Fungi

The invisible foundation of life on earth

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sources:

Entangled Life by Merlin Sheldrake
Finding the Mother Tree by Suzanne Simard
Scientific American
Microworld Micropia Nederland

What are fungi?

Until the 1960ies, there was no separate classification for fungi

Life on earth was classified as either flora or fauna. Fungi were a subsection of flora.

Growing out of the re-discovery of the healing and hallucinogenic properties of mushrooms, especially in America, interest in these strange life-forms was regenerated.

In medicine the discovery of the antibiotic qualities of some fungal growth, especially penicillin, sparked interest in the field of molecular biology. Fleming shared the Nobel prize for discovering penicillin in 1945. At first penicillin was made by fungi in large growing chambers, now it is made synthetically as its molecular structure has been copied.

Once microbiology started to focus on fungi, and their growth, the mycelium, extraordinary discoveries were made. Fungi were very different from plants.

The Mycologist David Hawksworth referred to it as the Neglected Megascience in 2009.

Origins

It’s now thought that fungi were the first life forms with a cell wall and a nucleus.

Fungi break down molecular structures by releasing enzymes and take up the result through their cell walls. They then both use and re-distribute the nutrients received. In fact more than 90% of all plants rely on the pre-digestion by fungi to take up nutrients (and possibly all).

Fungi chemically “burn” compost to make the nutrients available to the plants growing in it. That's why it’s warm. This burning does not produce CO2.

This fertilisation is very much more effective than artificial fertiliser.

Only since the development of relatively cheap and speedy DNA sequencing has it been possible to examine fossils of fungi from the very beginning of life on earth and scientists now think that fungi actually made life on land possible.

It's thought that they developed in the oceans near thermal vents about 3 billion years ago and teamed up with algae to form lichen, which was able to colonise the rocks of the earth from about 1.3 billion years ago. The algae would photosynthesize while the fungi could break down the rocks to extract the minerals.

Genes in fossils, common with living fungi today, were found in rock 600 million years old. Some scientists think that only the symbiosis between fungi and algae made life possible on land. There was no soil before they arrived out of the seas. They made the original compost. Unfortunately there is as yet no consensus about these dates, estimates vary enormously between 2.5 and 1.3 billion years.

Micropia Dutch Microbiology Foundation and Museum

In the spotlight: fungi

They help plants grow, make the most delicious food, and even clean up afterwards.

