctly or cease mass producing single-use plastics. But we don't do either.

Therein lies the issue.

According to a study published in the journal *Science Advances* in 2021, **the total amount of plastic ever produced up to 2015 was approximately 8.3 billion tonnes. Of this astronomical number, only 9% is estimated to have been recycled.**

So, where did the remaining 91% go? Into our landfills, oceans, lakes or into the air via incineration. Currently, the **annual global production of plastic is estimated at 300 million tons.** If we add that yearly production to the estimated numbers observed in 2015, that means **we currently have around 10.4 billion tons of plastic piling up around the world.**

**8.3 BILLION TONNES PLASTIC = ONLY 9% RECYCLED**

It's getting dark in here, no? We only have two more and we promise, there's a light at the end of this tunnel!

Next, we need to talk about radioactive waste. Though not as widespread as oil or plastic, its impact cannot be ignored.

**The nuclear disaster at Fukushima is estimated to have leaked 10 to 20X more radioactive material than Chernobyl did in 1986, 80% of which leaked into the ocean.** We're still uncertain what the long term impact might be, or when the next disaster may strike.

But one thing we're certain of is how disastrous the impact is on our ecosystems.

Finally, it's time to talk a bit of shit...like, literally.

# 9.3 THE FUTURE IS FUNGI

Human and animal feces used to be understood as a valuable resource for fertilizing land. Nowadays, it mostly ends up in our water.

A study published in the journal Environmental Science & Technology in 2020 estimated that globally there are **approximately 4.9 billion cases of waterborne illness each year,** many of which are caused by fecal contamination of drinking water sources.

**When there are more illnesses PER YEAR than there are half the human population on the earth,** you know it's an enormous issue.

Now let's say all this pollution suddenly stopped today. We still have to clean up all the mess we've already made. As you can imagine, we have A LOT of work to do. We're going to need some help.

Fungi to the rescue! Let's start from the top, shall we?

Oil spills are notoriously hard to clean up, especially when they happen in salty water. But thanks to people like Paul Stamets, Trad Cotter and Levon Durr, among many others, we now know that Oyster Mushrooms of the genus *Pleurotus* are able to nom nom all that sticky icky oil away. How we trained this organism to clean up our mess is best described by detailing Trad Cotter's experiment.

**By exposing Oyster mushroom mycelium to a 5% concentration of motor oil, then selecting the parts of the mycelium that survived and gradually increasing the oil concentration (i.e 10%, then 15%, and on and on), Cotter was able to hit a nearly 100% motor oil concentration while still keeping the mycelium going strong.**

Further, according to a 2011 paper, when mycelium is exposed to 100% oil it can sometimes perform even better than mycelium exposed to lower concentrations.

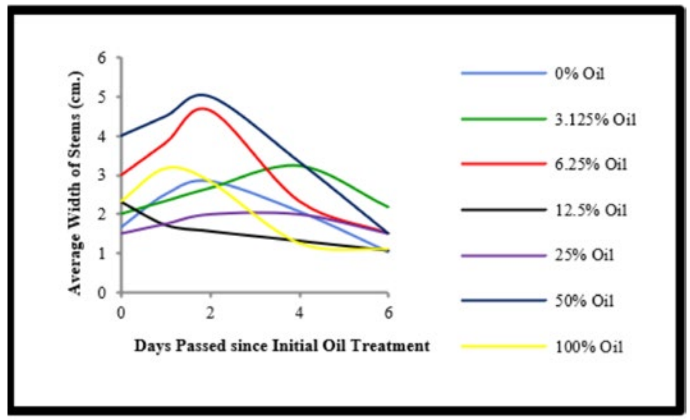



**Figure 3:** Average Width of Mushroom Stems in Six Days following Initial Oil Treatment

But the most famous experiment using fungi to clean up oil comes from myco-guru Paul Stamets himself. In one trial, Stamets and his team covered a large oil spill with Oyster mushroom mycelium grown on straw. **The oil contaminated soil contained up to 20,000 parts per million of contaminated particles at the start of the experiment.**

**16 weeks after inoculating the contaminated soil with Oyster mushroom mycelium, a beautiful flush of mushrooms emerged and the parts per million dropped to 200 parts per million!**

But these experiments are on land. How do we deal with oil contamination in water, or worse yet, salt water?

