# Before the Spawn



[Music]

*Izzie*: Welcome to Morel Dilemma, an exploration of why some mushrooms are so highly sought, some are so heavily cultivated, and some are so very dangerous. Today we're talking about the darkness before the spawn... that is, fungus sex. That sounds like a really weird place to start, but it makes sense. I promise.

Before we talk about how, when, and where people farm mushrooms, we need to talk some basic fungus biology.

Most produce is grown like this: Step 1: get some dirt. Step 2: put a seed in the dirt. Step 3: water the dirt. Step 4: the seed splits open and green things start sprouting from it, going up towards the sun, and, using the sun's energy, brown things sprout from the seed and go down into the ground. Step 5: after however many weeks or months of watering and fertilizer, the seed has become a full plant. Maybe it grew fruits or vegetables that we can take and eat.

This is what we learn in kindergarten, and it's pretty darn accurate. In general: you put a seed in the ground and you get a plant out of it.

That's not how fungi work.

[Music]

*Izzie*: The way plants and animals reproduce allows a seed to become a plant when you water it in soil, or allows a fetus to become a person in its mother's womb. Most of the time, we humans are "diploid", meaning that almost every cell in our body has two sets of genetic information in chromosomes. Altogether, each of our non-reproductive cells has 46 chromosomes: 23 from our father, 23 from our mother. Since our parents are also diploid most of the time, for us to happen, something needs to cut half of their chromosomes out. This happens via a process called meiosis.

Meiosis marks the border between the diploid phase and the "haploid" phase - where cells have "half" the normal number of chromosomes. Eggs and sperm are haploid. This is important because it means that when an egg and a sperm meet up, they can fuse, combining their two sets of 23 chromosomes. The result is a diploid cell with 46 chromosomes, all set to become a person. The fusing of sexual haploid cells generally happens when they meet, inside of a mother-to-be or, in flowers, inside the ovary destined to be fruit.

Fungi also pass through both the diploid and haploid phases in sexual reproduction. The big difference between plants and fungi is that where a plant seed is like a baby plant, all set to become an adult, the fungal spore is more like a human egg or sperm.

It can't make a grownup fungus by itself; it needs to meet up with another haploid cell.

Like seeds, spores settle wherever they land. In order to meet up with another haploid, each spore sends out long, thin "hyphae." Each hypha, still haploid, stretches outward, hoping to encounter a hypha from a different spore - the "egg" to its searching "sperm". When two hyphae meet, they fuse together. They may combine their DNA into one nucleus, resulting in the diploid state, or they may leave their nuclei separate, resulting in a "dikaryotic" state. Either way, the cells with two nuclei are known as "fertile" hyphae, because they're the ones that eventually give rise to new spores. The diploid cells continue to divide, forming the fruit of the fungus - in many cases, a mushroom!

Once the fungus is old enough, it can make spores of its own. If the fertile hyphae were in the dikaryotic, "roommate" situation, this is when they fuse to become diploid. If the fertile hyphae were diploid, they stay diploid. In both cases, they get ready to enter meiosis. This is a hugely important process for all sexually reproducing organisms on the planet, but I won't be offended if you don't take notes.

First, everybody duplicates. Doubling up on the DNA means all the new cells we're about to make will get some DNA, which is kind of important.

Then, the parental chromosomes swap small regions of their DNA. But only where it matches up! Remember how we humans get 23 chromosomes from each parent? Well those two sets of chromosomes are sort of symmetrical. So while chromosome number 1 from daddy and chromosome number 1 from mommy contain different information, they still contain information about the same kind of thing. For example, if chromosome 1 tells an embryo what kind of hair to grow, mom's version of chromosome 1 might say to make it brown and straight while dad's might say to make it black and curly. Fungi don't have hair, but you get the idea. So in the start of meiosis, the chromosomes add to the randomness of genetic variation by swapping some of that information around. This means that most of dad's version of chromosome 1 might stay intact, except the bit about color - that part now says "brown" instead of "black." What this means is that no matter which chromosomes end up where, the offspring of mom and dad will not be exactly alike either parent.

In the next part of meiosis, all the chromosomes line up in the middle of the cell. This is how the cell makes sure all the DNA is present and there aren't any missing chunks that will cause problems later. Once everybody's been accounted for, it's time to split up into *two* cells, each of which is fully diploid, and has one *extra* copy of all of its DNA. This is why we duplicated our DNA in the first step. The key thing about this step is that the chromosomes are divvied up randomly, so in each new cell you have a mix of mom DNA and dad DNA. This *also* helps make sure that the offspring are different from each parent.

Finally, it's time to separate one more time, into a new generation of spores. Because of the genetic exchange between chromosomes and the shuffling of mom and dad DNA, when the DNA gets divvied up into new spores, each one is genetically distinct from not only the mushroom itself, but from the parent spores *and* the *parent mushrooms*. And that's super important! It's basically the entire point of sexual reproduction! It makes sure that the species isn't a bunch of clones that can get wiped out by a single disease, as well as introducing variation that allows species to evolve and change and split and make new species. The genetic variation introduced by meiosis is one of the keys to the incredible diversity of all life on Earth!

