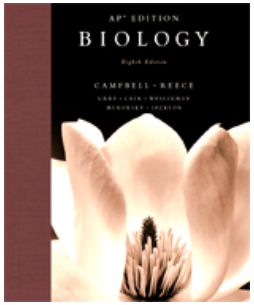

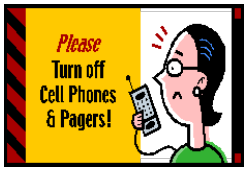

Overview of Lecture: Fungi

Read: Text ch 31

Bullet Points:

- fungi – our sister group!
- characteristics
- fungusfocus.com
- doctorfungus.com
  the biology of antifungal agents
- new phylogeny *(dang!!!)*
- microsporidia
- chytrids
- zygomycota – bread molds
- glomeromycota - mycorrhizzae
- ascomycota – yeasts & morrels
- basidiomycota - mushrooms

Two moldy oranges. More than 600 million people could be fed each year by halting the spread of fungal diseases in the world's five most important crops. (Credit: © buFka / Fotolia)

White-Nose Syndrome Killing Bats Is Spreading Fast

Scientists Fear a Fungus Could Kill Millions of Bats That Keep Insects in Check

By DAVID WRIGHT and JONANN BRADY
FRANKLIN, W.Va., April 3, 2009

abc GMA

27 comments

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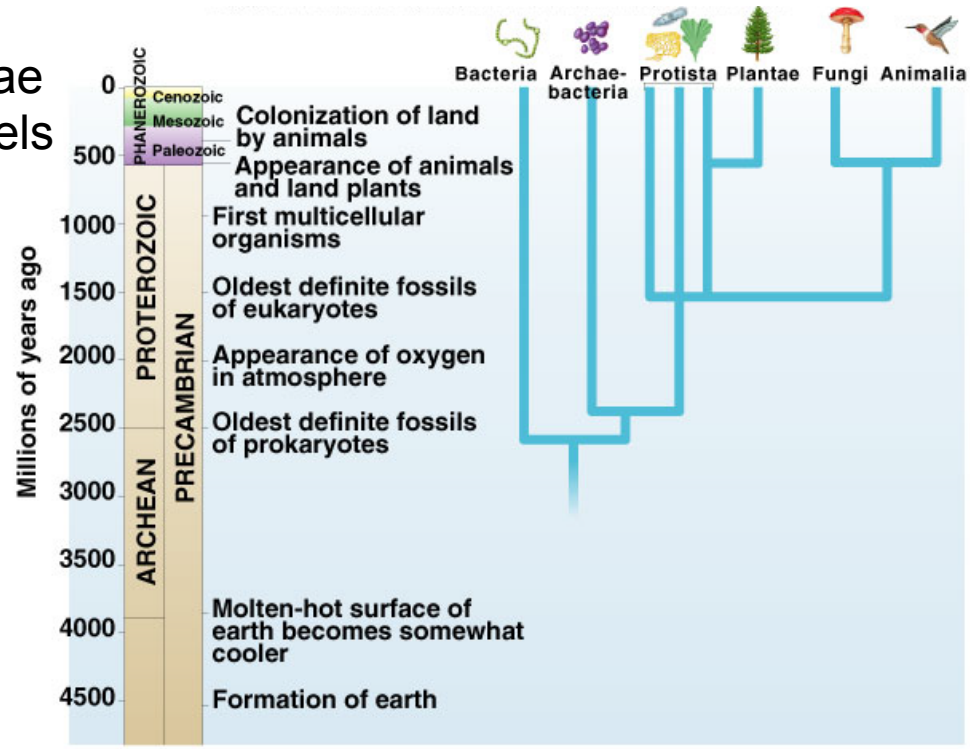
A mysterious fungus is killing off thousands of bats around the country. Scientists are calling it white-nose syndrome, because of the distinctive white smudges on the noses and wings of infected bats.

White-nose itself doesn't kill bats, but it disturbs their sleep so that they end their hibernation early. During the winter there are no insects to eat, so the bats literally starve to death.

Bats may be one of Mother Nature's least cuddly creatures, but they are ecologically important, keeping mosquitos and insects that attack crops in check.

Researchers say the syndrome has killed upward of half a million bats from New England to Virginia.



***NATURE* | REVIEW**

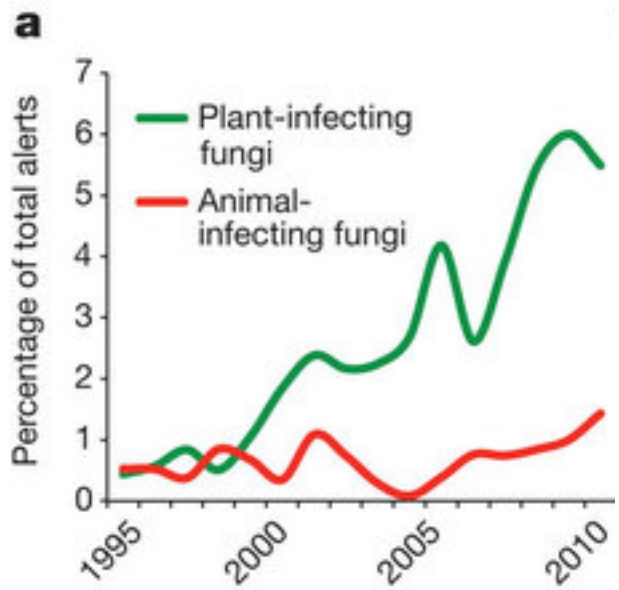
Emerging fungal threats to animal, plant and ecosystem health

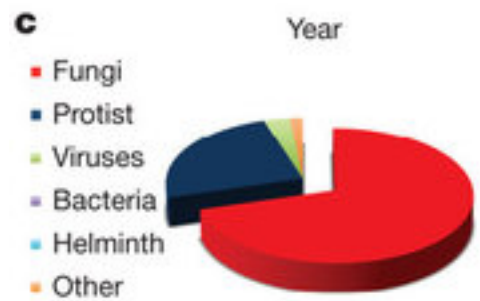
MC Fisher et al. *Nature* 484, 186–194 (12 April 2012) doi:10.1038/nature10947

The past two decades have seen an increasing number
of virulent infectious diseases in natural populations and managed landscapes.

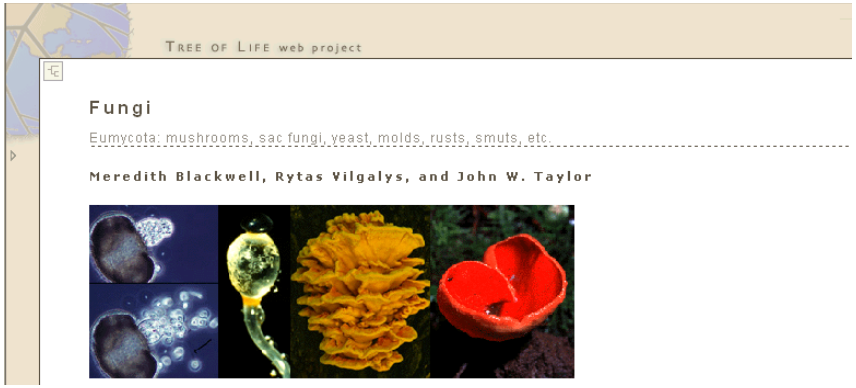
In both animals and plants,
an unprecedented number of fungal
and fungal-like diseases have recently caused

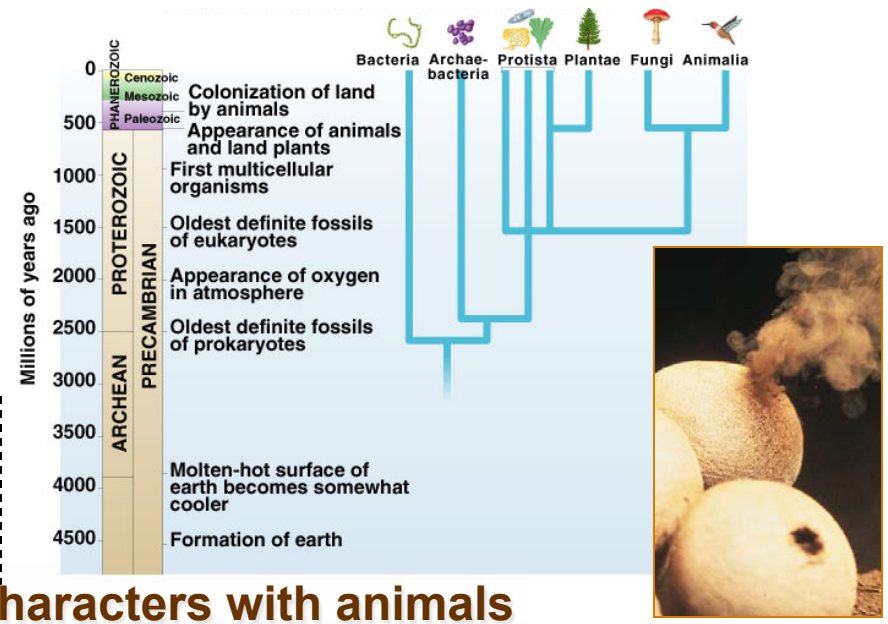
We argue that nascent fungal infections
will cause increasing attrition of biodiversity,
with wider implications for human and ecosystem health,
unless steps are taken to tighten biosecurity worldwide.