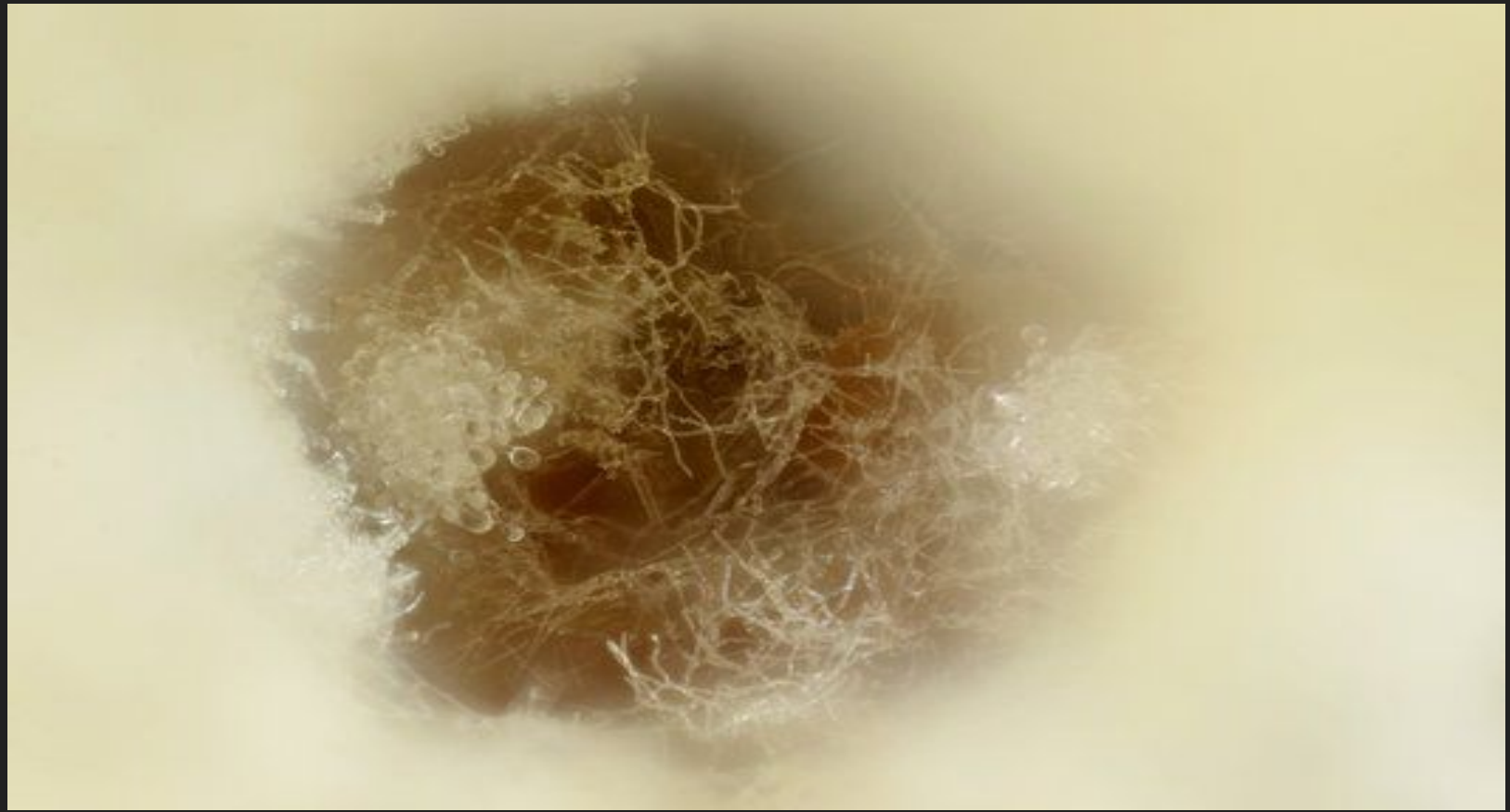
They may seem dirty, but without them there is no life.

What is a fungus ?

Fungi are eukaryotic microorganisms. In taxonomy, they form their own realm: the Fungi. This realm contains enormous diversity, although little is known about the number of species of fungi. Estimates range from 1.5 million to 5 million species. Of these, only about 5% have been classified.

Networkers and loners

Most fungi form fungal threads called hyphae. A lot of these hyphae together form a network, the mycelium. From the mycelium, reproductive structures can grow. These can be either relatively simple or complex, like a mushroom. Besides these networks, you also have fungi that grow as single-celled organisms, such as yeasts.



Fungal growth

Apples and mushrooms

A mushroom is also called the fruit body of a fungus. This is because it allows spores to form and spread. A mushroom is similar to an apple spreading the seeds of the tree. Certain mushrooms, such as the shiitake and oyster mushroom, are edible like most fruits.

Flavourful fungi

Fungi play an important role in our lives. They live on and in our bodies. As many as 150 species on your feet alone.We also use fungi in food and drink production. A well-known yeast is baker’s yeast (*Saccharomyces cerevisiae*), also known as wine or brewer’s yeast. It is, as its name suggests, essential in the process of baking bread and brewing beer.

Better together

92% of plant families cooperate with a fungus. Both the plant and the fungus benefit from this relationship. In the soil, the fungi form an external root network with which they collect nutrients and water the plant cannot reach by itself. The plants, in turn, supply sugars (products of photosynthesis) to the fungi.

Fungi as super recyclers

You may not see them, but they are all around us: fungi. In the soil, in the air, in water, on plants and animals. One of their most important functions is recycling. And you see that - especially in autumn - everywhere.

Rotten food

Many fungi are so-called saprotrophs. This is a name derived from ancient Greek. Sapros stands for “rotten, decaying”, and trophos for “food”.
Conclusion: fungi eat dead material. In the process, they break down large carbon molecules in organic material, returning essential building blocks to the soil. Fungi do not only clean up, but they make these nutrients available to plants again, completing the circle.