It was also six minutes of some pretty heavy science. I think you all deserve a break. But our story isn't over yet, so I'll be back in a little bit with lots more on the exciting world of fungus reproduction!

[Music]

*Voicemail Recording*: Hello! You have reached the voicemail for the podcast Morel Dilemma, hosted by me, Izzie Gall. I can't talk fungi right now, but if you leave me your name, number, and a brief message, I will get back to you as soon as possible. Thank you!

*Kay Labella*: Hi. My name's Kay Labella, and I'll be reading about fairy ring mushrooms from the Oxford Companion for Food.

*Marasmius oreades* is a small, common, edible mushroom. It resists drought by shriveling up and filling out again when it rains. The 'fairy rings' of darker green grass in fields are caused by successive generations of the mushrooms spreading out from an original small clump. Their flavor is excellent. A close relation, *M. scorodonius*, smells of fresh garlic.

Alright, Izzie, I hope that was good!

[Music]

*Izzie*: Alright, so we've gone from diploid fungi to haploid spores to diploid fungi - that's our sexual fungal life cycle. Fungi can also reproduce asexually, producing clones. This is done by budding, where a baby grows directly on the parent, or by fragmentation, where one adult splits to become two smaller adults. In some cases, a diploid fungus can actually produce spores by *mitosis*, a more common means of cell division that isn't as complicated as meiosis and doesn't involve any DNA swapping. Spores produced by mitosis are sort of like the fungus's "mini-me": they're just little clones of the parent

Generally, fungi perform asexual reproduction in relaxed situations, where there's enough food and water and not too many things eating them. When situations get stressed, they switch over to sexual reproduction. Since this makes a more diverse population, it lowers the risk that the species will be wiped out because of whatever is stressing the fungi out.

Understanding how fungi reproduce is super cool, but it doesn't tell us too much about what fungi actually look like when they're growing. Fortunately for fungus nerds, there's an astounding diversity in how fungi look! The fruiting bodies the hyphae produce can be large like the gilled mushroom *Macrocybe titans*, which can grow to several feet in diameter, or tiny, like the fuzz on old bread. In yeast, which doesn't use hyphae at all, the fruiting bodies are just one cell large enough to hold four spores.

There's also some diversity in how the hyphae behave. Some hyphae keep growing outward even after they've already fruited, making multiple spore factories. This is why bread molds and ringworm make circles: the hyphae are ever growing outwards from the place where the spores landed.

But we aren't here to talk about bread mold and ringworm; we're here to talk about mushrooms. Morels, specifically. Well, morels are *ascomycetes*. *Ascus* means "cup" in Latin, so ascomycetes are fungi that make spores inside of cups. Morels have a bumpy surface with what looks like tunnels going towards the center. Those are the cups, and spores are made inside by meiosis, then released from inside those little tunnels to be carried off on the wind. Morel hyphae are the boring kind that meet up, fuse, and make one mushroom. You won't find rings of morels, sadly - they stand alone. The good news is that when you've found one morel, you will find more later - they sprout up in the same place every year so long as the hyphae underneath them stay intact.

Truffles are also ascomycetes, but their cups are all contained inside the body of the truffle. This is why they need to smell delicious - so that humans (or pigs) will dig them out of the ground, eat them, move along, and, well… poop the spores out somewhere far away. What? Good fertilizer is hard to come by!

Gilled mushrooms that are more familiar in popular culture and commerce - think magic mushrooms, but also think portabellas - are called *basidiomycetes*, or club fungi. As ascomycetes are named for having their spores in a cup, basidiomycetes are named for having their spores on a *basidium*, a microscopically club-shaped surface. These clubs are the place where the spore nuclei finally join up to become diploid, and they are also the site of meiosis. The clubs line the gills of the mushrooms, each club holding four spores. When the spores are mature, they are released into the wind to fly off somewhere.

Puffballs are also basidiomycetes, even though they seem similar to truffles. Puffballs are above ground, though, and rely on the wind, not animals, to spread their spores. You may be familiar with puffballs as they are quite common and a lot of fun to poke because when they're ripe, they burst open with clouds of spores. I would like to ask you not to poke puffballs, though, because if they burst before they're ripe, they can't make mature spores and then we may end up with fewer puffballs.[1] If you're planning to eat the puffball, that's a different story… because you want to eat it waaay before there's any danger of it exploding into trillions of spores in your mouth.