a. Disease alerts in the ProMED database for pathogenic fungi of animals and plants.
c, Relative proportions of species extinction and/or extirpation events
for major classes of infectious disease agents





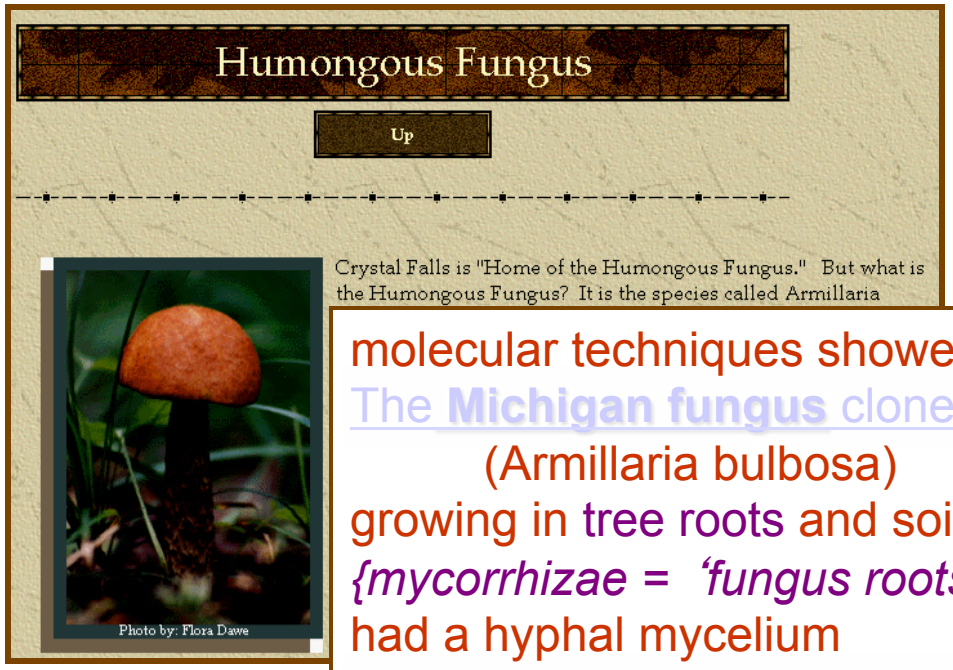
... a monophyletic group that **shares some characters with animals**
such as **chitinous** structures *{fungi have chitinous cell walls, unlike animals; arthropods secrete extracellular chitin sheets that are more like finger nails than cell walls}*
storage of **glycogen**, and **mitochondrial UGA coding for tryptophan**.
{ close phylogeny makes finding safe antifungal antibiotics challenging }

They are **heterotrophic**: export hydrolytic enzymes that break down biopolymers
*{ esp cellulose & **lignin** in wood }*, which can be absorbed for nutrition.
{fungi are aerobic; anaerobic bacteria can't decompose lignin; wood doesn't decompose in anaerobic conditions, like the bottom of a lake}

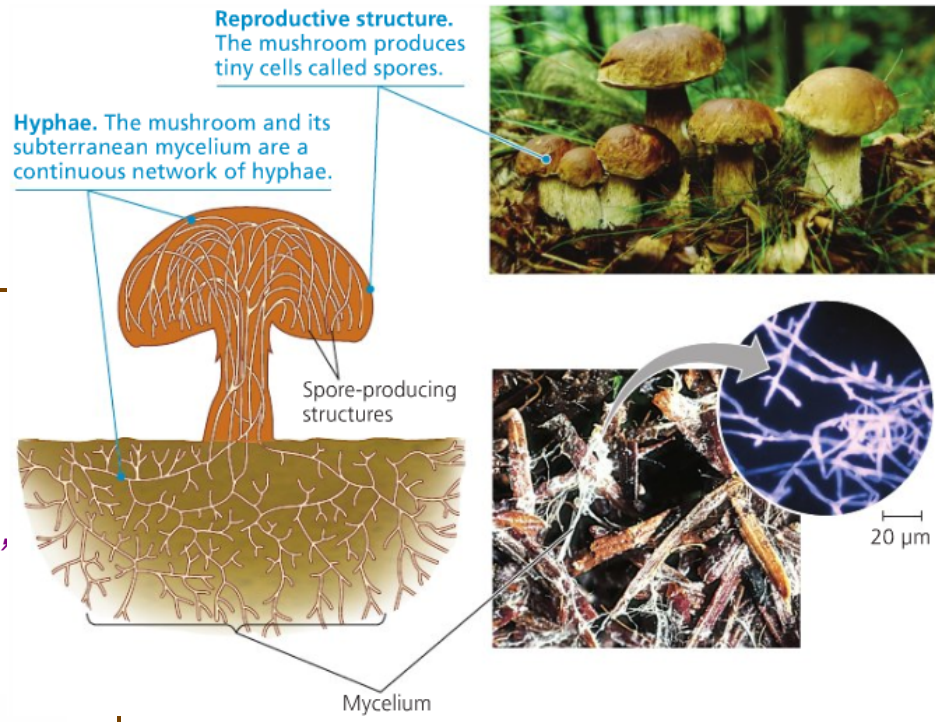
Fungi live in their own food supply and simply grow into new food … { ↑ *Surf/Vol* }

Should food become depleted, *{sex, and then}* **sporulation is triggered**.

Although the fungal filaments and spores are microscopic, the colony can be very large with individuals of some species rivaling the mass of the largest animals or plants.



molecular techniques showed
The **Michigan fungus** clone
(Armillaria bulbosa)
growing in tree roots and soil.
{mycorrhizae = 'fungus roots'
had a hyphal mycelium
spreading through **37 acres**
w/ an estimated wt of **110 tons**.



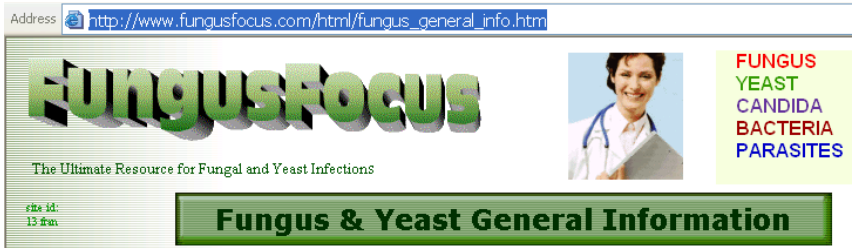
Humongous Fungus

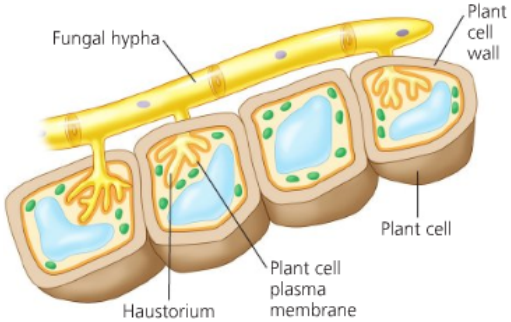
Honey Mushroom Blankets Forest, Kills Trees

By Jeff Barnard
The Associated Press

Aug. 6 — Walking through the Malheur National Forest in eastern Oregon you would be hard pressed to notice it. But a fungus spreading through the roots of trees now covers 2,200 acres, making it the largest living organism ever found.

In 2000, scientists discovered
the mycelium of one giant individual of
the fungus Armillaria ostoyae in Oregon
that is 3.4 miles in diameter and
spreads through 2,200 acres of forest.
This fungus is at least 2,400 years old,
qualifying it as one of Earth's oldest and largest organisms.

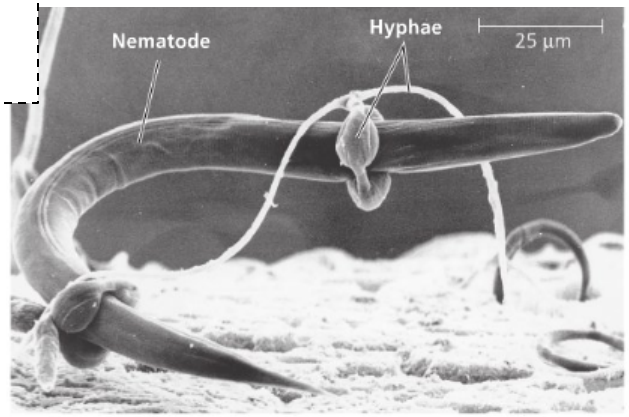




athlete's foot, swimmer's ear, ringworm,
fingernail and toenail infections,
and yeast infections.