Plastic picnic

Fungi can recycle much more, even plastic! We already know dozens of species that digest polyurethane. One of these is *Cladosporium cladosporioides*. This common fungus is capable of digesting 87% of the plastic it lives on in two weeks. This process is too slow to be applied on a large scale, so research is being done on the degradation process and how to speed it up. We may be able to use these fungi in the future to combat global plastic pollution.

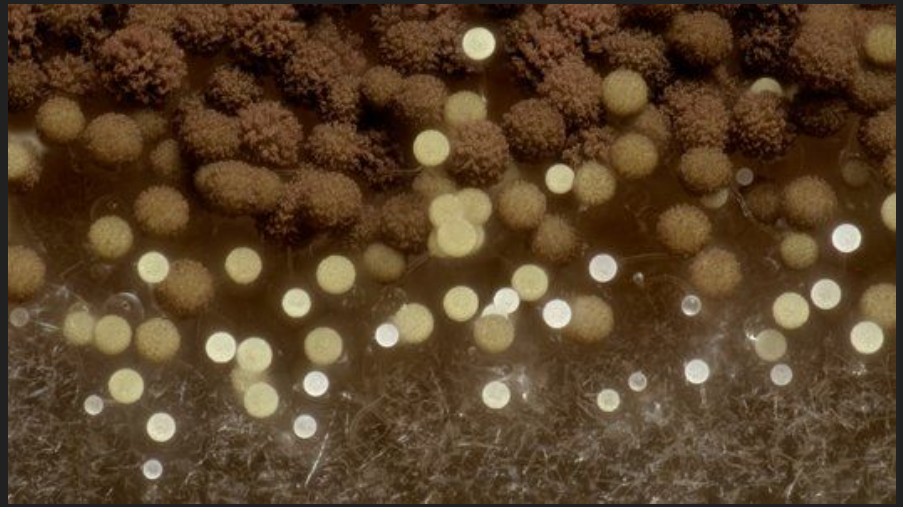
Getting rid of cigarettes

Another fungus that is very good at breaking down plastic is the oyster mushroom. This tasty fungus breaks down cigarette filters. Every year, 845,000 tonnes of cigarette butts end up in nature. Over 15 years, the cigarette butts slowly decompose into microplastics. These enter the water via the soil, where fish eat them. This is how microplastics enter the food chain, including ours. It is incredibly important to clean up these butts. With its mycelial filaments, the oyster mushroom penetrates the cigarette butt, after which it breaks down the plastic into nutrients.

e-waste

People are becoming increasingly dependent on electronic devices. From smartphones to electric cars. All these devices have batteries full of rare and precious lithium. Fungi can recycle these types of lithium-ion batteries. This is important because lithium sources are slowly being depleted. With acids from the fungi *Ustilago trichophora* and *Aspergillus niger*, the lithium can be isolated from the battery and reused.

Fungi grown on soiled nappies produce perfectly clean compost free of bacteria. Fungi seem to adapt to almost all materials for recycling, even radioactive waste in Chernobyl.



Tripping truffles

Fungi have been known for their psychedelic properties for thousands of years. From mind-altering 'Flesh of the gods' to medicine for depression. A whole new world opens up to you.

Flesh of the gods

They were already being eaten thousands of years ago: psychedelic fungi. Better known as magic mushrooms or truffles. In Mexico and Guatemala, the mushroom was called Teonanácatl by the Indians. This means 'flesh of the gods'. The Indians used these mushrooms to have spiritual experiences and perform rituals. Even now, years later, the magic mushroom is still used by some people to have a psychedelic and surreal mind-expanding experience. How exactly does such a trip work?

All psychedelic mushrooms contain the same active ingredient: psilocybin. In your body, psilocybin is converted into psilocin. This substance enters your brain via your bloodstream. Once here, psilocin binds to the receptors for serotonin. As a result, you start experiencing reality differently. Colours can be much more intense, walls can become wavy and your emotions intensify. The trip lasts about 3 to 4 hours, but time perception can also be very different for someone under the influence of magic mushrooms.