Well, good 'ole uncle Paul has thought of that, too.

Trav Williams Broken Banjo Photography

# 9.3 THE FUTURE IS FUNGI

Oyster mushroom myceliated straw can float and one of Stamets' strains of Oyster mushrooms is tolerant to saltwater exposure. In fact, **the mycelium of one particular strain can fully consume salt water soaked straw with a salt percentage of 3.3%, just 0.2% less than the average salinity of the world's oceans.**

So why isn't this already being implemented on a large scale? Well, as with most mycoremediation experiments and projects, **more funding and research is needed.**

Unfortunately, in today's capitalistic society, there's a lot more money to be made producing and transporting oil than there is cleaning up the mess these activities create.

Side note: If you're interested in a low-tek approach you can try at home or to a small spill in your immediate area, check out the Mycoremediation Rapport by Fungaia Farms. Levon offers a full explanation of his process so other people can replicate it themselves!

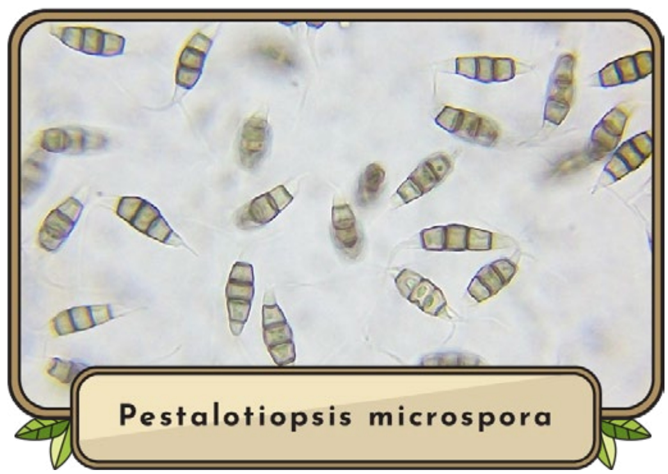
Remember that big butt problem we mentioned earlier? No, not those butts! Maybe you need fungi to help clean up *your* mind. Anyways...

Peter McCoy, author of the seminal work Radical Mycology, also **trained a strain of Oyster mushrooms to completely consume and break down the pesky cellulose acetate present in the cigarette butts.** How?

We'll let him explain in his video:
**Radical Mycology: Training a Mushroom to Remediate Cigarette Filters.**

Alright, so thanks to Oyster mushrooms, we may have oil spills and cigarette butts covered. But what about the bane of modern human existence, plastic?

If you've dove this deep down the fungi rabbit hole, you've probably already heard that **there are a few plastic-eating fungi.** Let's meet them.



Pestalotiopsis microspora

*Pestalotiopsis microspora* is probably the most famous of the plastic eating bunch.

Since 2011, we've known that ***P. microspora* can, within anaerobic environments, break down polypropylene and polyurethane plastics completely!** Up to today, large scale applications of *P. microspora* have yet to be found.

But a recent discovery may completely revolutionize the way we deal with plastic waste.

Enter *Aspergillus terreus* and its friend, *Engyodontium album*. **These two fungi can completely break down polypropylene plastic after it has been pre-treated with either UV, heat or the Fenton reaction.** Yes, the same Fenton reaction that brown rot fungi utilize to break down conifers.

This is especially striking because currently **only about 1% of all Polypropylene** – often used in plastic bags and takeout food containers (–) **is being recycled.**

Aspergillus terreus

Engyodontium album

But the key aspect is speed.

**It takes these fungi just 140 DAYS to break down polypropylene.**

"It's the highest degradation rate reported in the literature that we know in the world," Dr. Ali Abbas said of this discovery.

Just as amazing, according to the paper published in Nature, initial tests have also found that these fungi can grow and survive on the surface of these plastics. In other words, **we could hypothetically just treat the plastic with heat or ultraviolet radiation before inoculation and wham, in 140 days the polypropylene could be a thing of the past.** For comparison's sake, with *P. microspora*, the plastic needs to be in an anaerobic environment to be adequately broken down.