Tinea capitis
(Ringworm of the scalp)

ADAM.

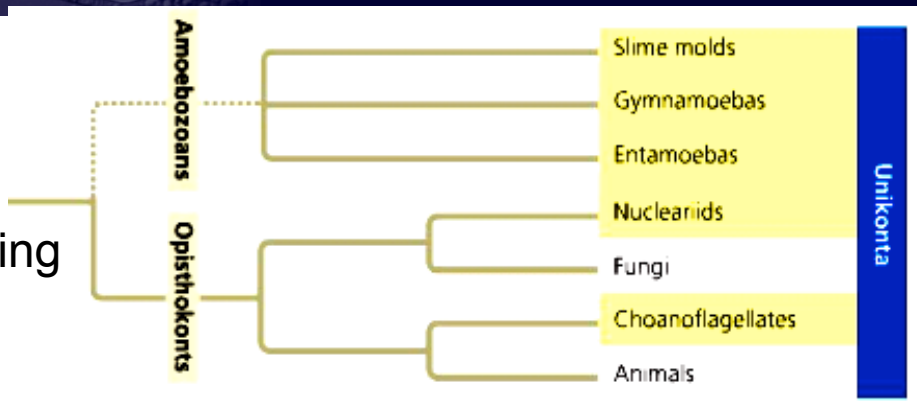


(a) Hyphae adapted for trapping and killing prey. In *Arthrobotrys*, a soil fungus, portions of the hyphae are modified as hoops that can constrict around a nematode (roundworm) in less than a second. The fungus then penetrates its prey with hyphae and digests the prey's inner tissues (SEM).

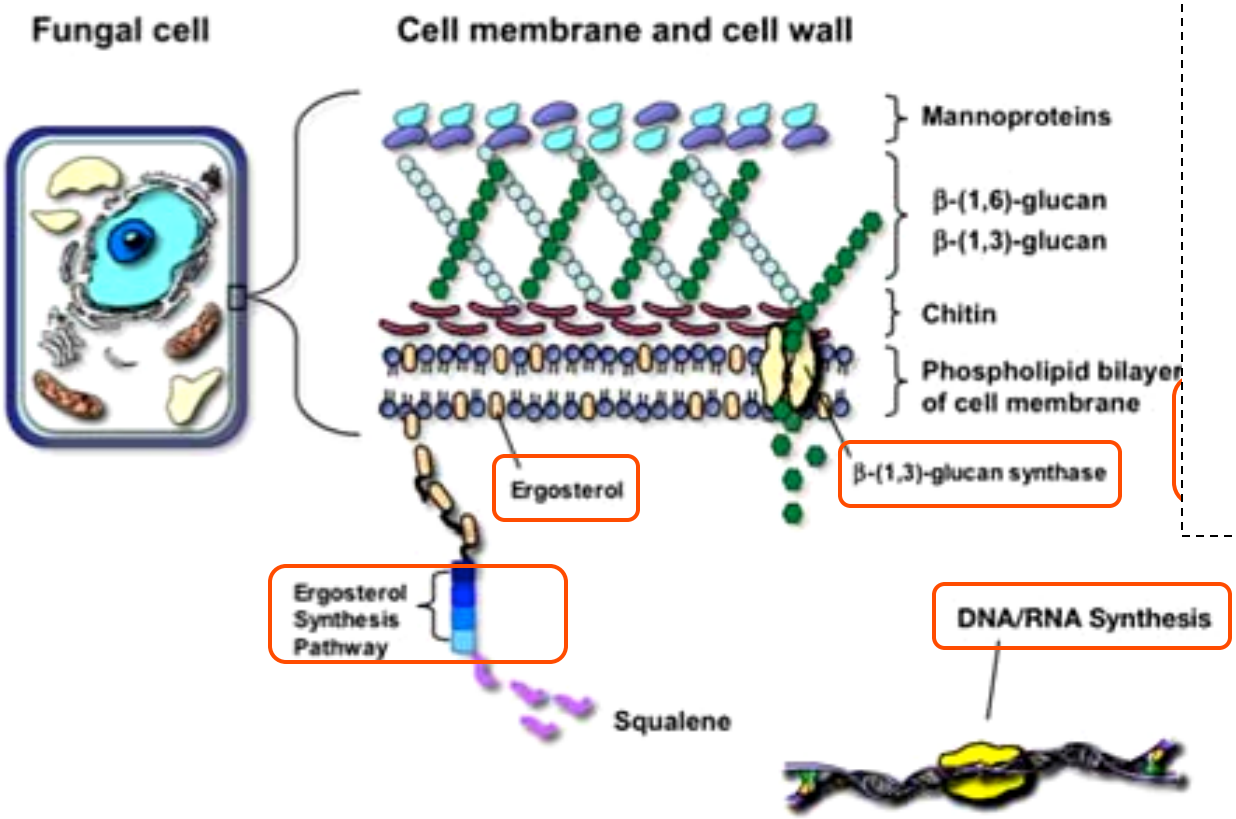
Fungus ... must live in damp environments
so that the hyphae can absorb nutrients that are dissolved in water.
They ... release extracellular enzymes into their environment
to degrade complex nutrients like cellulose.
In addition to simple enzymes,
many fungus produce toxins (called mycotoxins)
and enzymes that can disable, kill, and dissolve their food ...
Some toxins, such as **gliotoxin** produced by Candida and Aspergillus (among others),
inactivates important enzymes, kills cells and disrupts the immune system.

Like mammalian cells, fungi are eukaryotes
with DNA organized into chromosomes
within the cell nucleus
and distinct cytoplasmic organelles including
endoplasmic reticulum, Golgi apparatus,
mitochondria, and storage vacuoles.

This homology to mammalian cells
also extends to biosynthetic pathways ...



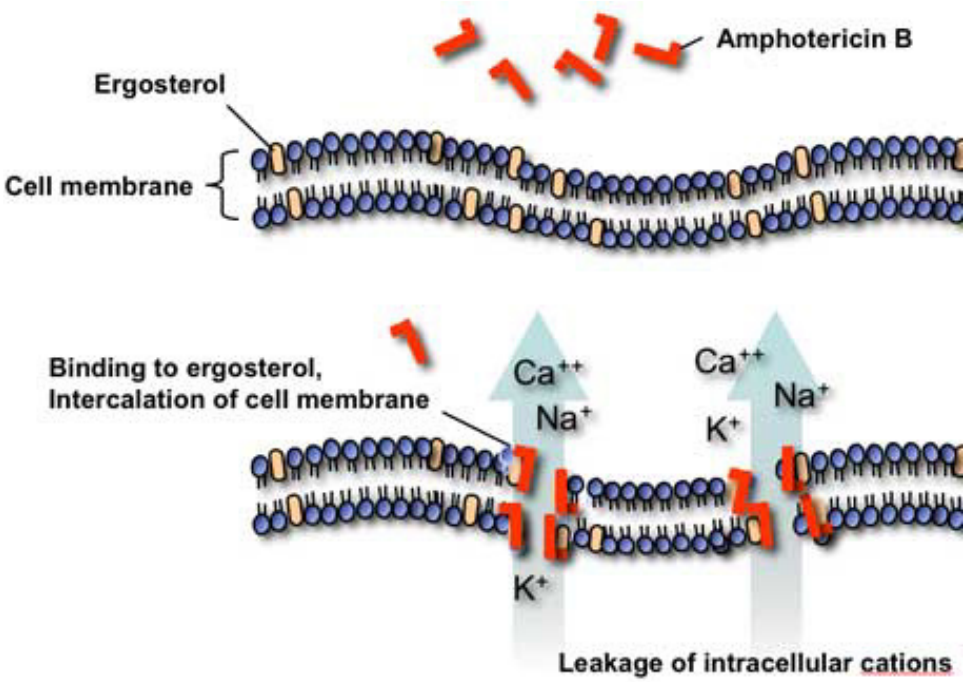
{we're all opisthokonts on this bus!}



Complex lipid particles, called sterols, account for approximately 25% of the weight of the cell *{plasma}* membrane *{of eukaryotic cells}.*

This difference has been exploited as the target of antifungal drug action ... several classes of antifungal agents target ergosterol, including the **polyenes**, **azoles** & **allylamines**

.