The magic mushroom

There are about two hundred different species of fungus that produce psilocybin. The substance is mainly in the mushroom, and not in the underground fungal network. However, sometimes a fungus makes underground storages of nutrients, a kind of nodules. These nodules, in turn, are called truffles (not to be confused with the truffles you get on your plate in a restaurant) and are also sold as psychedelics.

Magic medicine?

In recent years, psilocybin has also been used as a medicine for depression. Whereas therapy and antidepressants have no effect on some people, psychedelics do seem to bring about change. Probably because it breaks fixed patterns of thinking. Treatment has a positive effect in some patients for up to six months. It will still be a few years before magic mushrooms and truffles are in pharmacies as medicine, but researchers are hopeful.

Yeast: microbial friends for life

Humans have been friends with a special microbe for thousands of years. A microbe that helps us to produce all kinds of foods and beverages: yeast. From beer to bread, from wine to chocolate, yeast can do it all. But nowadays we can do even more with yeast than just making tasty food or drinks. In the era of biotechnology, our friendship has only grown stronger.

The life of a yeast

Yeasts are an intriguing group within the microbes. They are unicellular, and seem relatively simple under the microscope. But appearances are deceptive: yeasts are more like us than bacteria and are actually single-celled fungi. So yeasts are eukaryotic just like us, and we share about a quarter of our DNA with them.

However, the life of a yeast is a little bit more organized than ours. The yeast searches for substances to extract energy from, which it can do in several ways. It can use simple sugars like glucose directly, but can also break down more complex carbohydrates until sugars are left to live on. Once the yeast is in a nice and cozy environment, it will start to grow by dividing itself.


YG
YG
YG

The birds and the yeasts

When yeasts multiply, they can do it in two distinct ways, sexually or asexually. The most common is asexual, which is called budding. The yeast cell forms a bulge (bud) in its cell membrane, doubles its cell nucleus, moves the copied cell nucleus to the bud and then separates the bud. The result is a perfect clone.

Sexual reproduction however, requires two yeast cells; their copied genetic material is first combined, after which the new cell will have half of the DNA from both mother cells.

Sexual reproduction is switched to in stressful circumstances. The yeast makes new combinations of its DNA that are hopefully better adapted to where it lives. This is also useful for us humans, because this way we could select yeasts over time that are very well-adapted to certain types of fermentation. Yeasts are now genetically engineered to produce drugs for instance.


5 µm

Fermentation station

Man discovered the wonders of fermentation with yeasts very early on. In 2018 a set of 13,000-year-old mortars with the remains from a beer brewing process were discovered in Israel.

Making beer was probably the first example of using yeast, although the brewers probably had no idea which microbe was behind this process.

Today, most types of alcoholic beverages produced by fermentation use the same type of yeast: *Saccharomyces cerevisiae*. This strain is easy to grow, propagates quickly, and has a fairly high alcohol tolerance. The latter ensures that fermentation does not cease at a very low alcohol level.

Random brewing

However, other yeasts can also be used to brew beer, including wild yeasts. An example is the artisanal Belgian Lambic beer, which is made by the use of yeasts present in the air, including the genus *Brettanomyces*. The ratio of the yeast species in the air changes over the seasons, and therefore Lambic can only be brewed between October and April. But wild yeasts can also be discovered closer to home. For example, in ARTIS they found the wild yeast *Pichia barkeri*, with which they brewed an interesting beer together with the Oedipus brewery: the Wild Microbe Ale.

Available at the museum

Unusual yeast products

It is well-known that yeast plays an important role in the production of bread and alcohol. But did you know that yeast is also essential for making chocolate? It is the first step in the production process of cocoa mass, the main raw material of chocolate. By fermenting the cocoa beans in heaps, the structure and taste of the beans improve.

Yeast is even used for making stock cubes, not to ferment but as an ingredient. Grown yeast cultures are treated so that the yeast cells burst and their contents are released. The liquid that is left is then boiled down until yeast extract in the form of powder or paste remains. This yeast extract contains a lot of glutamate which gives a nice savory (umami) taste to the stock. Marmite ??

Fermenting cocoa beans

Yeast as a microfactory

Today, yeasts are also used to produce very different products than food. The way in which substances are converted in the yeast cell is recorded in the DNA of the yeast.