Imagine a future where all of our trash gets separated by AI. The compost goes where it can feed the soil, recyclables are properly recycled, and the literal tons of plastic and cigarette butts are fed to fungi trained for the job, reducing these "wastes" into bioavailable nutrients for the soil.

It may sound like science fiction but if we set our minds towards this, I believe we can get to this utopian ideal within the next 5 years!

Now, onto Nuclear.

You don't have to be a nuclear scientist to know nuclear waste is incredibly hard to clean up. Remember the module about Lichen when you learned that some fungi can survive the radiation in space?

Now, what if I told you that if you buy one in the next five minutes you'll get the second one free! Wait a second, that's not where I was going. Oh yeah...

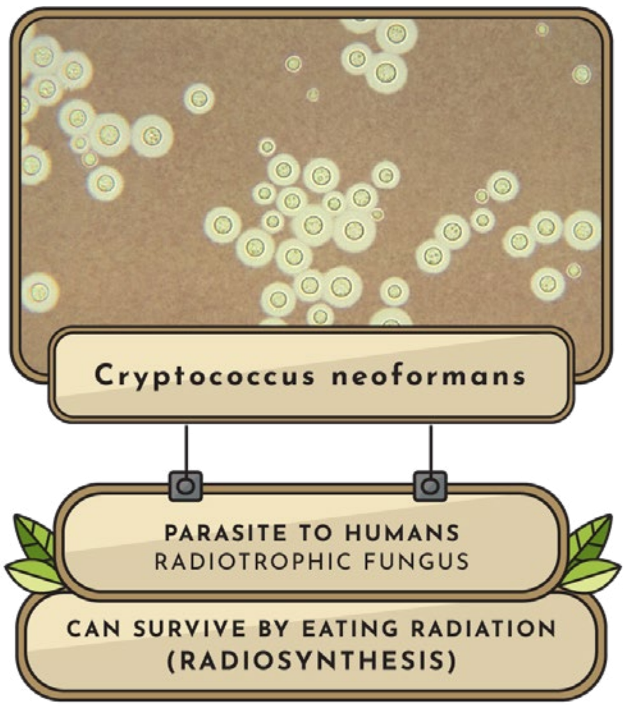
What if I told you that there are some fungi that can actually eat radiation?!

# 9.3 THE FUTURE IS FUNGI

***Cryptococcus neoformans,*** an encapsulated yeast fungi, is not only a parasite to humans; it's also a **radiotrophic fungus,** meaning it **can survive by eating radiation!**

This process is called **radiosynthesis.**

In fact, three fungal species—*Cladosporium sphaerospermum, Wangiella dermatitidis, and Cryptococcus neoformans*—actually increased in size and accumulated acetate faster in an environment where radiation levels were 500 times higher than the normal environment in one study.




**As these fungi's biomass increases, the environment's radiation levels drop.** In fact, the radiation levels drop so much that NASA has started to experiment to see if these radiotrophic fungi may be able to act as a radiation shield for future endeavors into space.

By now, it's pretty clear: we're at the forefront of a completely new chapter in human-fungal relationships.

Unfortunately, humanity's incredible rate of pollution and destruction is happening at a pace far too fast for Fungi to handle. We need to reduce our consumption drastically for these fungi to catch up to us.

Finally, let's talk about the elephant in the room: Water, AKA the basis for all biological life on Earth.

We can use **mycoremediation—remediating the earth with the help of fungi**—to clean up all the oil, butts and plastic we want. But if we can't get a clean cup of water into our bodies every now and again, well, we're dead.

**Mycofiltration—filtering out pollutants from water using fungi**—may not be the most promising option, but it certainly could be a useful tool in the toolbox.

Earlier, we talked about the lasso-like abilities of Oyster mushrooms when hunting nematodes. But there's another mushroom that's a secret underground hunter: Garden Giants, AKA *Stropharia rugosoannulata.*

When you run water through straw that's consumed with Oyster or Garden Giant mycelium, an incredible reduction in parasites like *E. coli* has been observed. A drop in the levels of petrochemicals and heavy metals has also been found.

The techniques are a bit too complicated to explain. And in all honesty, there are still a good deal of kinks in this system of filtration. Nonetheless, there's some real potential here just screaming to be funded and studied more extensively.

And that, my friends, is a crash course in the possibilities of Mycoremediation.

