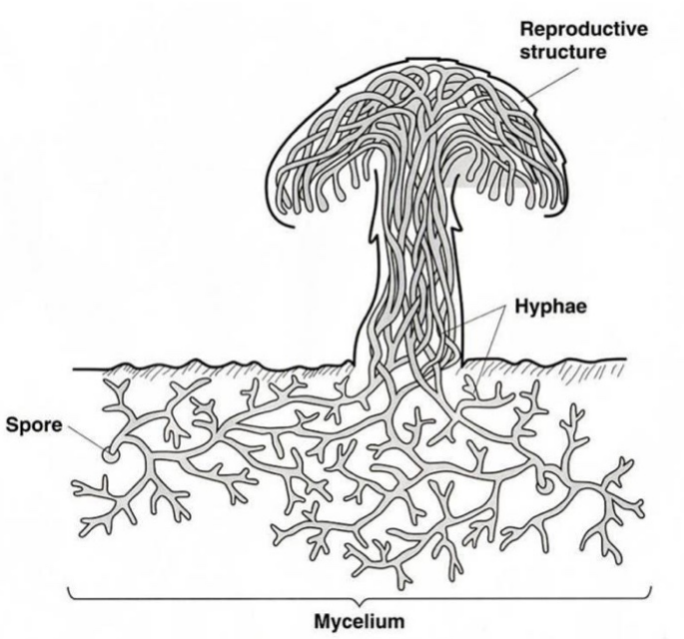
MYCOLOGY REVISION

Lecture 1 - the basics of fungi

Kingdom fungi

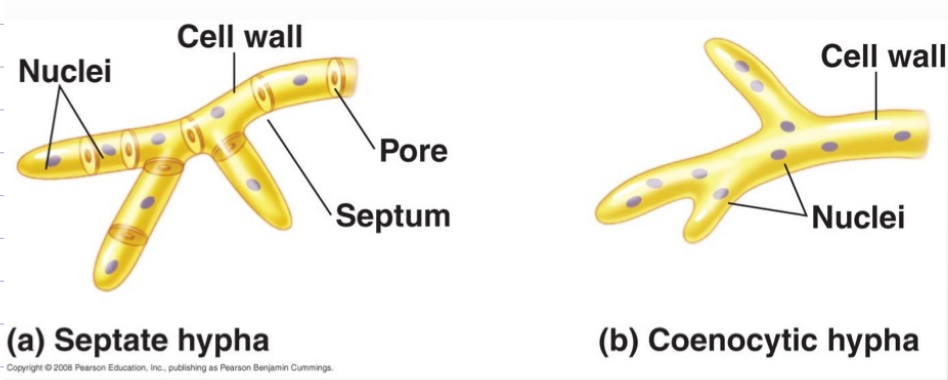
- High-level taxonomic group (equivalent to Plantae, Animalia)
- Approximately 120,000 described species.
- They are heterotrophs that have no chlorophyll, so they have to get their nutrients from somewhere else. Therefore, they absorb their nutrients.
- They have cell walls like plants, but they're made of chitin and not cellulose.

General structure



Hyphae

- Septate hyphae - there are walls between the nuclei.
- Coenocytic hyphae - no cell walls in the hyphae.
- Cells can be dikaryotic. This means they can have two nuclei per cell. These cells are dikaryon. It is a feature unique to cells of certain fungi.