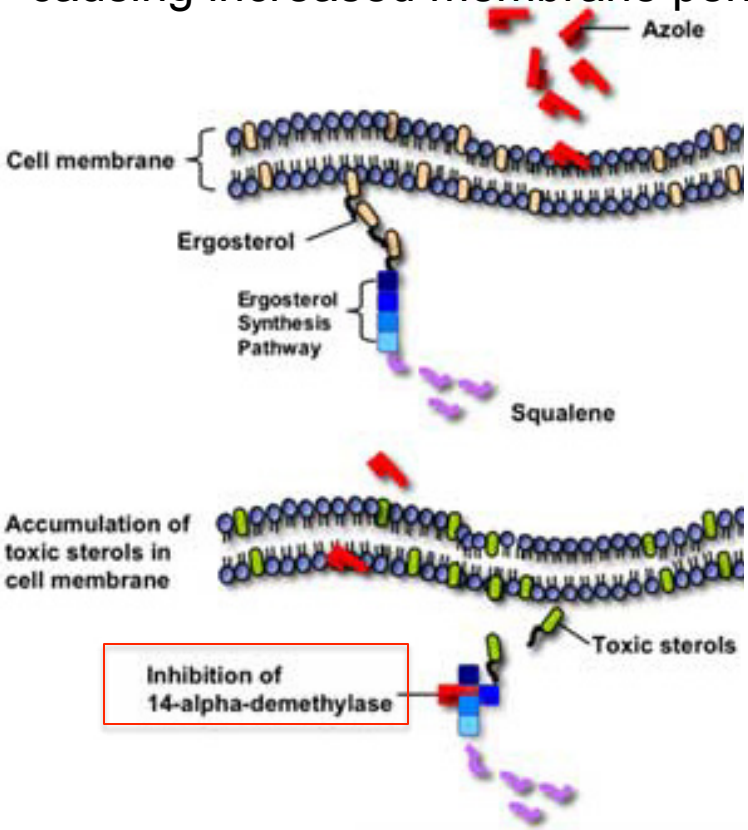
Polyenes such as amphotericin B act by binding to ergosterol

... results in the formation of pores that depolarize the membrane and increase permeability to proteins and cations, leading to cell death.

Azole antifungals

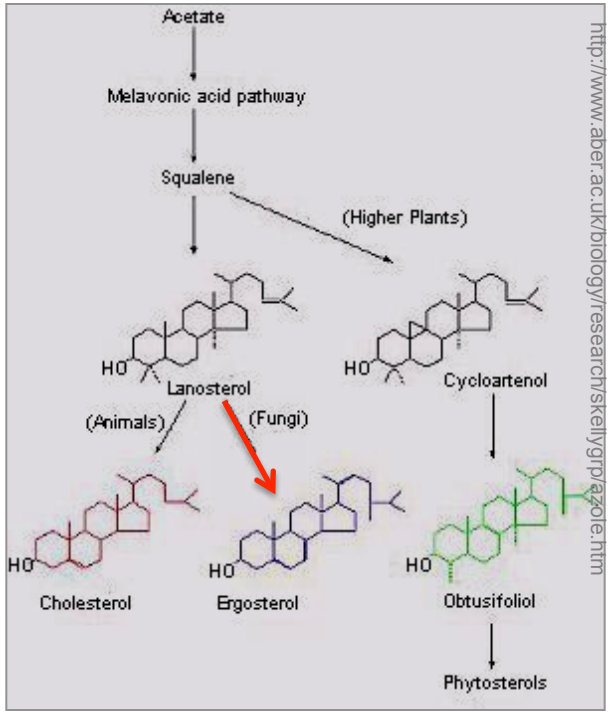
inhibit the fungal cytochrome P-450 3-A dependent enzyme 14-alpha demethylase,

causing increased membrane permeability and inhibition of fungal growth.



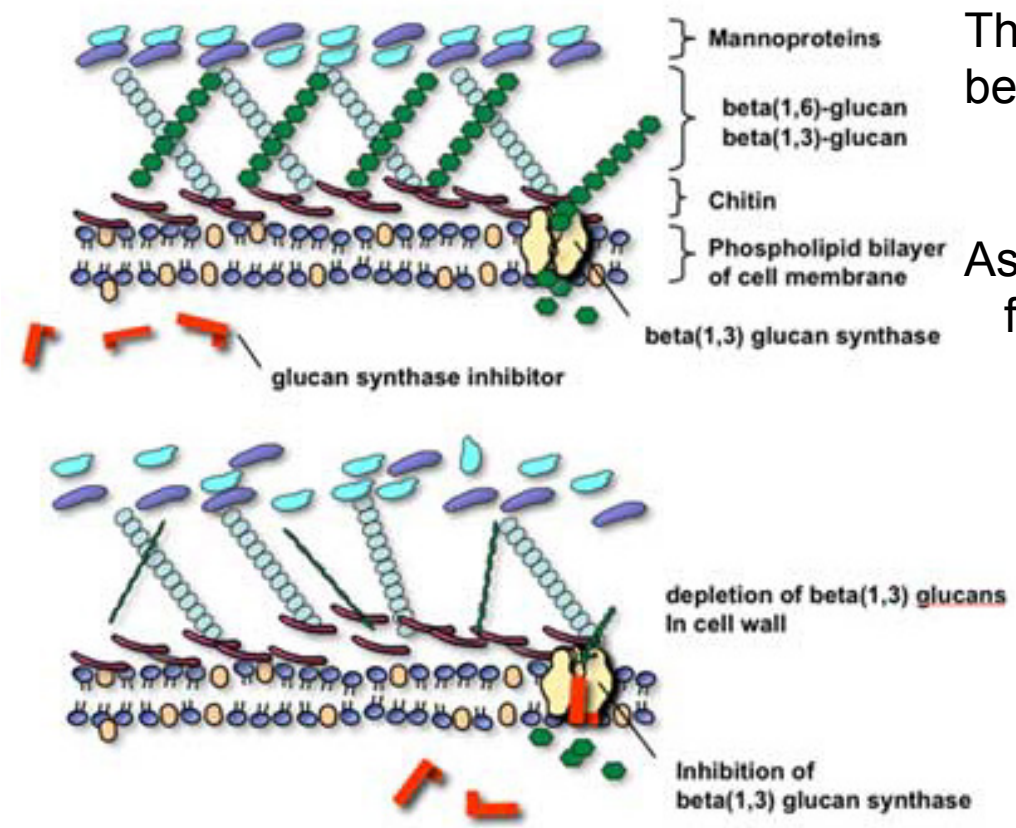
Azole antifungals can also inhibit many mammalian cytochrome P450-dependent enzymes involved in hormone synthesis or drug metabolism.

Azole antifungals are particularly susceptible to drug interactions with medications metabolized through the P450 pathway.



Allylamines like terbinafine inhibit the synthesis of ergosterol earlier in the ergosterol synthesis pathway by inhibiting the enzyme squalene epoxidase.

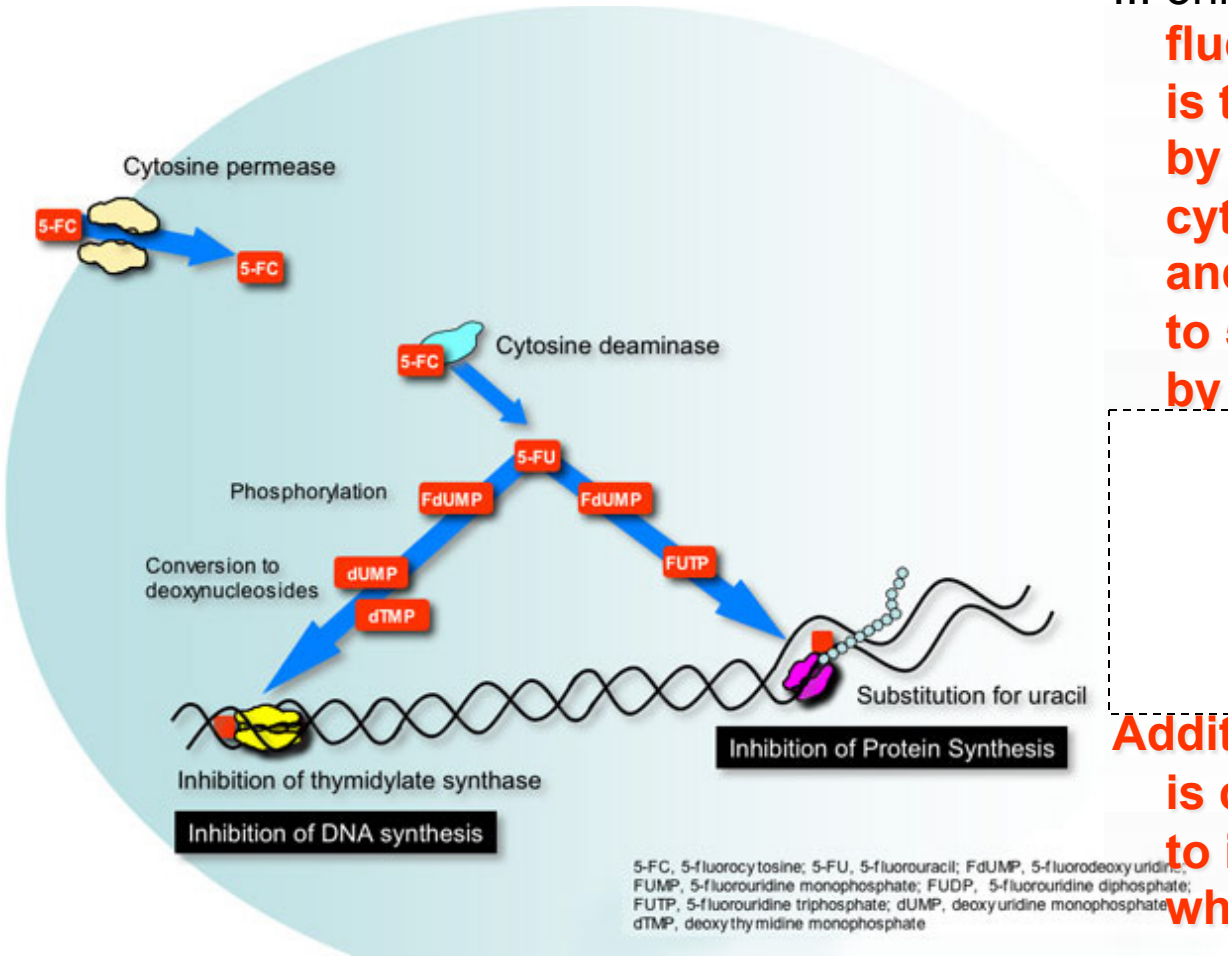
Animal cells lack cell walls.
The **fungal cell wall** is composed of a complex network
of proteins and polycarbohydrates that varies across fungal species.



