Lecture 18

- Zygomycota
- Chytridiomycota
- Microsporidia

Zygomycota

The “true” Zygomycetes
- asexual reproduction: sporangia;
- sexual reproduction: zygote;
- < 1,000 species known (< 1% of all known species);

Zygomycota traditionally included:

Class Zygomycetes
- Mucorales, Mortierellales: saprobes;
- Entomophthorales: parasites on insects

Class Trichomycetes
- ecologically and morphologically distinct from all other fungi:
  ---- obligatory associated with insects, commensalism / parasitism; e.g.,
  Zoopagales etc..

AM fungi (now Glomeromycota) - see Lecture 18
**Zygomycota**

- Zygomycota Class Zygomycetes is paraphyletic
- Trichomycetes groups with Blastocladiales (chytrids).

**Zygomycota : Mucorales**

- largest group of Zygomycetes
- many common moulds species
- fast grow in culture; efficient at using sugars as C source
- many species used in industry and food production
  -- e.g., *Rhizopus* spp. used in production of fumaric, lactic, citric, succinic & oxalic acids; fermentation of tempeh (Indonesian dish); alcohol production from palm by tribes in S. America
- coenocytic (mutinucleate) hyphae; except at bases of reproductive structures
- often form rhizoids to adhere to substrate
- stolons connect two groups of rhizoids

Asexual reproduction
- sporangiophores simple to branched; possess a columella
  -- can form both sporangia and sporangioles from the same sporangiophore
  ------ sporangia >>100 spores; sporangioles 1- few spores

Sexual reproduction
- conjugation by two morphological similar gametangia to produce a zygosporangium (zygote)
- homo- & heterothallic species
Zygomycota: Mucorales

Sexual reproduction

- formation of specialized hyphae: *zygophores*
  --- compatible zygophores are attracted to each other and fuse in pairs at their tips;

- zygophores swell to form *gametangia*
  ---- fusion septum dissolves (anastomosis)

- plasmogamy results in *prozygosporangium*
  --- subterminal cells are called *suspensors*

- plasmogamy followed by karyogamy.
  --- enlargement and development of a thick multilayered wall: the *zygosporangium*

- meiosis followed by multiple mitoses

**Zygote** = *zygosporangium* + suspensor cells + appendage (when present)

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Zygotes

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From Malloch
**Zygomycota : Mucorales**

- Sexual stages are rarely formed (found?) in nature; ---> Taxa are typically distinguished from their anamorphs

**Major genera**

*Pilobolus*
- phototropic sporangia;
- frequent on horse dung

*Mortierella*
- differs from *Mucor* from small / absent columella
- several species produce chlamydospores ©
- evolutionary basal group of zygomycetes

**Fungi : Zygomycota : Mucorales**

**Major genera**

*Mucor*

*Camposolitum*

*Ichkeulen trisporn*
**Fungi : Zygomycota : Mucorales**

Life cycle of *Rhizopus stolonifer* (from Kendrick)

Zygomycota : Entomophthorales

- mostly parasites on insects
- some parasites on nematodes, algae, etc. or saprobic
- kill host by proliferation of mycelium : ---&gt; though as agent for biological control
- not monophyletic

- some species have septate mycelium that can break up into “hyphal bodies” (arthroconidia-like) that can germinate to produce asexual spores

- sexual reproduction --&gt; zygote known in many species
- --- all species studied so far are homothallic

*Entomophthora muscae* on house fly

http://www.nysaes.cornell.edu/ent/biocontrol/pathogens/entomophthora_m.html

Multiple, unicellular and multinucleate sporangiophore in *E. muscae* (from G.Barron)
“Trichomycetes”

- ecologically and morphologically distinct from all other fungi:
  ---- **obligatory associated** with insects, commensalism / parasitism;
  ---- some are myparasites (Dimargitales)

- not a monophyletic group;

Some examples:

*Genistelloides helicoides*.