Though the future can appear gloomy, if we keep building and strengthening our alliance with Fungi, the picture becomes brighter.

In the next lesson, we'll learn how fungi can help slow the tide of man made destruction and pollution.

That's right, we're talking Mycomaterials babyyyy!!!

## REVOLUTIONIZING OUR CREATIONS

Sure, we can clean up our mess with the help of fungi. But wouldn't it be way better if we didn't trash our home in the first place?

It may come as a surprise to you but in today's world, small rural communities struggle the most with trash. It makes sense when you start to think about it: cities that have existed for hundreds of years have well developed trash disposal systems in place. Rural communities, on the other hand, do not.

Up until the second half of the 20th century, rural communities were able to practically throw everything they consumed over their shoulders and let nature take care of it au natural. But when plastic burst onto the rural scene, education in its proper disposal often didn't come along with the technology. So, people carried on doing the same thing they've always done: throw their trash out the window, over their shoulder, or into the woods.

What if we could go back to the old ways when everything we produced found its way back to the soil?

**Tamales** (MESOAMERICA)
Corn dough wrapped in a banana or corn leaf

In this lesson, we'll learn about one approach that could help us reapproach our past: **Mycomaterials, or more simply put, stuff made out of mycelium.**

Packaging, houses, bacon, rowboats, chairs, surfboards, shoes, coffins, hats, heck, even computers; Mycomaterials can do it all!

First up, let's talk about the main fungi being utilized in this quickly emerging arena: ***Ganoderma spp.*, AKA Reishi mushrooms and their relatives.**

**Ganoderma lucidum**
(Reishi)

If you've ever grown Reishi mycelium too long on a Petri dish and then tried to cut through it to transfer to a new Petri dish, you've experienced how tough as nails Reishi mycelium can be.

Aside from being strong and durable, Reishi mycelium has a couple other things going for it: it grows incredibly quick and easy, it's biodegradable, and since humans have hundreds (if not thousands) of years of experience growing them, we don't need to reinvent the wheel here.

## PACKAGING

So, what can Reishi mycelium replace? How about the petroleum-based styrene known as styrofoam?

Reishi mycelium can easily eradicate our need for styrofoam, which is produced by the millions of tons each year for packaging, insulation and disposable containers like beverage cups, then leaches chemicals into our water when it's disposed of improperly.

Ecovative, an industry leader in the production of mycomaterials, already has commitments from companies including Ikea and Dell to use their mycomaterial in place of styrofoam for packaging. This packaging is made of hemp that's inoculated with Reishi mycelium and placed in a mold, where it is then completely myceliated by the Reishi mycelium over the course of several days or weeks.
The final step involves baking the myceliated hemp so it hardens into its final shape. The high heat also kills the mycelium, ensuring the Reishi mycelium doesn't continue to grow and warp the final molded shape.

*Mushroom Packaging by Ecovative for TREATY*

*Mushroom Packaging by Ecovative for DELOS*

*Mushroom Packaging by Ecovative for KEAP*

But when it comes to mycomaterials, packaging is just the tip of the iceberg.

You might not have the industrial capabilities of Ecovative but if you know how to grow Reishi, you know how to grow your own plant pots, lamp shades, ashtrays, coat hangers and mush more. The sky, or more so, your creativity, is the only limit!

After watching our Masterclass on Mycomaterials with Catherine, you will have the foundational knowledge to not just grow common household items yourself, but even set your sights on larger projects.

Like what, you ask?

Some companies have begun to build surfboards out of mycelium. A Dutch company is building coffins out of Reishi mycelium. Our friends at Me & Myco have built furniture! Heck, a Nebraskan student even built a kayak!

Reishi mycelium coffin by Loop Biotech

Chair 2.0 (reishi binding hemp) by Me & Myco

But how about an even more ambitious undertaking?