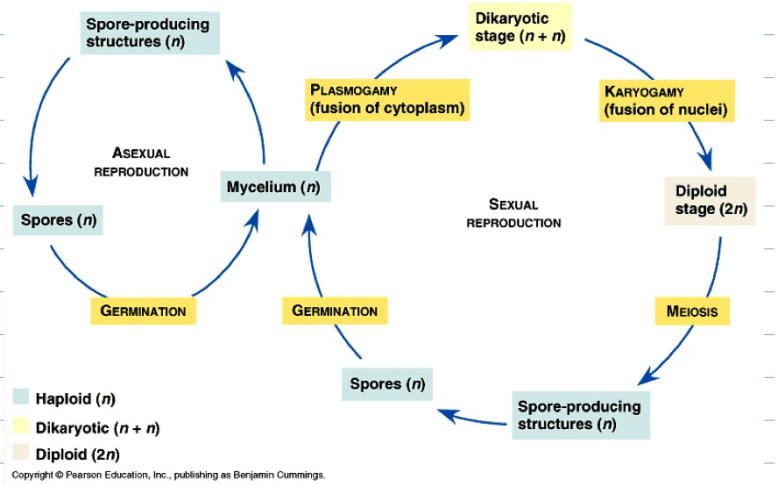
Spores

- Spores can be used to determine the species of the fungi.
- They are haploid and can vary in size and shape.
- They are produced sexually or asexually. This is dependent on environmental conditions or the reproductive cycle of the fungi.
- The spores are dispersed by wind or water.

Fungal life cycle

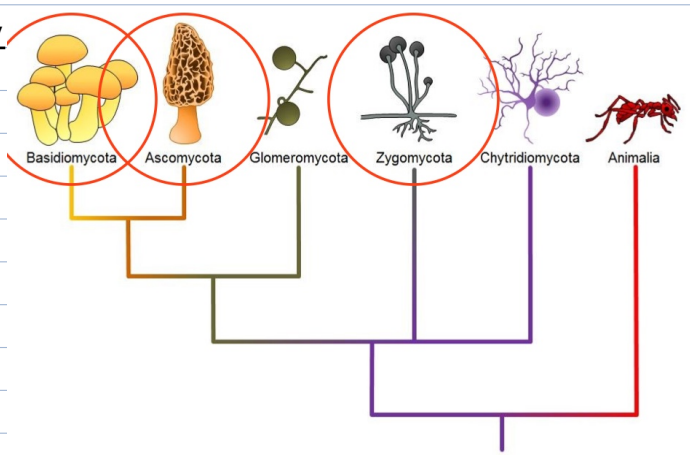
- Fungi can reproduce sexually or asexually, as shown in the diagram.
- Fungi have thousands of sexes (mating types), which increases the chances of finding a mate.

- There are lots of exceptions to the fungal life cycle shown in the diagram.
- Sexual reproduction:
  - The haploid phase ends with nuclear fusion.
  - The diploid phase begins with the formation of the zygote (the diploid cell resulting from the fusion of two haploid sex cells).
  - Meiosis restores the haploid number of chromosomes and imitates the haploid phase, which produces the gametes.
  - Nuclear fusion takes place at the same time of zygote formation, and meiosis follows immediately.
  - Sexual reproduction produces meiospores.
- Asexual reproduction:
  - Asexual reproduction produces mitospores.
  - The asexual phase usually precedes the sexual phase in the life cycle and may be repeated frequently before the sexual phase appears.



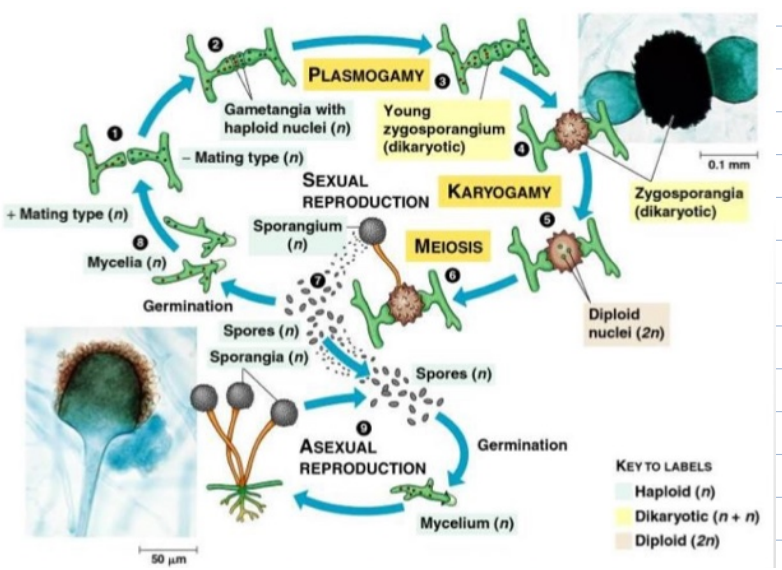
<u>The place of fungi on the tree of life and fungal phylogeny</u>

- Fungi are much more closely related to animals than plants.