If we change certain genes in the DNA, we can let the yeast make a different conversion, with a different end product as a result. Or a whole new gene can be introduced, even from different species. For example, we can use yeast to make the sweetener steviol by adding adapted genes from the stevia plant to the yeast.

The yeast can produce steviol a lot more efficiently than a plant. Moreover, the steviol that is extracted from yeast is also tastier, due to the lack of a bitter variant that does occur in the plant.

The stevia plant

Large-scale yeast production

Special factories have been developed to extract the substances that yeast can make on a large scale. The yeast is grown in large tanks, which are called bioreactors. These bioreactors usually look like a large closed steel vessel with multiple pipelines connected.

By adding and removing the right quantities of certain substances at the right times, the fermentation process can be controlled very precisely. Usually the main added resource consists of liquid with sugars, which the yeast uses to grow and convert into the substances we want. This can be a continuous process in which a little sugar always goes in and product comes out, but it can also be performed in batches where everything is added in one go. The fermented mix is then processed to extract the desired product.

The possibilities with yeast are endless.

A fungal future

Everyone knows them from mouldy bread and decomposing trees. But few people know that fungi are also the perfect material from which to make all kinds of objects. Artist Maurizio Montalti and Utrecht University have developed a method that harnesses fungi's biological vigour to make a range of sustainable substitutes for traditional and often environmentally-unfriendly products.

By pairing different cultivation methods and fungus species, Montalti has already managed to create a range of objects with some very unique characteristics, from soundproof tiles, fire retardant insulation panels and waterproof vases to lightweight chairs, shoes and lampshades.

Cultivating fungi

Among the species of fungus with the most applications for Montalti's process is the well-known oyster mushroom (*Pleurotus ostreatus*). Oyster mushrooms grow best in damp spots and live mainly off dead plant material. These conditions are replicated in the cultivation process. Montalti uses a mix of food for his fungi, including wood chips and hay. After soaking in water and sterilising it, the food source (called the substrate) is ready to be inoculated with a small piece of the fungus. Its threads then grow through the substrate, tightly binding the fibres. Effectively, the fungus acts as an all-natural glue. And with the use of a template, it can be shaped into almost any form. After about two weeks, the resulting form is fired in an oven. This halts the growth process and prevents the fungus from eventually decaying the whole object.

Sustainable material of the future?