There are three such agents at present,
belonging to the chemical family
known as the **echinocandins**:
caspofungin, micafungin & anidulafungin.
As would be predicted
from their mechanism of action,
these agents appear to be well-tolerated
and have relatively fewer toxicities
than polyene or azole-class antifungals.
{fungal cytochrome P-450 3-A
is similar to
mammalian cytochrome P-450}

DNA and protein synthesis have been difficult targets for the development of selectively-toxic antifungal therapy, as fungal and mammalian cells share remarkable homology in DNA replication and RNA translation.

However, advances in molecular biology are beginning to find important differences between mammalian and fungal cells that could be exploited for antifungal therapies.



... only one example,
flucytosine (5-FC)
is transported into fungal cells
by a specific enzyme
cytosine permease
and converted in the cytoplasm
to 5-fluorouracil (5-FU)
by cytosine deaminase

Additionally, 5-FU
is converted
to its deoxynucleoside,
which inhibits DNA synthesis.

A preview of "innate immunity" (in tomatoes) and "cloaking" to avoid detection

Fungal Defenses

One of the major driving forces of evolution is the constant arms race between plants and animals and the microbial pathogens that infect them.

The fungus C. fulvum causes leaf mold on tomato plants.

One of the ways tomato plants sense infections by C. fulvum is by detecting chitin, a component of fungal cell walls. {*chitin is an indicator of fungal attack*}

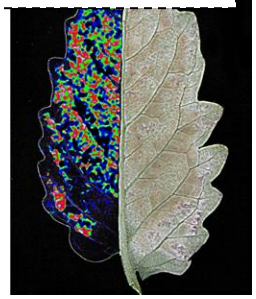
In response, the fungus has evolved strategies to evade detection.

{ *a fungal "cloaking device"* }

De Jonge et al. (*Science, 2010; 329: 953-955*) have now identified one such mechanism in C. fulvum, mediated by the effector protein Ecp6.

Secreted Ecp6 is able to bind to chitin oligosaccharides that are released upon degradation of the fungal cell wall and sequester them

Proteins with domain structure similar to Ecp6 are conserved throughout the fungal kingdom, which suggests that chitin sequestration may represent a general mechanism used by fungi to evade immune detection.



Science AAAS

Hide and Seek

Caroline Ash

Science 2 August 2013: Vol. 341 no. 6145 p. 436

Plants and their **fungal pathogens** are at war.
Plant surface receptors, which contain lysin motifs (LysMs),
sense fungal chitin oligomers,
which are basic components of fungal cell walls,
and thereby trigger immune defenses
against the fungus.

The fungi, in turn, have evolved molecular countermeasures.
Sanchez-Vallet et al. report studies
of a fungal effector protein {Ecp6}
which is secreted by the leaf mold Cladosporium fulvum
and provides a means for the pathogen to hide from the host.

LysM seems to be ubiquitous among fungi
and may represent a common mechanism
by which such pathogens can evade host defenses. …

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

T.Y. James et al. 2006. *Nature* **443**, 818-822 Full Text

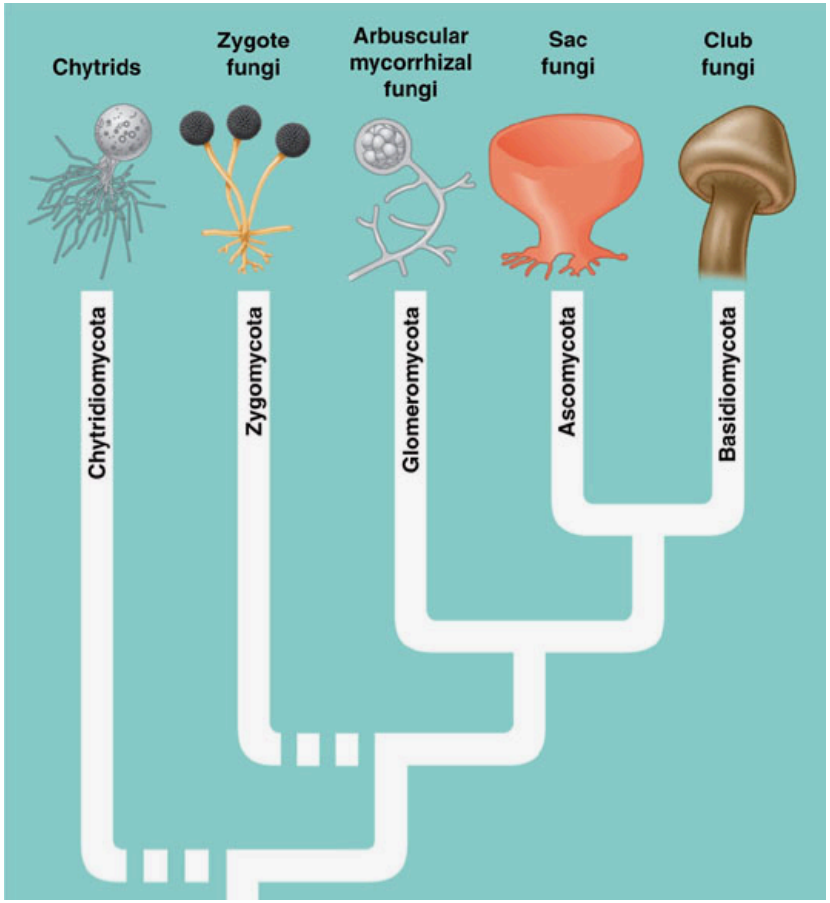
that radiated extensively on land.

Key adaptations to the terrestrial habit in the fungi include
the evolution of a filamentous growth form
and the development of aerially dispersed spores.

The sister kingdom to the Fungi (Animalia)
evolved diverse body plans
capable of feeding by ingestion,
whereas **the fungal branch developed**
a myriad of unicellular and filamentous
forms optimized for absorptive nutrition.

Traditional fungal phylogenies indicate that
fungi with flagellated cells (Chytridiomycota)
are the sister group of the remaining
non-flagellated fungi

Zygomycota, *{bread molds}*
Glomeromycota, *{endomycorrhizae}*
Ascomycota & *{yeasts & morels}*
Basidiomycota ... *{mushrooms}*



However ... *continued*

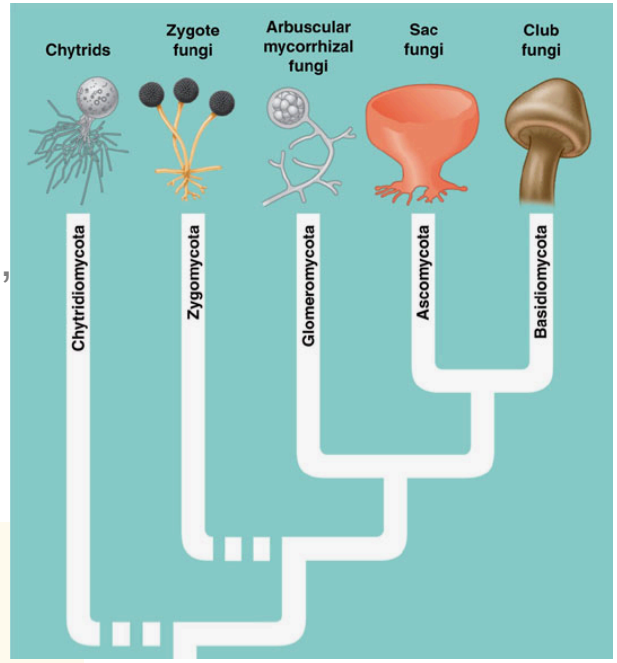
continuing James et al.