<u>Zygomycota ('Z')</u>

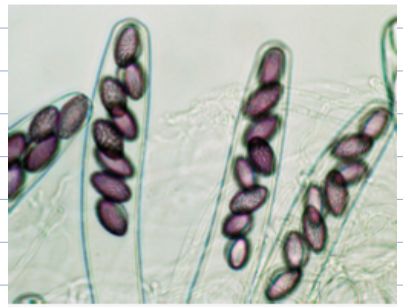
- Their hyphae are coenocytic but septate in reproduction.
- Fungi in this phylum are called zygomycetes.
- They are usually sapotrophs but some are parasites.
- Fusion of two hyphae leads to the formation of a zygosporangium, a thick-walled structure that is capable of surviving environmental extremes.
- Before karyogamy (the fusion of two nuclei), the zygosporangium contains many haploid nuclei.
- After karyogamy, it contains many diploid nuclei.
- They include bread mold - *Rhizopus stolonifer.*
- Life cycle:
  - Zygomycetes have sexual and asexual phases in their life cycles.
  - In the asexual phase, spores are produced from haploid sporangia by mitosis.
  - In the sexual phase, plus and minus haploid mating times conjugate to form heterokaryotic zygosporangium. Karyogamy then produces a diploid zygote. Diploid cells in the zygote undergo meiosis and germinate to form a haploid sporangium, which releases the next generation of haploid spores.

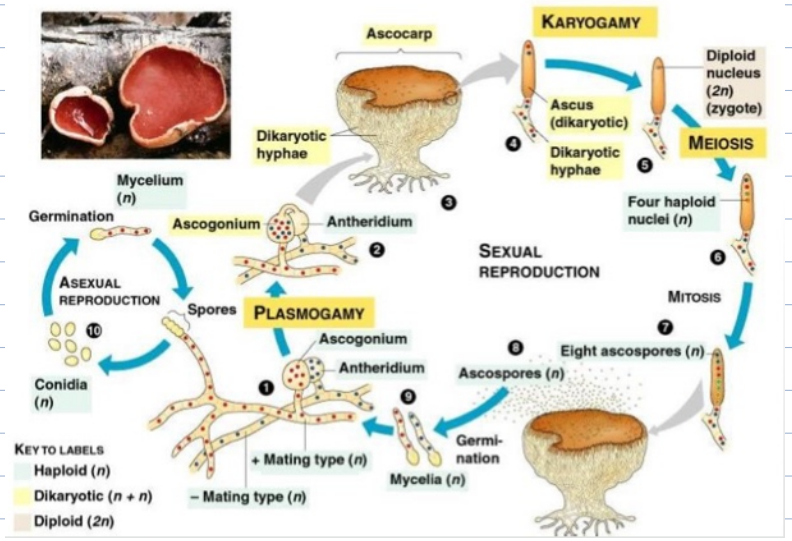


- When spores land on a suitable substrate, they germinate and produce a new mycelium.
- Sexual reproduction starts whe environmental conditions become unfavourable.
- Two opposing mating strains (type + and type -) must be in close proximity for gametangia from the hyphae to be produced and fuse, leading to karyogamy.
- Each zygospore can contain several diploid nuclei.
- They remain dormant until environmental conditions are favourable.
- When the zygospore germinates, it undergoes meiosis and produces haploid spores, which will, in turn, grow into a new organism.