Released trichospore with two coiled appendages. Appendages may function to restrain spores from drifting downstream, thus retaining them in the vicinity of the host population and leading to possible ingestion and germination in the insect gut.

http://www.bsu.edu/classes/ruch/msa/litchwart.html

*Stachvlna pedifer* (Harpellales, Harpellaceae) in the peritrophic membrane (midgut) of a midge larva (*Boreoheptagyia lurida*) from turbulent waters of a Rocky Mountain stream. The simple, holocarpic thallus of this species, usually with 4 trichospores, penetrates through the peritrophic membrane as a means of attachment, an unusual feature in the Harpellaceae.

http://www.bsu.edu/classes/ruch/msa/litchwart.html
Fungi: Chytridiomycota

Major characteristics

- ca. 100 genera and 1,000 species described
- chitin in cell wall $\Rightarrow$ fungi
- flagellate zoospores $\Rightarrow$ fungi?

Ecology
- aquatic and terrestrial (found in soil);
- saprobes, some parasites of protists, invertebrates, fungi and plants;
- a few anaerobic species in the rumen of herbivores (Neocallimastigales)

flagellate zoospores

- one or several flagella
- essentially the same structure among all the eukaryotes:
  -- 9 pairs of peripheral microtubules
  -- 2 central microtubules
Fungi: Chytridiomycota

Major characteristics

Zoospores of Blastocladiella emersonii
(viewed in phase-contrast microscopy).

The spores are about 2.5 microns in diameter and contain:
- a prominent nucleus (n);
- a nuclear cap in which the ribosomes are aggregated (nc);
- a large mitochondrion (m) near the base of the flagellum (flag);
- lipid bodies (lip).

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Blastocladiales clusters with the Trichomycetes.

Chytridiomycota; phylogeny

- basal fungal lineage;
  ▶️ the presence of flagella is a plesiomorphic character

- paraphyletic, as indicated from both complete mitochondrial genome sequence phylogeny (Clark & Moncalvo, left fig.), 18S rDNA phylogeny (James et al. 2000), and combined 18S+25S +RPB2 phylogeny (Lutzoni et al. 2005).

--- Blastocladiales clusters with the Trichomycetes.
Fungi: Chytridiomycota

Five major groups
Based on molecular phylogeny + ultrastructure
Chytridiales
Spizellomycetales
Monoblepharidales
Neocallimastigales
Blastocladiales

The hyphochytrids (Hyphochytriales) have been removed from the Fungi, and are now classified with brown algae and diatoms in the Heterokonta.
Chytridiomycota: Major groups

**Chytridiales:** mostly aquatic

**Spizellomycetales:** mostly in soil

- Otherwise mostly distinguished from ultrastructure

- The **thallus** do not form a mycelium -- it is either:

  ----- **holocarpic** = the thallus uniquely consists of a reproductive **sporangium** (as in *Olpidium*, far right), or

  ----- **eucarpic** = the thallus is differentiated into assimilative **rhizoids** and one or more **sporangia**, as in *Spizellomyces* (top left) and *Cladochytrium* (lower drawing).

A thallus bearing a single sporangium is said to be **monocentric** (e.g. *Spizellomyces*), and **polycentric** when bearing multiple sporangia (e.g. *Cladochytrium*)

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**Chytridiomycota: Major groups**

**Chytridiales**

**Spizellomycetales**

- Mostly parasites
  -- on pollen
  -- in root
  -- vector of viruses
  -- on algae (on *Spirogyra* below)
Chytridiomycota : Major groups

Chytridiomycota:
- Chytridiales
  - Spizellomycetales
    - Mostly parasites
      - on pollen
      - in root
      - vector of viruses
      - on algae (on Spirogyra below)

-Synchytrium endobioticum causes wart disease of potato;
  - widespread in Europe;
  - resistant varieties of potato help to keep the disease under control.

Chytridiomycota : Major groups

Neocallimastigales
- Discovered in 1975 by Orpin in rumen of herbivores (Neocallimastix)
- form rhizomycelia which efficiently penetrate plant material
- possess enzymes that very efficiently break down cellulose
- obligately anaerobic (lack mitochondria);
  - ferment sugars to generate a mixture of formate, acetate, lactate, ethanol, CO2 and H2.
- multiflagellate zoospores.
- to date, seventeen species described in five genera
Chytridiomycota: Major groups

Monoblepharidales

- form hyphae;
- polycentric;
- sexual differentiation of gametes in adjacent, differentiate gametangia:
  - motile gametes
equal 'a sperm', male gamete) are formed in a differentiate gametangia called antheridia;
  - non-motile gametes
equal “an egg”, female gamete) are formed in a differentiate gametangia called oogonia.