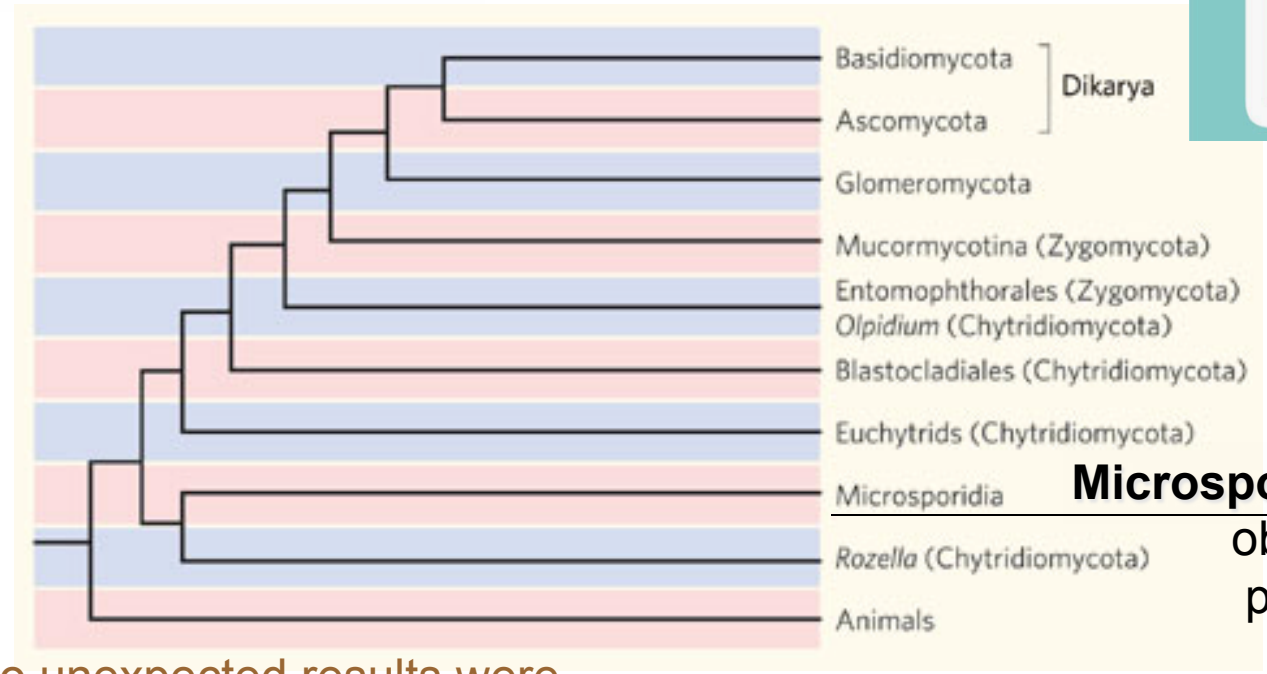
The combined gene phylogeny supported monophyly of the **Ascomycota**, **Basidiomycota** & **Glomeromycota**.

The Ascomycota & Basidiomycota formed a clade 'dikarya'

... also supported a clade uniting dikarya & Glomeromycota, in agreement with previous 18S rRNA phylogenies.

The opisthokont clade (Fungi, Metazoa and Choanoflagellida) was also recovered ...





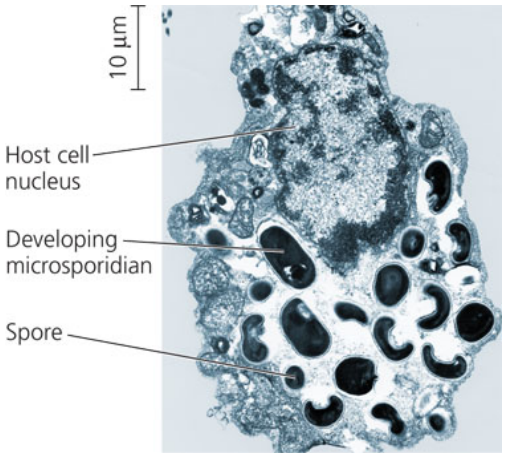
Microsporidia are obligately endoparasitic, protist-like organisms

Two unexpected results were

the placements of the ... **chytrids** ... is polyphyletic

and *{the "chytrid"} Rozella* grouped with the **microsporidia** as the earliest diverging branch of the Fungi.

Microsporidia – unicellular parasites of animals & protists, characterized by the production of *{tiny}* resistant spores.
Unlike most eukaryotes, they lack conventional mitochondria.
... microsporidia are not primitive eukaryotes, but rather highly derived *{obligate intracellular parasites}*



They are often used in the biological control of insect pests.

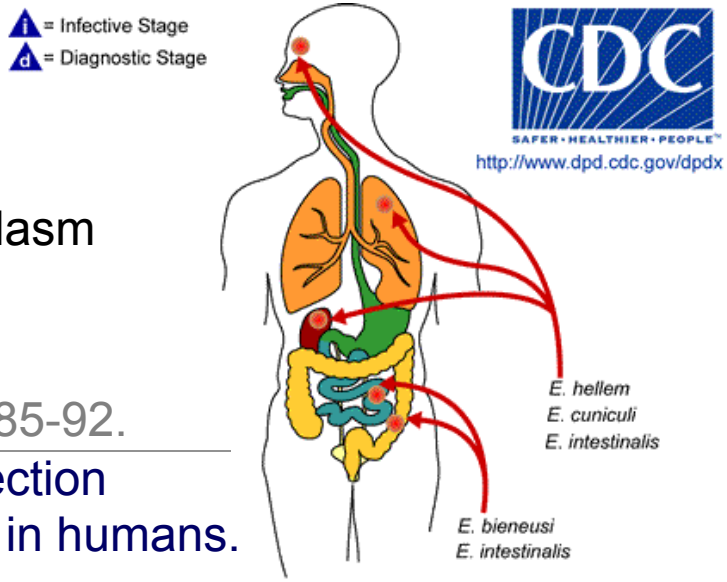
United States Department Of Agriculture
Agricultural Research Service

The microsporidium, *Thelohania solenopsae*, causes the slow demise of a fire ant colony.
... the most common pathogens of fire ants in S. Am.

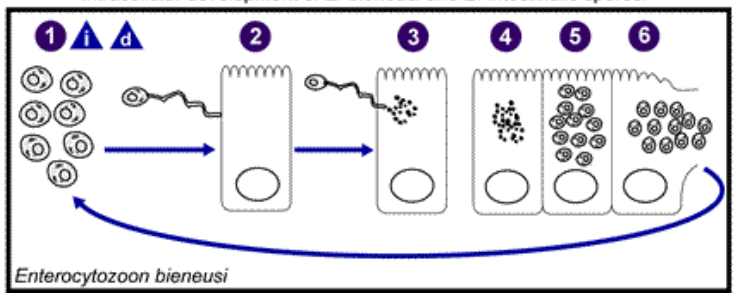
A defining characteristic is the mechanism by which the spore contents are injected into the host's cytoplasm through a tube.

Microsporidiosis: current status.
Didier ES, Weiss LM. Curr Opin Infect Dis. 2006 19:485-92.

Microsporidiosis is an emerging and opportunistic infection associated with a wide range of clinical syndromes in humans.
Effective commercial **therapies** for Enterocytozoon bieneusi, the most common microsporidian species identified in humans, **are still lacking** ...

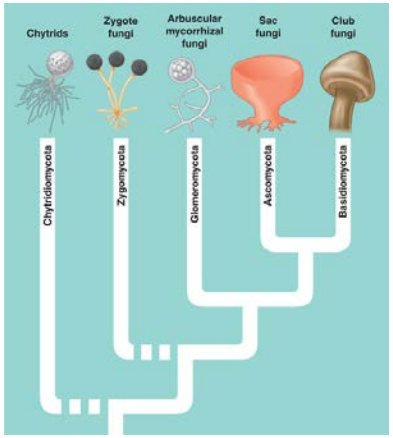


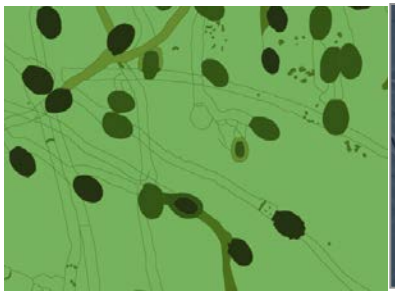
Intracellular development of *E. bieneusi* and *E. intestinalis* spores.