Hold on a second, did I just say "trillions of spores"? That has to have been a slip, right? Nah, that's legit. Mushrooms produce a *lot* of spores. The biggest mushrooms, like the three-foot *Macrocybe titans* I mentioned earlier or foot-long puffballs, release maybe seven trillion spores each. To put this into perspective, a recent study published in

[1] Correction: picking mushrooms does not influence future harvests from the area. See "Foragin' Policy" (Season 2, Episode 1) for more information.

the Annals of Human Biology estimated that there are around 3 trillion cells in the average adult human's nervous system, two trillion in the skin, and two trillion cells lining the circulatory system - so if you were to combine your skin, your entire nervous system, and a good part of your circulatory system, you'd have the same number of cells as a large adult mushroom releases. Obviously this comparison is not perfect - spores are much smaller and much less complicated than the cells in your body, since they don't have to do anything but *be spores*. But it's still wild to think about! Now think about how many puffballs there are in all the woods and lawns on Earth, of varying sizes, and that's a lot of spores, right?

Make sure not to forget the other airborne spores from all the other mushrooms. If this is making you feel like sneezing, that's probably because there are tons of spores wherever you are right now. Viable bread spores have been found happily bobbing around 40,000 feet in the air. Maybe don't put your sandwich on the outside of your plane next time you fly. It could get moldy before you land

In this episode so far, you've crammed your brain full of all kinds of information about sexual and asexual reproduction, hyphae behavior, fungal fruiting, and spore dispersal. I'm very proud of you, so I'm going to let you in on one more awesome tidbit before we wrap up for the day. You may have been wondering why all these trillions and trillions of spores in the air don't mean that the planet is totally overrun with mushrooms. I mean, spores land eventually, right? Well, that's because spores are different from seeds in yet another fun way: *nobody actually knows what spores need* to germinate! Oh, we know they need to be somewhere wet, and we know they need a food source. But they also apparently need something a little extra. Not all of the spores that land on bread grow into molds - otherwise you'd never be able to eat bread.

To produce hyphae, spores have to land near something that can activate them. I'm not just trying to make this sound cooler; the special something a spore needs is actually called an "activator." The activator can be physical or chemical. Various activators have been discovered, but not all of them work for all spores that have been tested. Alcohol, detergents, and certain acidic or basic treatments have been known to activate some spores. Okay, you say, this doesn't make spores sound *very* different from seeds. Seeds can't live on dirt and water alone; a lot of people fertilize their gardens. What's the big deal? What makes activators so important they get an awesome name like "activator"?

Well, the amazing thing is that if an activated spore loses its food source or its water, *it doesn't get un-activated.* If the spore has been activated once, it can wait for ages and as soon as it finds food and water again, the spore will germinate! This would be like if you tried and tried to grow an apple seed, but nothing was working - you tried fertilizer, plain dirt, compost, enriched soil, a different kind of fertilizer, tap water, purified water, distilled water, and so on, in lots of combinations, and nothing worked. Then you abandoned your apple seed in the kitchen and accidentally spilled some soap on it. In a fit of madness you decide to try the apple seed again in plain soil and water a month later ...and BOOM, instant apple tree.

So spore activation rounds out our understanding of why growing mushrooms is so different from growing other produce. First of all, plant seeds are tiny embryos all set to become grownups, while spores are more like sperm and eggs that have to meet up with each other before they can make anything useful. Then there's the fact that spores are finicky indeed, and nobody fully knows what they need to start growing up, so even if you were committed enough to collect a few trillion spores, you'd have no guarantee that you could make a mushroom from them.

Because of this, most mushrooms you buy at the grocery store aren't grown from spores at all. Instead, growers use thick masses of hyphae called *mycelium*. These hunks of haploids are big enough to be seen with the naked eye and all set to put up fruiting bodies wherever they can. This way, growers don't have to wait for hyphae to find each other or mess with spore activating agents until something magically works. Doesn't that sound better?

[Music begins]

*Izzie*: "Morel Dilemma" is written and produced by me, Izzie Gall. This episode's research was made possibly by NSF DBI grant 120-6197, in association with the New York Botanical Garden in Bronx, New York. Our theme song was composed and performed by John Bradley. Special thanks this episode for Kay Labella for doing the intermission. If you'd like to have your voice on the podcast, you can call the hotline at 347-41-MOREL. That's 347-416-6735. You can find other ways to contribute, and other Morel Dilemma content, at moreldilemma.org.

I would like to remind everyone that mushroom hunting is tricky business, and you should never eat a wild mushroom unless an expert has positively identified it in person and told you it is safe to eat. Remember that even so, everyone is different, and allergies to uncommon foods can be hard to predict. Species marked as edible in guidebooks could still make you sick. There are other ways of enjoying fungi. My favorite is photographs.

[Music ends]

## Resources

*In addition to background knowledge gained earning my Bachelor's degree in Biology, the information in this episode comes from the following sources.*

Bernstein, H; Bernstein, C. "Evolutionary Origin and Adaptive Function of Meiosis." In Meiosis: Bernstein, C and Bernstein H, editors. 2013. ISBN 978-953-51-1197-9.

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