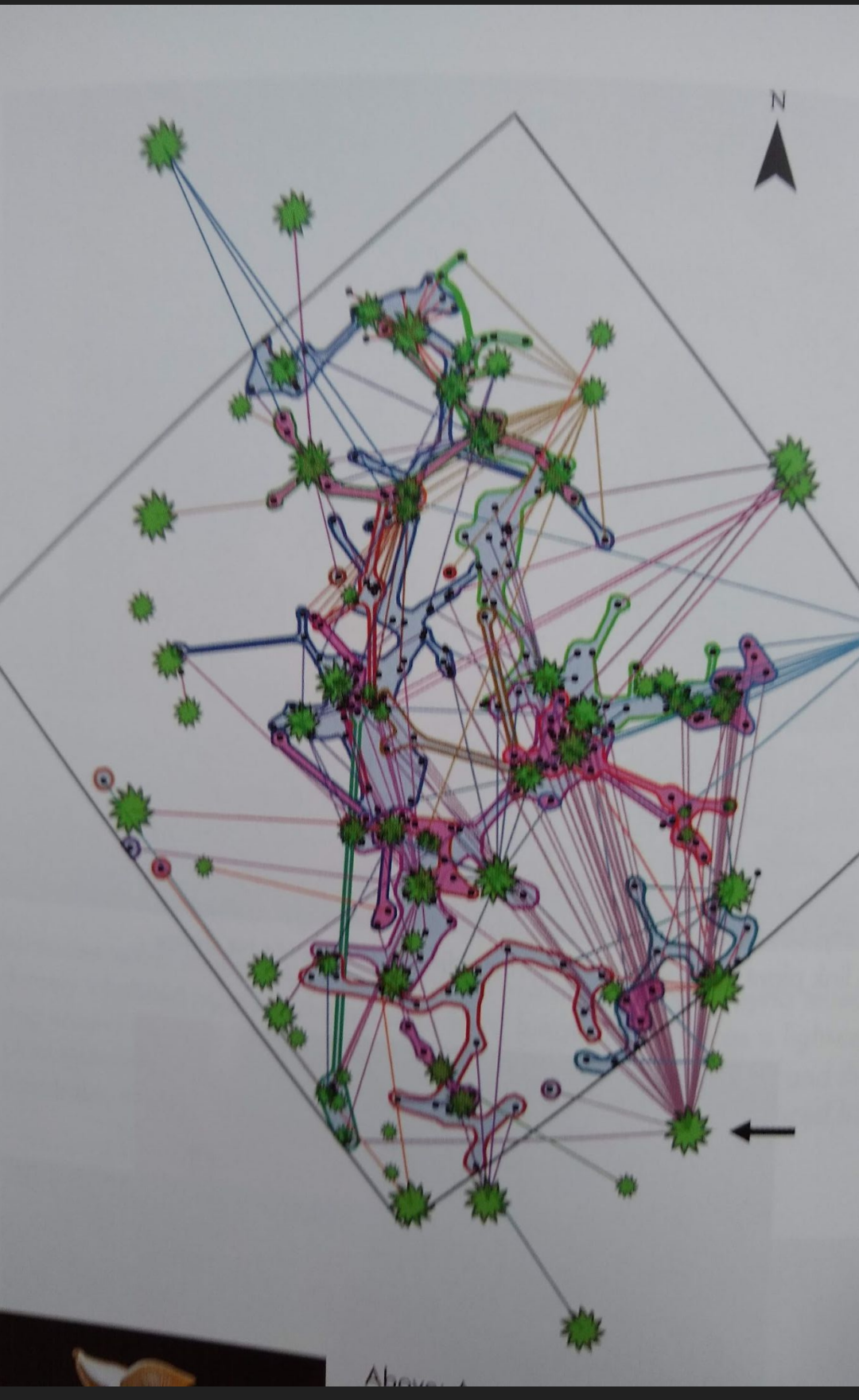
Montalti uses mostly agrarian waste for his substrates, which he turns into valuable products that are 100% natural and completely biodegradable. Already, the material's applications have gone beyond art to a potential replacement for wood, rubber, paper and even plastic, as a sustainable solution to the polluting products and production processes used today. Could fungi be the material of the future?

The mycorrhizal world

The Wood Wide Web

In the last 40 years or so, more and more biologists and forestry scientists have investigated the mycorrhizal system underground. They have found uninterrupted networks of fungal hyphae linking all trees in the soil. A single fungal network in an Oregon forest spanned 10 square km.

Suzanne Simard spent all her life researching the connection between trees in the canadian forest and could prove, against much opposition from the forestry establishment, that different species of trees cooperate with each other via what is now called the wood-wide web of fungi. By giving plants radioactive CO_2 to breathe, she could trace the carbon from one tree to another. She also found that trees used the web as an alarm system to warn other trees of attack by pathogens. Kevin Beiler made the following diagram of a network between Douglas firs.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The mother trees

Suzanne also found that mature trees will aid seedlings in their fruiting zone to establish them. Seedlings with their mother’s genes are given precedence.

Moreover she found that the communication along the mycorrhizal web resembled very closely the way our own brains process information, using the amino acids glutamine and glycine to transmit information via hubs.

Incidentally that is how computers work too. Rather than amino acids, they use electrical impulses.

Cooperation between plants

Trees that have been attacked by pathogens, sometimes hostile fungal growths, will pass on their healthy nutrients to their offspring before they die back. This is done via the fungal network in the soil.

Suzanne also found that broadleaved trees passed on nutrients to pines in the summer when there was plenty of sunlight and received returns in the winter when the evergreens carried on synthesising.

This is the opposite to the Darwinian theory that competition is paramount between life forms.

There has recently been some critique of her methods and findings, and more research is being financed.