Ascomycota ('A')

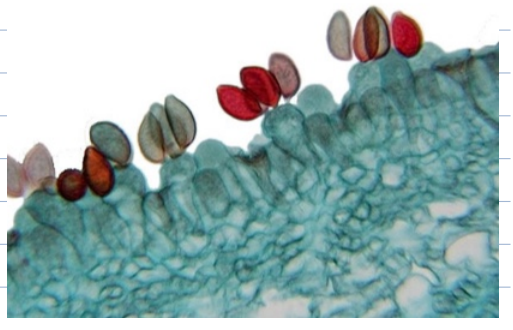
- These are 'sac fungi'.
- Their spores are usually in an ascus and there are usually 8 haploid spores per ascus.
- As there are usually 8 ascospores in asci, they have undergone meiosis 3 times.
- The life cycle:
  - The lifecycle of an ascomyte is characterised by the production of asci during the sexual phase.
  - The haploid phase is the predominant phase of the life cycle.
  - Asexual reproduction is frequent and involves the production of conidiospores.
  - Sexual reproduction starts with the development of special hyphae from either one of two types of mating strains.
  - Thousands of asci fill a fruiting body called the ascocarp. The diploid nucleus in each ascus gives rise to haploid nuclei by meiosis, and spore walls form around each nucleus. The spores in each ascus contain the meiotic products of a single diploid nucleus. The ascopores are then released, germinare, and form hyphae that are disseminated in the environment and start new mycelia.



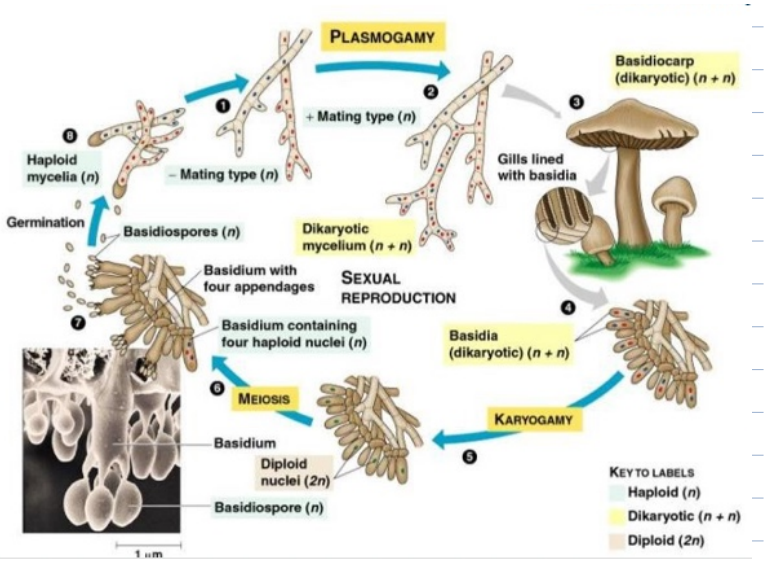


Basidiomycota ('B')

- These are 'club fungi' because their spores sit on what looks like a 'club'.
- They have septate hyphae.
- They have 4 basidiospores on a basidium. Therefore there are 2 meitoic divisions. The basidia (singular - basidium) are the swollen terminal cell of a hypha. The basidia are the reproductive organs of these fungi.
- The life cycle:
  - The life cycle of dasidiomycetes includes sexual and asexual reproduction, but asexual reproduction is more rare.
  - Basidiomycetes produce both haploid and dikaryotic mycelia, with the dikaryotic phase being dominant.
  - Each basidiospore germinates and generates monokaryotic haploid hyphae.