## CONSTRUCTION

According to research by the U.S. Green Building Council (USGBC), **the real estate industry accounts for 40% of energy usage worldwide.** Further, new research by construction blog Bimhow estimates **the construction sector contributes 23% to total air pollution, 50% to climate change, 40% to drinking water pollution and accounts for 50% of landfill waste.**

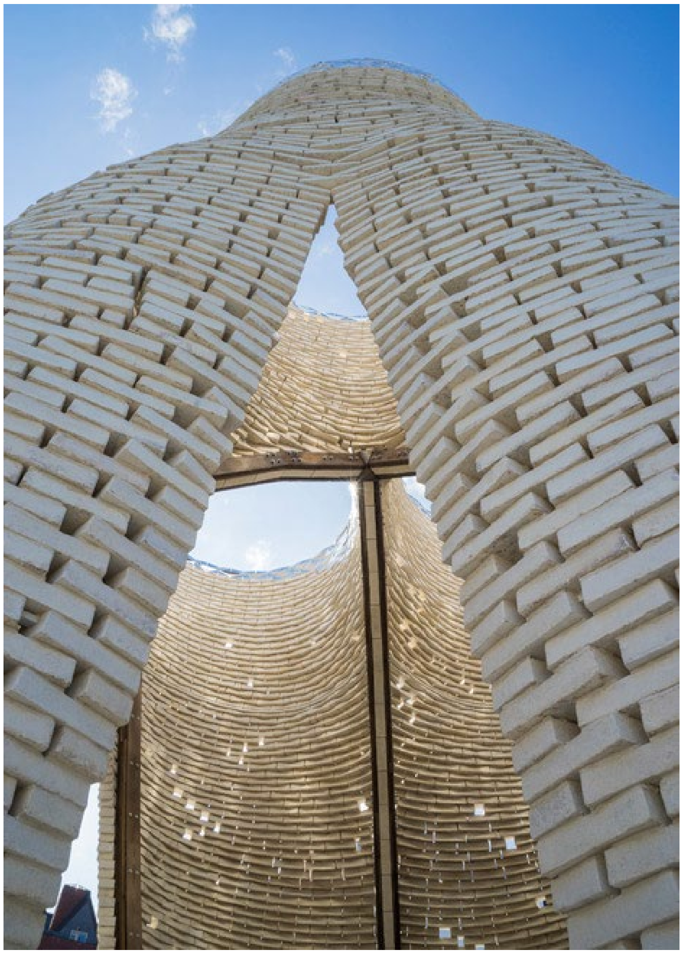
It's impossible to overstate the impact the construction industry has on the pollution, waste and climate change we see around us.

Obviously, if we could build the structures of the future in a more sustainable way, we could make a real dent in all this environmental carnage.

The Hy-Fi Tower, an organic mycelium brick tower designed and constructed by the architectural firm The Living for display at New York City's Museum of Modern Art (MoMA), shows us the way forward.

Hy-Fi Tower by The Living

Using the same technique developed by Ecovative in 2007, a cluster of circular towers over 12 meters (39ft) tall were built using 10,000 bricks composed of shredded corn stalks myceliated with Reishi mycelium. After three months of display at MoMA, the structure was disassembled and the bricks were composted.



*Hy-Fi Tower by The Living*

Of course, that's a lot of work for a building that only stood for three months. But the concept is what matters. Before we completely replace all our construction materials with mycelium bricks, we could at least start by insulating our houses with mycelium.

## LEATHER

Reishi isn't just strong. It can also be smooth, supple and slick.

Mycelium foam has already been developed by Ecovative (hello, mycelium mudras and dreams on mycelium yoga mats and mattresses). But it's the development of mycelium "leather" that has people really excited.

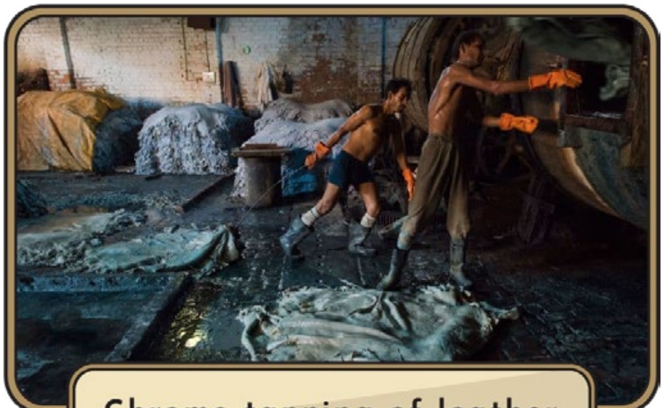
Humans like leather for good reasons: it's durable, water resistant, smooth and damnit, it looks cool! But leather is oftentimes produced using the skins of dead animals that were raised in the horrendous conditions of factory farming. And that's just the start of this wildly destructive process.