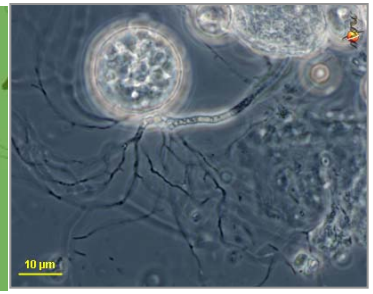


Chytrids are primitive, aquatic flagellated fungi.

{Chytrids are 'polyphyletic'}







Origin of the amphibian chytrid fungus.

Weldon et al. Emerg Infect Dis [serial on the Internet]. 2004 Dec.
Available from http://www.cdc.gov/ncidod/EID/vol10no12/03-0804.htm

The sudden appearance of **chytridiomycosis**, **the cause of amphibian deaths**

was introduced into the affected regions.

However, the origin of this virulent pathogen is unknown.

A survey was conducted of 697 archived specimens of 3 species of Xenopus collected from 1879 to 1999 in southern Africa ...

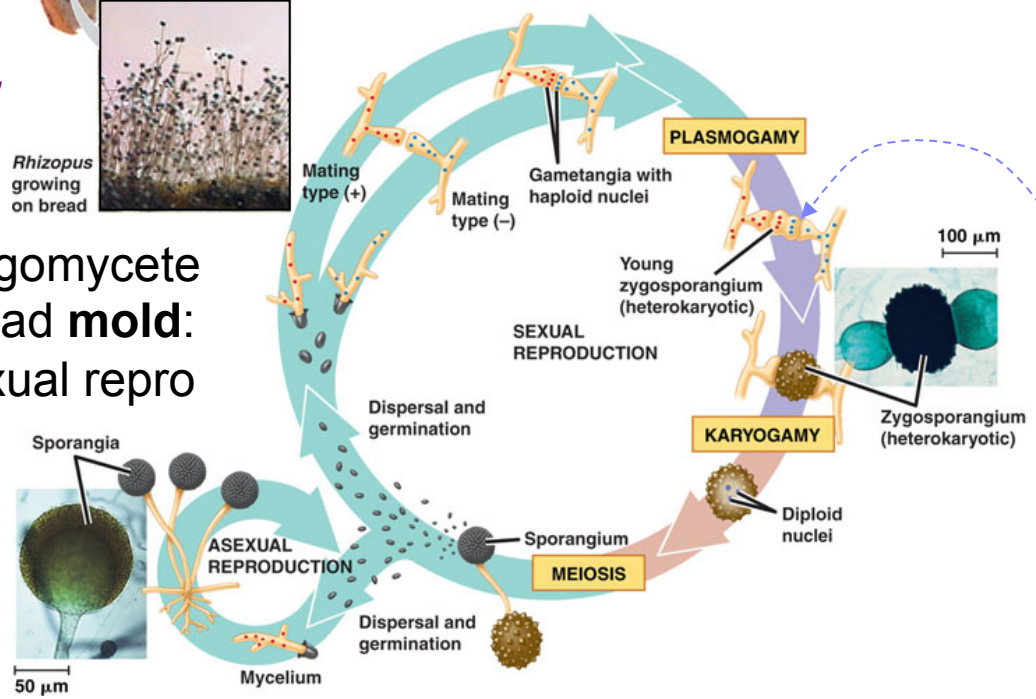
The earliest case of chytridiomycosis found was in a Xenopus laevis frog in 1938,

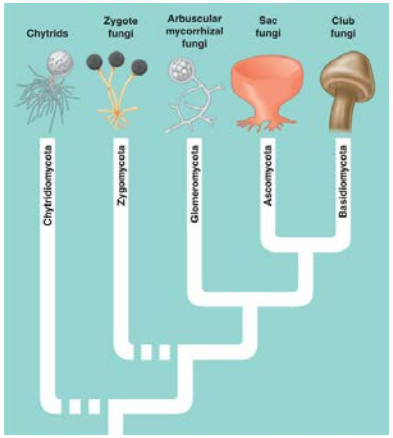
Chytridiomycosis was a stable endemic infection in southern Africa for 23 years ...

Zygomycota
– molds
polyphyletic
{note: "mold" is a growth form, like "tree," not a clade}

Complementary mating types:
different genotypes;
signal with pheromones.

A common zygomycete is black bread **mold**: asexual repro



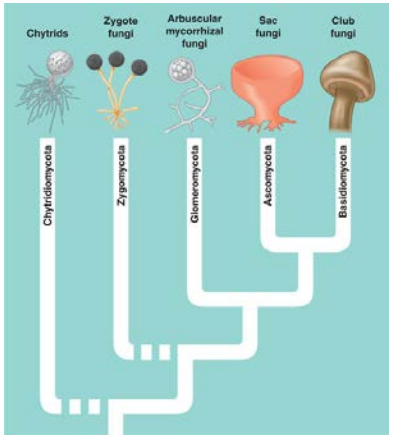


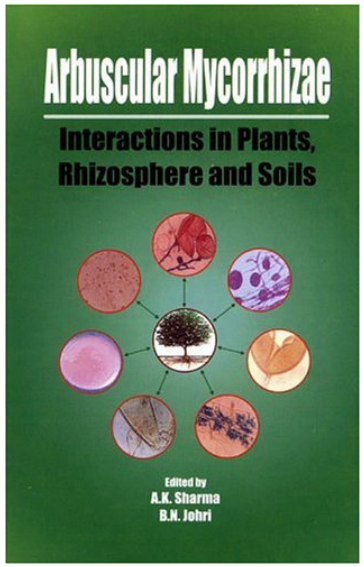
'**Safe Sex**:
the barrier method'
mycelium is aseptate, except to wall off area where haploid nuclei are combining - keep "parasitic" DNA out!

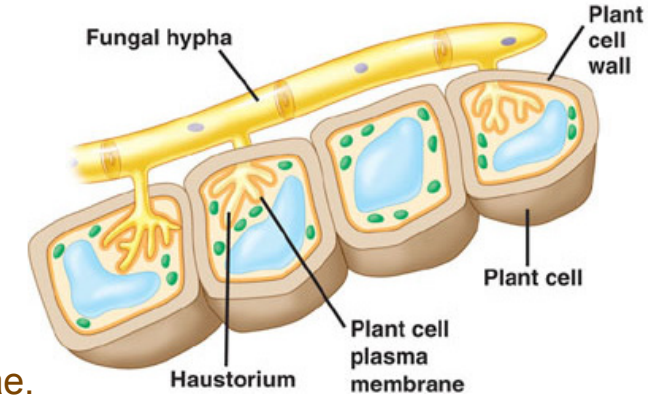
http://www.pacificcoast.net/%7Emycolog/CHAP3b.htm
…a petri dish containing nutritive agar medium.
Two sexually compatible strains of *Phycomyces blakesleeanus* were inoculated on opposite sides of the plate.
The mycelia spread across the surface.
Where they met, a line of **zygosporangia** with spiny appendages formed.

Glomeromycota - arbuscular, {endo}**micorrhizal** fungi

... an ecologically significant group.
All glomeromycetes form
a distinct type of **endomycorrhizae** *{inside-fungus-root}*
called arbuscular mycorrhizae.
The tips of the hyphae that push into plant root cells
branch into tiny treelike structures
known as arbuscules.



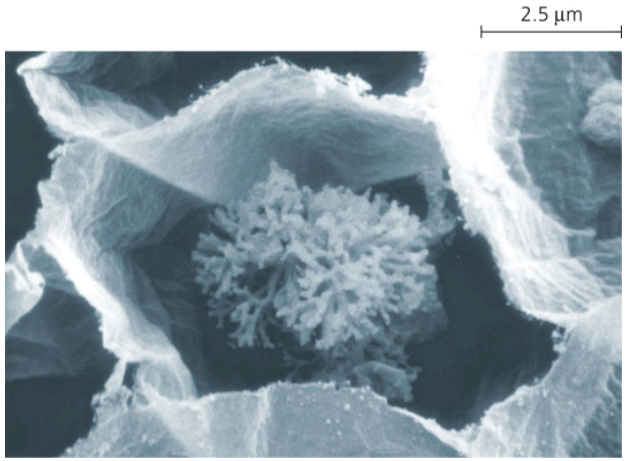




Mycorrhizal Root Dip Gel

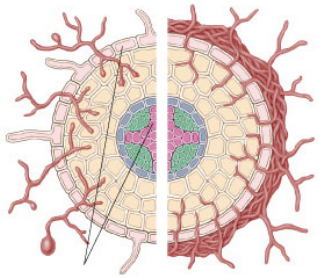
13 different species of beneficial Endomycorrhizae & Ectomycorhizae.

Increases Fruit/Vegetable yields.
Promotes Fast Growth.