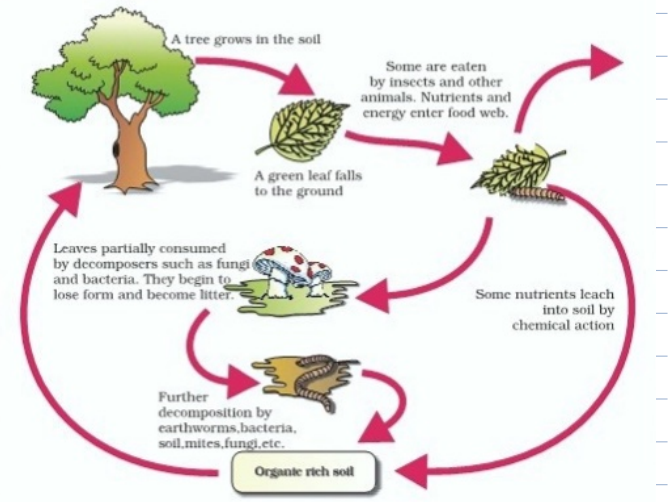


- The mycelium that results is called a primary mycelium.
- Mycelia of different mating strains can combine and produce a secondary mycelium that contains haploid nuclei of two different mating strains.
- Each cell in the mycelium has two haploid nuclei, which will not fuse until formation of the basidium.
- Eventually the secondary mycelium generates a basidiocarp, a fruiting body that protrudes from the ground. This is what we know as a mushroom.



Environmental roles of fungi

- Decomposers - break down dead material.
  - Fungi are primary decomposers of litter:
    - Hyphae can penetrate larger items such as leaves and twigs.
    - Enzymes for breaking down lignin which is found in trees.
    - Nutrients absorbed from decaying material.
    - Nutrients made available to other organisms.
    - Nutrient recycling. Without them, our ecosystems would be poorer.
    - No fungi, no decaying of wood.



- Symbionts - mutualistic relationship with other species (such as crop plants).
  - Mycorrhiza - symbiotic association between fungus and roots of a vascular plant.
  - Fungus benefits because it gains access to carbohydrates produced by the plants.
  - Plant benefits because it gains access to mineral nutrients.
  - Ectomycorrhiza - extracellular (2% of all plant species).
  - Endomycorrhiza - intracellular (70% of all plant species). In this case, the fungus grows into the plant cell wall which is more efficient. The fungus has a specialised structure called a haustorium which penetrates the plant root cell wall.
  - Lichens - symbiosis between fungi and green algae or cyanobacteria. The algae or bacteria provide nutrients to the fungus, and the fungus provides a stable environment to the algae or bacteria.
  - Ants and termites - these organisms cultivate fungi in their ‘gardens’. This is mutualistic symbiosis as both benefit. The ants get the nutrients and the fungi get a stable environment.
- Pathogens/parasites - feed off living organisms.
  - Rust fungus - plants.
  - White-nose syndrome - bats.
  - Chytridiomycosis - amphibians (especially frogs). Some species have gone extinct.
  - Entomopathogenic fungi - feed on insects. The fungus produces more aerial conidiophores on exterior of insect. The aerial spore disperses and lands on the insect cuticle. The spore germinates and then penetrates into the insect cuticle. The fungus then grows through the body, as blastospores and mycelium. This kills the insect in 4-14 days, then transforms into mycelium on host’s death.

Lecture 2 - 'good' fungi

Fungi as food (direct)

- Fungi have a high nutritional value.
- They are low in fat, high in protein, high in minerals, vitamins and antioxidants and they are a good source of fibre.