Globally, it's estimated that we produce around 2,200 square kilometers (or 550,000 acres) of leather every year. That's a lot of dead animals.

But the modern tanning process is also a major issue.

Back in the "old days," the bark of trees like Chestnut trees was soaked together with the animal hide for up to three months to prepare the hide properly for further processing.

These days, we can do that entire process in a single day using chromium, which is used for up to 90% of the world's leather production.



Chrome tanning of leather

Surprise, surprise! Chromium isn't good for humans or the environment, with a lethal dose of chromium at only like a gram. In fact, leather tanners who work with chromium day in and day out have much higher rates of certain types of cancer.

Toxic impacts on workers

Consumers aren't spared either. Modern leather contains up to 5% chromium, so the old idea of eating your leather boots when you find yourself lost in the wilderness doesn't really hold up anymore.

According to the United Nation Industrial Development Organization, producing a single square meter of leather creates about 16,500 liters of wastewater polluted with chromium, sulfates and other gnarly stuff.

And according to a 2014 study, a single square meter of leather puts at least 65 kg of $CO_2$ into the atmosphere.

Add that all up to a yearly rate and we're creating an unbelievable 3.3 trillion liters of toxic wastewater and adding a ridiculous 130 billion kilograms of $CO_2$ to our lovely planet's atmosphere every year.

So, how do we rid the world of this animal and environmental carnage yet still get our leather fix?

Cue Reishi leather.

Mycoworks, another company in the Mycomaterials scene, has developed an incredible fungal-based leather alternative that doesn't use chromium or any other pollutant and is completely free from animal cruelty.

It's also water resistant, durable, smooth, strong and sexy, just like the editor of this workbook, Sam. Well, he's more resistant to the water of Guatemala than he is water resistant...

Sam the Mushroom Man

Get this: this mycelium-based leather alternative is already in the marketplace. Mycoworks has teamed up with Adidas to replace the leather in their shoes, and Hermès to replace the leather in some of their handbags.

*Mycelium-based leather handbag - Mycoworks & Hermès*

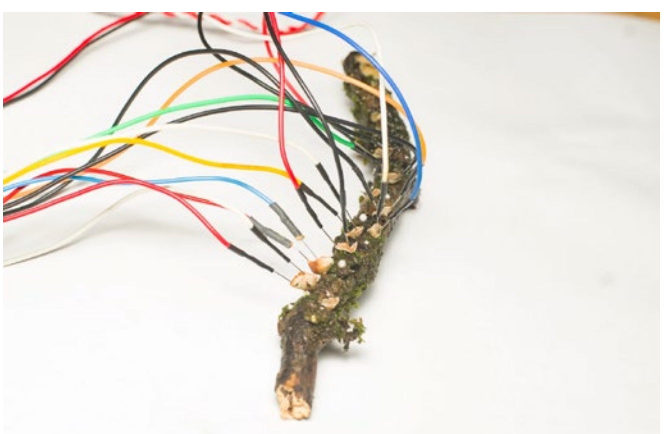
As this process becomes more refined, expect these products to become cheaper and more accessible. Hopefully, maybe in our lifetime, Reishi leather will become the most popular leather in the world.

As with much of mycology but especially with Mycomaterials, the field is so young that practically anybody with a dream and a lot of R&D is capable of contributing a breakthrough discovery that inches us one step closer to our mycelial dreams.

We can't end this module without mentioning maybe the coolest and maybe the most creative way to work with mycelium:

Building a mycelial computer!!!!!

*Andrew Adamatzky*



Andrew Adamatzky, director of the Unconventional Computing Laboratory at the University of the West of England in Bristol, has been building fungal and slime mold computer interfaces since 2001.

The goal? Bridge the gap between living and artificial life.

Presently, his lab has already discovered that fungi can receive and transmit electrical signals. If you pay attention to our newsletter and to random fungi-centric news, you may remember reading about his lab's discovery that there is a pattern in the electrical signals emitted from fungi that he argues is a type of 'fungal language.'

We won't even try to get into how he builds these interfaces because frankly, we have no freaking idea.