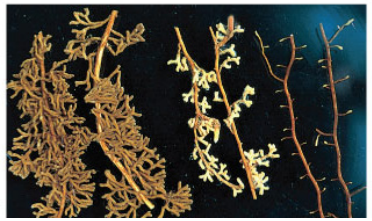


News Feature
Fungal roles in soil ecology: Underground networking
John Whitfield *Nature* **449**, 136-138
(13 September 2007)

about 95% of plants
have **mycorrhizal symbionts**



Mycorrhizal symbioses: two types are recognized:



Usually produces single spores in the soil for reproduction,
not large fruiting bodies {**not mushrooms**}.

Many large forest fungi form ectomycorrhizal partnerships,
both **truffles** with underground fruiting bodies and
fungi w/ the umbrella-shaped fruiting bodies: **mushrooms**.

http://daphne.palomar.edu/wayne/ww0504.htm#soil

The beautiful, red, fly agaric mushroom (**Amanita muscaria**) is unmistakable with its bright red cap covered with white scales. It contains the toxic alkaloid, muscimole;

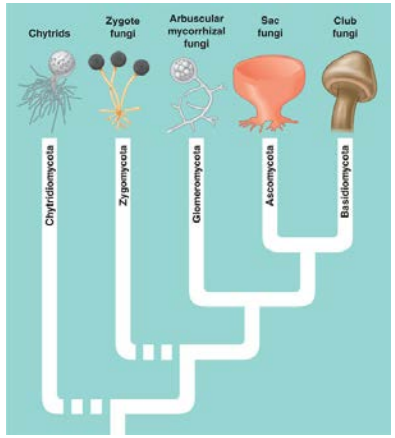
mycelial strands (lower) of *Amanita muscaria* on *Pinus strobus*

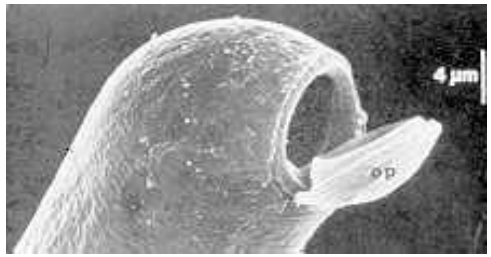
http://www.pacificcoast.net/~mycolog/chapter17.htm

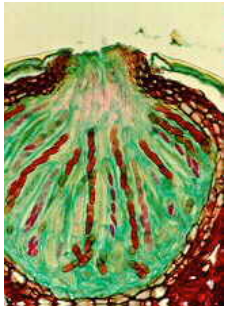
seedlings of Douglas fir with and without **ectomycorrhizal** partners.

Ascomycota - sac fungi

Asexual 'naked' spores (= conidia) formed at ends of hyphae; produce **Sexual spores in saclike asci**

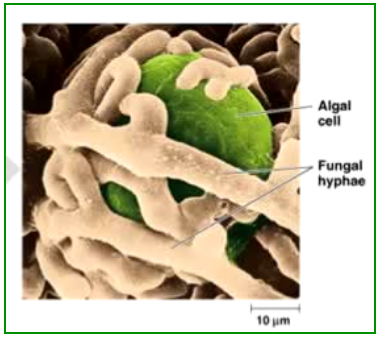


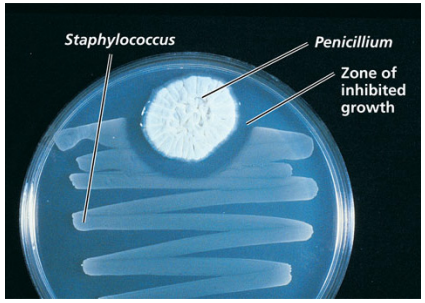




Sacchromyces cervisiae , an ascomycete

http://www.perspective.com/nature/fungi/ascomycota.html





Truffles & morels - ectomycorrhizal with tree roots

Penicillium (Penicillin)

≈ half the 60k species live as lichen partners

Some of the fungi that attack food crops are toxic to humans. For example, some species of the mold Aspergillus contaminate improperly stored grain and peanuts by secreting compounds called **aflatoxins**, which are carcinogenic.

(c) Ergots on rye

One type of ascomycete, Claviceps purpurea, forms purple structures called **ergots** on rye.

If diseased rye is inadvertently milled into flour and consumed, poisons from the ergots cause gangrene, nervous spasms, burning sensations, hallucinations, and **temporary insanity**.

One of the hallucinogens that has been isolated from ergots is lysergic acid, the raw material from which LSD is made.

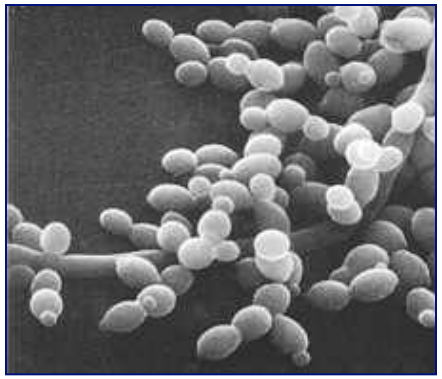
ERGOT:
A History Changing Plant Disease
Ergotism, Holy Fire, St. Anthony's Fire
http://www.plant.uga.edu/labrat/ergot.htm

Ergot.org

LSD, an ergot derivative

http://tolweb.org/tree?group=Ascomycota&contgroup=Fungi

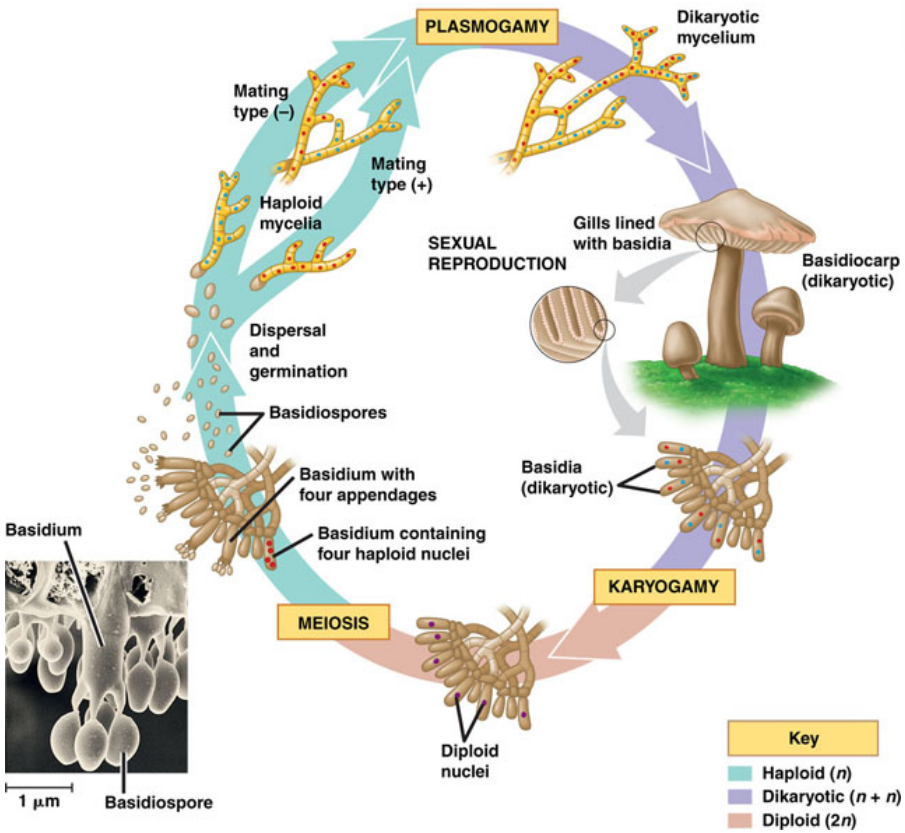
... the comparison of nucleic acid sequences ...
has permitted the integration of asexual fungi
such as the **yeast Candida albicans** into the **Ascomycota**.

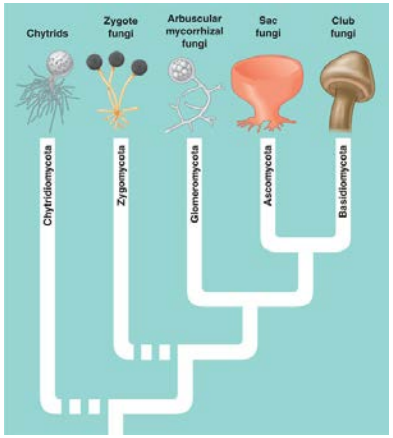


vaginal yeast infections are caused by **Candida albicans,**
which, along with a few types of bacteria,
are normally present in small numbers in your crotch.
Sometimes the yeast multiply rapidly and take over,
causing a full-fledged yeast infection,

Basidiomycota: Club fungi w/ long-lived dikaryotic (n+n) mycelia and transient diploid (2n) stage = Basidium

= mushroom





http://www.perspective.com/nature/fungi/agaricus.html

The Agaricus family
includes the best known mushroom in the US:
The white buttons sold generically as "mushrooms"
are a cultivated variety of Agaricus
The "wild" Crimini and Portabella mushrooms
are also cultivars of this species.