Food

- Yeast
  - Yeasts are not a taxonomic group. They can be Ascomycota and Basidiomycota, but not 'Z'.
  - Growth form:
    - Single-celled.
    - Asexual growth through 'budding' (no hyphae).
    - Sexual reproduction through spores.
    - Sexual reproduction depends on environmental conditions.
  - *Saccharomyces spp* ('A')
    - The species name for yeast.
    - There are two pathways for yeast to produce ATP from sugars:
      - Respiration - this delivers more energy (28 ATP molecules) but it require oxygen. It also releases carbon dioxide.
      - Fermentation - this delivers less energy (2 ATP molecules) and it results in ethanol and carbon dioxide being produced. The carbon dioxide can be used to help bread dough rise. The ethanol can be used to make alcoholic drinks.
    - Yeast extract.
      - To make yeast extract, you add salt and heat to a suspension of yeast cells.
      - The yeast cells die and break up.
      - Yeast digestive enzymes break resulting large molecules down into smaller molecules such as amino acids and peptides.
- *Aspergillus oryzae* ('A')
  - It has the same role as yeast in the fermentation of rice (sake, shochu).
  - It is involved in the fermentation of soy beans (soy sauce, ketchup).
- *Fusarium venenatum* ('A')
  - Fermentation of glucose to produce mycoproteins (quorn).
- *Penicillium camemberti* and *P. roqueforti* ('A').
  - Added to substrate in the cheese-making process.
  - Either grows on the surface or penetrates into the cheese.
  - Gives unique flavour and texture to Camembert and blue cheese.
- *Botrytis cinerea* ('A').
  - Also known as 'noble rot'.
  - It is highly valued in viniculture.
  - It's spores are sprayed on grapes. The grapes desiccate which concentrates the sugars.
  - It makes sweet dessert wines.

Recreation

- Magic mushrooms.
  - Many species of fungi, all Basidiomycota (illegal).
  - Active ingredients include psilocybin, psilocin. These are hallucinogenic.
  - Possibly evolved as a defence mechanism against insects. The insects would change their minds.

- Psilocybin is structurally similar to serotonin therefore magic mushrooms interfere with serotonin receptors in the brain. This has a range of effects on the body.

Biopesticides

- The following are entomopathogenic fungi meaning they are parasites that can kill or seriously disable insects:
  - *Beauvaria bassiana* (‘A’).
  - *Metarhizium anisopliae* (‘A’).
- The above are common soil fungi so they are not obligate parasitic.
- The are mass produced on whey-based culture media.
- They can be used to control the growth of pests such as locusts, aphids, bedbugs, thrips, whiteflies and termites.
- Nematophagous fungi:
  - Nematodes attack the roots of crop plants.
  - We can use nematopahgous fungi to control nematodes.
  - They trap nematodes, they are endoparasitic and they can attack the nematode eggs.
  - They have rings so that as soon as the nemaotde goes through the ring, the ring constricts and traps the nematode.
  - An example of a nematophagous fungi is *Drechslerella spp* (‘A’).
  - Their hyphae can also be adhesive.

Crop yield boosting

- Many crop plant species are in symbiosis with mycorrhizal fungi.
- Inoculating the soil with spores of mycorrhizal fungi increases yield.

Mycoremediation

- Fungi can be used in the decontamination of an environment.
- Soils with heavy metals can be treated with:
  - *Pleurotes* (‘B’).
  - *Aspergillus* (‘A’).
  - *Trichoderma* (‘A’).
- Organic pollutants such as PAHs, petroleum and PCBs can be treated with wood-decaying fungi such as:
  - *Pleurotes* (‘B’).
  - *Pestalopiosis* (‘A’).
- Overall, the fungi break down pollutants.

Enzyme production

- Approximately 50% of industrial enzymes are produced by fungi.
- Examples of industrial enzymes that are produced by fungi include:
  - Proteases.
  - Cellulases.
  - Xylanases.
  - Lipases.
  - Amylases.
  - Phytases.
- Examples of fungi that produce enzymes include:
  - *Aspergillus* (‘A’).
  - *Penicillium* (‘A’).

- *Rhizopus* (‘Z’).
- *Trichoderma* (‘A’).

Medicines

- Antibiotics such as penicillin can be produced by fungi.
- They evolved as a way for fungi to compete with bacteria.
- Examples of medicines produced by fungi include:
  - Statins:
    - *Penicillium spp* (‘A’).
    - *Aspergillus terreus* (‘A’).
    - *Monascus purpureus* (‘A’).
  - Anti-cancer drugs:
    - *Penicillium spp* (‘A’).
  - Anti-fungal drugs:
    - *Penicillium spp* (‘A’).
  - Immunology-suppressant drugs:
    - *Penicillium spp* (‘A’).
    - *Tolypocladium inflatum* (‘A’).
  - Drugs against malaria.
  - Drugs against diabetes.
  - Production of D vitamins.