Farming methods

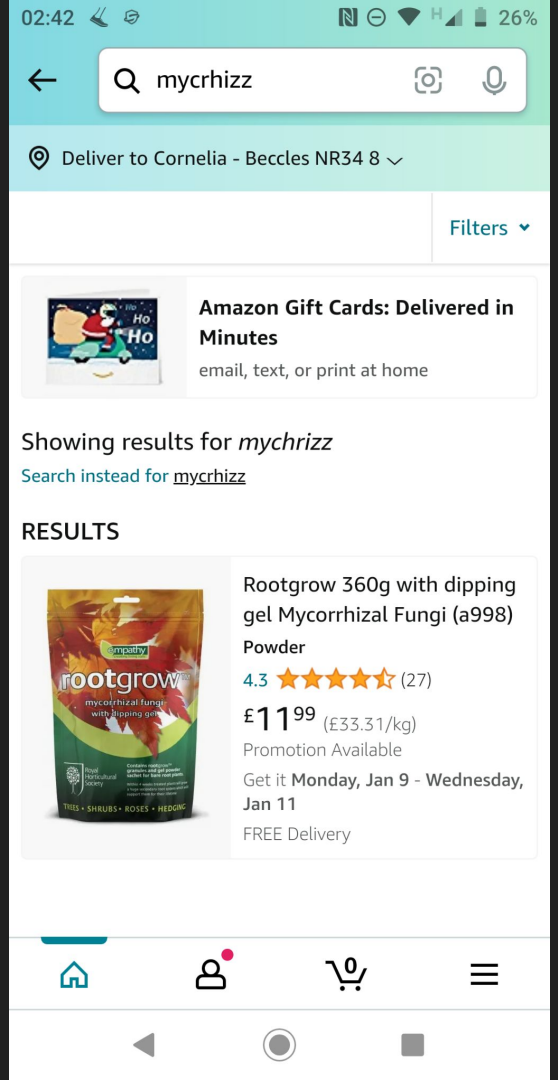
The research into the fungal networks has penetrated into all cultivation areas and farmers are now making use of the increased plant resilience in an undisturbed fungal environment….the no plough movement.

Grasses have fungal cooperators which enter their hyphae into the roots of the grass to feed it and provide it with water. This makes grass very drought resistant. The fungus will also feed grain crops inserted into the field that has this grass network. No fertiliser is needed in many cases.

The research of cooperation with fungal networks is very new in farming and would merit a complete presentation by a specialist.

It has arrived

at Amazon



Fungi in Humans

Danger to humans

Apart from the well known dangers of foraging for fungi and deaths every autumn caused by people confusing safe and delicious mushrooms with poisonous ones, much was made in the news about a toddler who died from the inhalation of fungal spores in his flat.

Black fungus will grow in damp, badly ventilated spaces in any home. All it needs is some carbon, even dust (shed skin), and moisture. We have probably all had to clean it out of our shower stalls and from behind heavy furniture on north facing walls. When inhaled the spores from these black growths can cause problems with lungs and other organs.

In southeast Asia people keep their clothes on rails on the balcony to keep them dry and stop them becoming hosts for fungi.

Problem fungi in humans

Our digestive system also relies very much on the combined labour of fungi and bacteria in our saliva, stomach and gut. They in fact digest the foodstuffs for us and extract the nutrients so our bloodstream can access them.

Sometimes the balance can be disturbed and one fungus, like Candida becomes dominant and causes illness. An increase in “fungal infections” has been recorded recently in hospitals. This has affected mainly people with compromised immune systems, which are regulated by the intestinal biome. Many people now rely on kefir, actimel and yakult to improve their gut biome and therefore their immune system.

Although we need the fungi and bacteria in our stomach to digest our food, if the digestive tract is perforated, these same organism cause sepsis and possibly death. This was one of the common causes of death after operations before it was recognised. Also burst appendices often led to death.

Some research has found other fungal growths which can combat pathogenic fungi in humans, but that research is still in its infancy.

A Megascience indeed

Microbe Monsters

It is well known that nature can be ruthless sometimes. But you don't often see it as colourful as microbes make it. Where predators and carnivorous plants simply devour their prey, some microbes have a more sinister approach. Parasitic fungi turn their victims into mindless zombies by penetrating their nervous systems, drugging them or taking over their muscles. How Halloween can it get ?

Arthropods held hostage

Like all life, these fungi have only one goal: to reproduce and spread. But unlike many other species, they have found a unique way to do so. Fungi of the genus *Ophiocordyceps* are masters at holding their arthropod victims hostage. More than 200 species of *Ophiocordyceps* fungi infect ten different species of insects and arachnids.