But we hope that by now the crux of this module is clear: with some creativity, the sky is the limit when it comes to cleaning up and rebuilding a better world with the help of fungi.

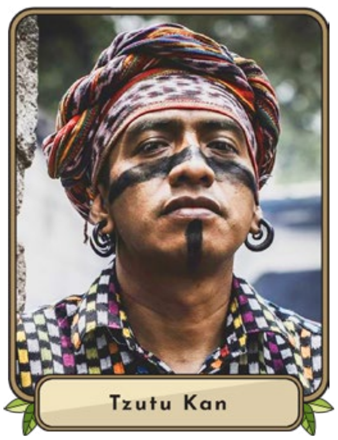
We can't wait to see what will come out of this Fungal Renaissance as the minds of millions begin to look at fungi through a new lens.

## WRAPPING IT ALL UP

Here we are: the final lesson of this course! It's been quite the journey, hasn't it? I am beyond proud of what we have accomplished with the resources that we have. As we mentioned in the first lesson, this has been a project of incredible passion, and before we get into the nitty gritty of the content, I just want to thank everyone that has put their time and heart into making this course a reality.

You've already met **Corie**, the magic behind the lense, our Director of Cinematography! Helped out by Mayan Fungi resident and Video Editor protégé, **Tzutu Kan**. Maltiox!


Corie


Tzutu Kan

**Milly**, the mushroom mama who moved her family across continents TWICE during the making of this course, our Project Mama aka Project Manager, always making sure we're keeping each other in check in an incredibly nourishing way.


Milly


Karena

**Karena**, who made sure our retreats and all the other fantastic fungal activities that we host ran smoothly while the rest of the team was buried head-first in this monstrous project!

**Geegee**, our lead Graphic Designer who has made all the promotional material, AND the whole workbook (which looks magical as fuck!)

**Julia**, the illustrator who has done an incredible job in making heady, technical graphs look fun, clear and beautiful!


Geegee


Julia

**Sam** the Mushroom Man of Mindful Mycology, the Editor who turns all the craziness I put onto pages, into narrative sense. *(The smooth fella you saw a couple pages back)*

**Shahar**, for all the great ideas and epic Midjourney skills.

**Richard**, who kept the Fungi Community active and taken care of while we ventured into the realms of deep digital work and online course creation.

Shahar

Richard

And of course, my Obi Wan Kenobi, **Oliver Merivee**, Father Fungi who dreamed this project into reality. Without him we'd be nowhere and you wouldn't be reading this right now. Forever grateful for his life and all he has given us!

Oliver Merivee

I can't forget the people who helped kickstart the course, the boys of **Plaga Studio** and **Holden**, for getting the first lesson off the ground.

Antonio & Alejandro
(Plaga)

Holden

And, of course, YOU - you reading this right now! Without your support we wouldn't have been able to create this massive course! We did not receive any outside funding, it's genuinely all because of people like you, who trusted us to make something epic, that we find ourselves here today.

As we round out this huge course, I want to point out that, of course, we couldn't cover everything. During the making of this course doors to new, interesting and exciting areas of study kept opening and at some point, we just had to keep some of them shut. In hindsight I would've liked to spend a bit more time on the module on Mycorrhizal and Endophytic Fungi. Later down the line I also got really into Aquatic Fungi, an often forgotten story that would've found its perfect home in Fungal Ecology. Alas, the work of an artist, or teacher, is never done. It's hard for us to call this project truly finished. Yet we have to in order to share it with the world. If we missed your favorite fungal fact, feel free to share it in the comments below!

Sentimentalities aside, let's wrap up this last module and put a nice ribbon on it.

So, what do we do with all this understanding of the Fungal realms? How do we build a Fungal alliance?

Often it just starts with giving these wonderful organisms attention! Luckily we seem to be in the middle of the Fungal renaissance. So, to begin with, share what you found to be most exciting in this course! You never know who you might inspire when you share the magic of fungal wisdom.

Corie Bidgood @corie__bee

Here at Fungi Academy we believe it's all about the human connections that we make through our common love for these ancient weavers of the world as we know it. And that's where the human-mycelial network comes into play - the best way to start your journey towards creating a fungal alliance is by finding the human beings in your ecosystem who love mushrooms! Find the local grower, foraging club or mycological society. And if there are none around you: START ONE! Dozens of Fungi Academy Alumni have started local foraging groups, mushroom farms, medicinal mushroom extraction companies, microdosing integration circles… The list goes on and on. You can do this too!