This type of sexuality is called oogamy (we are oogame!) (From Kendrick)

- In Monoblepharis (figure) male and female gametes are not ripe at the same time, probably to avoid self-fertilization (⇒ selection for outbreeding, similar to heterothallism).
- After the egg has been fertilized, the resulting zygote becomes amoeboid, moves out onto the top of the oogonium, and encysts, developing a thick wall.

Chytridiomycota: Major groups

Blastocladiales (related to some Trichomycetes)

Thallus consists of both hyphae and rhizoids; - polycentric - sexual differentiation

One common and well studied species: Allomyces arbusculus
- haploid and diploid thalli.
  - haploid thalli produce male and female zooflagellate gametes in two juxtaposed, specialized cells called gametangia;
  - a colourless gametangium is produced at the tip of a hyphal branch, and an orange gametangium is produced on top of it.
  - gametes come in two sizes, a condition called anisogamy, and are referred as “male” and “female” zoospores.
- diploid thalli produce zoospores in a single, resting (= resistant) sporangia.

From Kendrick
Chytridiomycota: Major groups

Blastocladiales

Sporangia of *Allomyces arbusculus*

http://www.ucmp.berkeley.edu/fungi/chytrids.html

Fungi: Chytridiomycota


Chytridiomycosis is a fatal disease in frogs caused by a newly identified chytrid fungus, *Batrachochytrium dendrobatidis*. The fungus invades the superficial epidermis.

Section of skin from a heavily infected adult [frog] of *Litoria caerulea*. Note homogenous immature stage (I), zoosporangium with discharge papillae (D) containing zoospores, and empty zoosporangium formed after zoospores have discharged (arrow) E= epidermis

Berger et al. (1998).
*Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America.* Proceedings of the National Academy of Science, USA 95: 9031-9036.

Microsporidia

Microsporidia are tiny single-celled endoparasites primarily known to infect insects and fish, but also mammals.
- They lack mitochondria
- They have a small, degenerated nuclear DNA

These protists were originally classified as protozoa, but molecular phylogenetic evidence suggests closer evolutionary relationships with Fungi.

Transmission electron micrograph of ultra thin section through a Nosema locustae spore.

http://bioweb.usu.edu/emlab/Galleries/parasites/microsporidia_1.html

A Kingdom-Level Phylogeny of Eukaryotes Based on Combined Protein Data

Combined data from alpha-tubulin, beta-tubulin, EF1-alpha, actin

Science 290:972-977, 2000
Microsporidia

Several species of microsporidia have recently been identified as opportunistic or emerging pathogens of humans. One species, Enterocytozoon bieneusi, was first identified in a male patient with acquired immunodeficiency syndrome (AIDS).

Intracellular microsporidia clusters in bovine kidney cells grown in tissue culture.

http://www.dpd.cdc.gov/dpdx/HTML/Microsporidiosis.htm

To date, more than 1,200 species belonging to 143 genera have been described as parasites infecting a wide range of vertebrate and invertebrate hosts. Microsporidia, are characterized by the production of resistant spores that vary in size, depending on the species. They possess a unique organelle, the polar tubule or polar filament, which is coiled inside the spore as demonstrated by its ultrastructure. The microsporidia spores of species associated with human infection measure from 1 to 4 µm and that is a useful diagnostic feature. There are at least 14 microsporidian species that have been identified as human pathogens. Based on recent data it is now known that some domestic and wild animals may be naturally infected with microsporidian species: E. cuniculi, E. intestinalis, E. bieneusi.
Microsporidia

Fire ant infected with *Thelohania solenopsae* cysts.

http://cmave.usda.ufl.edu/ifahi/microsporidia_pics_spores.html

Infected *Daphnia pulex*. The parasite infects the carapace (visible as whitish area). Usually the head is covered last.

A variety of parasites have been proposed for the biological control of mosquitoes.

LEFT: An *Aedes camptorhynchus* larva is infected with a Microsporidia which kills mosquitoes in the larval stage. Infected larvae typically show a diffuse coloration throughout the body (note this larva also has an orange algal growth).

BOTTOM: A *Culex sitiens* larva infected with the microsporidia *Amblyospora indicola*. The white swelling caused by the parasite can be observed in the abdominal segments.

FURTHER READING:

James et al.
Reconstructing the early evolution of Fungi using a six-gene phylogeny