Research

- The of best studied eukaryotes is *Saccharomyces cerevisiae* (‘A’) which is yeast.
- It is model organism in cell biology, genetics, DNA repair and aging, and it was the first eukaryote to have its genome sequenced.

Lecture 3 - ‘bad’ fungi

Poisonous mushrooms

Fly Agaric

- Many mushrooms are toxic as a defence against being eaten.
- Examples of poisonous mushrooms (the *Amanita* species):
  - *Amanita muscaria* (‘B’). Also known as the fly agaric mushroom. It is not that poisonous as its not likely to kill you but you shouldn’t eat it. It contains the hallucinogenic compounds muscimol and ibotenic acid.
  - *Amanita phalloides* (‘B’). Also known as the death cap mushroom.
  - *Amanita virosa* (‘B’). Also known as the destroying angel mushroom.
- The *Amanita species* and species in several other genera (*Conocybe*, *Gallerina*, *Lepiota* (‘B’)) contain amatoxins.
- Amatoxins are an inhibitor of RNA polymerase II. When RNA polymerase II is inhibited, cell metabolism is halted and the cell lyses.
- When you eat poisonous mushrooms there is a biphasic clinical pattern:
  - There is an initial period of acute symptoms such as:
    - Headache.
    - Dizziness.
    - Nausea.
    - Shortness of breath.
    - Coughing.
    - Insomnia.

Death cap

        - Diarrhoea.
        - Gastrointestinal disturbances.
        - Back pain.
        - Frequent unrination.
    - There is 12-24 hour recovery period.
    - This recovery period is followed by death through multiple organ (liver and kidney) failure.
    - There is no reliable treatment known as of yet.

Destroying angel

Toxic moulds

- Toxic moulds include *Claviceps purpurea* and related species ('A'). It is also known as ergot.
- There are pathogens of crops such as rye, wheat, barley, sorghum.
- They grow spore producing bodies.
- The earliest records of ergotism date back to 600BC.
- They produce alkaloids which affect:
    - The nervous system:
        - Muscle spasms.
        - Fever.
        - Hallucinations.
        - Nausea.
        - Seizures.
        - Vomiting.
        - Unconsciousness.
        - Death.
    - The vascular system:
        - Violent burning.
        - Peripheral pulses.
        - Shooting pains in the fingers and toes.
        - Gangrene.
        - Loss of limbs.
- Toxic moulds can cause death but they can be treated.
- Treatment options include sodium nitroprusside or nitroglycerine.
- Despite treatment, you may still get long lasting damage.

Moulds on food

- The fungi that grow as mould on food include Zygomycota and Ascomycota.
- These moulds lead to food wastage.
- The effects of ingestion on humans basically harmless to carcinogenic (they can be carcinogenic due to aflatoxins which can be found on *Aspergillus* moulds on peanuts).
- There is no treatment.

Rusts and smuts

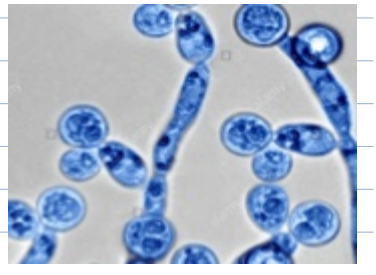
- These are plant pathogens and they are all Basidiomycota.
- There are approximately 7000 species.
- Smuts typically have one host.
- Rusts typically have two hosts. They have to alternate between one host and the other to complete their life cycle.
- They don't normally kill the plant, but they can

cause a severe drop in yield.
- Treatment options include fungicides and breeding of plants from resistant genotypes.