You don't need to be an expert to connect with the fungi in your ecosystem. This has become so much easier with tools like iNaturalist, an app built to log the findings of citizen scientists. You can actually use it to learn about literally all the creatures and critters roaming your ecosystem, even amoeba and bacteria aren't overlooked with iNaturalist.

One of the coolest things about working with Fungi: you never know when you could be the first to discover something. Especially in areas not often explored by mycologists and mycophiles, they may be filled with mycelial mysteries yet to be revealed - you might find something that baffles the community, you might even find a new species!

Finding Fungi in the wild and building authentic human connections aren't the only ways that we can revolutionize our local mycosphere.

As a mushroom cultivator, I truly believe I learn the most working directly with the mycelium - I propagate their growth so they can propagate mine. I feel I understand their behaviours, I come up with new ideas to apply this knowledge and damn, there's nothing like seeing a successful grow come to fruition! And by learning how to grow mushrooms (or, more correctly, mycelium), not only do we learn how to grow our own food and medicine, we're also preparing ourselves for learning about mycoremediation, mycoconstruction, inoculating our orchards with beneficial, local mycorrhizae or endobionts and all of the other wonderful practices that we've learned about during this last module of the Fungal Ecology course.

We are often raised to think that humanity has gotten it all figured out. Studying Fungi in all their various shapes and forms has taught me that's not the case at all! Innovations are happening ALL the time, and it's just SO EXCITING!

The fungal renaissance nowadays goes hand-in-hand with what some call the psychedelic renaissance. Maybe because mushrooms are the most easily accessible psychedelic, or maybe because the mushrooms cheekily infuse mycophelia into the journeyer… either way, psychonauts are often also myconauts, and the other way around.

Millions of people around the world, myself included, have found an immense improvement in our lives by working with sacred mushrooms. They have taught me many things about myself and the world around me, the most profound of which is that we are not separate from nature, we are nature. I could talk about these magical substances and their benefits forever, but we have already made a whole course about Psychedelics and how to get the most out of them so check it out!

And that's it!

Thank you so much for supporting our endeavors and for loving the fungi as much as we do! If you're still craving more fungal wisdom, we have conglomerated a list of our favorite books, documentaries, youtube videos and all of that good stuff for your viewing pleasure. We also compiled a list of mycological societies or associations for you to check out! Understandably, this list is not exhaustive but we'd love to make it as thorough and as global as possible so if you want to add yours, feel free to hit us up!

Ok now this is really the end… I should probably end it on an inspirational note…

Here we go:

Humanity is at a crossroads. The rapid, human-induced change has significantly reduced the abundant, liveable space on this planet. This is an existential threat to us, and to the animals, plants and even fungi that we share our planet with.

Ironically, if we continue on this course and make life completely uninhabitable on Earth for humans, Fungi will pick up the pieces and create a wonderfully thriving ecosystem in some 30-40 millions years or so. They have done it before, they can do it again.

But that destiny is far from certain: we can change, we can work hard to make the more beautiful world our hearts know is possible (to quote Charles Eisenstein once more). We just have to listen.

Fungi teach us many things, but most of all they teach us that there is no such thing as an "individual" on this planet. We are ALL an interconnected network of organisms: from the micro to the macro, we are inherently codependent on the success of thousands of other beings. Fungi showcase that collaboration, not competition, is the key to success. If we take that lesson from the fungi, if we live by their example, I have no doubt that a very, very bright future is in store for us.

Thank you for your presence, for your curiosity, for your support; we are forever grateful.

May life smile upon you.

Maltiox, ahau, aho, ometeo, ashe, PEACE.

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Page 176 - According to the UN Food and Agriculture Organization, we use about 100 billion kilograms of synthetic nitrogen fertilizer globally per YEAR.

Page 181 - Trad Cotter's experiment

## MYCOLOGICAL SOCIETIES/ ASSOCIATIONS:

International Mycological Association

British Mycological Society (BMS)

Central Texas Mycological Society

North American Mycological Association

FIN