The fungus eats the insect from the inside out, makes new spores, and spreads to the next victim. But to increase the chance of successful spores distribution, the fungus causes the insect to do something unnatural. A good example of this is shown in the image. The spider hangs itself by its thread.

Bewitched ants

Ophiocordyceps unilateralis occurs in the Asian tropics where it turns ants into zombies. Once inside the ants body, the fungal threads form a network in and around the muscles. In this way they force the ant to leave the nest and look for it higher up.

The bewitched ant climbs into a plant, bites itself at the bottom of a leaf in the vein, and waits for death. After a few days, the ant's head bursts open, and a fruiting body full of spores grows outwards. And because of the elevated position of the ant carcass, the spores spread extra far.

Brains!

Some fungi go a step further and influence the behavior of insects by infecting their brains. *Entomophthora muscae*, literally translated as ‘insect destroyer of the fly’, penetrates the nervous system of a fruit fly (*Drosophila melanogaster*) and leads it to its death.

A few hours before its death, the fungus forces the fruit fly to climb to a higher place. There it bites itself into something, raises its abdomen and spreads its wings. In this way, the fly clears the path for the contagious spores that the fungus spreads after it has broken out of the fly’s abdomen.

Hallucinogenic drugs

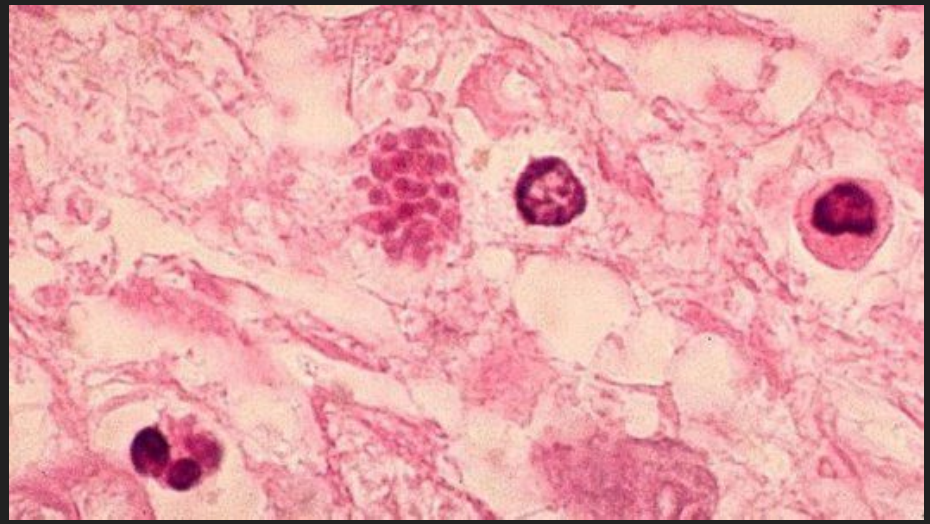
However, it can be even stranger. American cicadas spend the first 13 or 17 years of their lives underground. On their way out, some of them come across traces of the *Massospora fungus*. A week after the infection, the abdomen of the cicada falls off, and a white ball of fungal spores becomes visible.

The fungus has grown throughout the insect and has eaten all its organs. Meanwhile, the ‘bottomless’ insect lives on as if nothing is wrong. The fungus has drugged the cicada with a hallucinating substance. And while the tripping cicada flies around, other cicadas are buried under a deadly rain of spores from its zombie-fungal bottom.

Heroic mice

But microbes don’t only influence the behavior of insects. Large animals are also targeted by them. The single-celled parasite *Toxoplasma gondii* can only reproduce in felines. And to get there it has developed a bizarre trick.

Rodents are no longer afraid of cats after an infection with this microbe. They react slowly to danger and don’t flee when a cat comes near them. In addition, the mouse is brainwashed so he feels attracted to the smell of cat’s urine. The helpless rodent is devoured, and the parasite can infect the cat.



Blood slide

Some fungi are good for ants

Leafcutter ants cultivate fungi in their nests and anthills to pre-digest the leaves for them.

Connie Topping 3/23