Tree pathogens
- Tree pathogens are important for forestry.
- There are range of species which infect forest trees:
  - Dutch elm disease:
    - This is a major factor in the loss of elm trees from the UK countryside.
    - It is caused by *Ophiostoma ulmi* ('A').
    - It devastated elm populations in Europe and the US in two epidemics in the 1920s and 1970s.
    - Approximately 60 million trees killed in the UK alone.
    - Bark beetles are vectors of Dutch Elm disease.
    - There are some methods that have been carried out to fight against Dutch Elm disease:
      - Destroy diseased trees to stop the spread.
      - Target the bark beetles.
      - 'Vaccinate' trees with a weaker fungus strain. This had some effects but it didn't quite work.
      - Breed trees from resistance genotypes. This is a long term attempt.
  - Ash dieback:
    - It is caused by *Hymenoscyphus fraxineus* ('A').
    - In the UK, since 2012, 85% of trees that are infected will die.
  - Honey fungus:
    - It is caused by *Armillaria spp* ('B').
    - It is quoted as the "single most destructive plant disease in the UK".

Wood-decaying fungi
- If you have structures in your house that contain wood that get infected with these fungi, the structures will breakdown.
- There are various types including:
  - Brown rot.
  - Soft rot.
  - White rot.
- It is caused by a wide variety of fungi including Ascomycota and Basidiomycota.
- They break down cellulose and lignin.
- Infection by these fungi has lead to high economic damage. Dealing with dry rot alone has been estimated to cost more than £150 million annually in the UK alone.
- Treatments:
  - Change the environment by lowering the humidity and increasing ventilation.
  - Fungicides.
  - Heat.
  - Biological control with competing species. Infect the wood with another fungal species. The two species will compete and the rot doesn't win.

Fungal pathogens
- There are approximately 300 fungi known to be pathogenic to humans:
  - Candidiasis:
    - It is caused by *Candida albicans* and other species ('A').
    - It is dimorphic so it grows as yeast and filaments.



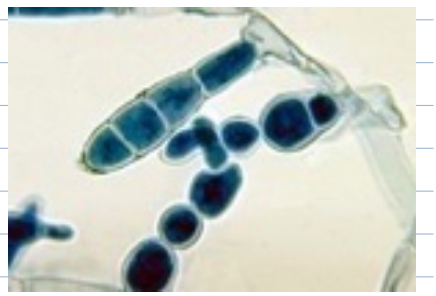
        - It causes oral and genital thrush.
        - Treatment options include antifungal medications.
    - Dermatophytosis:
        - It causes Athlete's foot, ringworm and fungal nail.
        - It is caused by *Trichophyton*, *Microsporum* and *Epidemophyton* ('A').
        - Infection is spread through spores in the environment. These spores can remain viable for 18 months or more. The spores are known to spread through pets.
        - Treatment options include antifungal medications.

Trichophyton

    - Asperigillosis:
        - It is caused by inhaling spores of *Aspergillus spp* ('A').
        - It has a range of effects on the lungs, sinuses and other tissues and cells such as the blood stream.
        - If it gets into the lungs, you can get fungus ball called an aspergilloma in the lungs.
        - Treatment options include antifungal medications.

Microsporum

    - Cryptococcosis:
        - It is caused by inhaling spores of Cryptococcus spp ('B').
        - It infects the lungs followed by the central nervous system.
        - It can lead to meningitis and meningoencephalitis.
        - Treatment options include antifungal medications.



Epidemophyton

    - Fungal allergies:
        - They are caused by inhaling spores of moulds and mildew (which is a part of daily life).
        - They are by a wide range of species.
        - Everyone breaths in fungal spores. The spores are not the issue, the immune system is, as it goes into overdrive.
        - It can lead to allergic reactions and flare ups for people with asthma.
        - Treatment options include antihistamines and steroids.
    - Microsporidia (next lecture).

Opportunistic mycosis

- Many fungal infections cause no problems to healthy individuals.
- They become a problem in individuals with weakened immune systems such as individuals with HIV, undergoing chemotherapy and individuals who have had a transplant.