

Biology of Fungi, Lecture 1: What are Fungi?

Fungi in the Tree of Life

- ◆ Living organisms on earth first arose about 3.5 billion years ago
 - * Prokaryotic
 - * Anaerobic
- ◆ Oldest fossils of fungi are about 460 million years old
- ◆ Coincides with the rapid expansion of multi-cellular organisms
- ◆ Major multicellular eukaryotes are divided into Kingdoms
 - * Animals
 - * Plants
 - * Fungi
- ◆ Each of these three kingdoms differ in their basic cellular structure and mode of nutrition (defined by Whittaker, 1969)
 - * Plants - photosynthetic, cellulosic cell walls
 - * Animals - digestive systems, wall-less cells
 - * Fungi - absorptive nutrition, chitinous walls
- ◆ The estimates for the expansion of multicellular organisms are based upon phylogenetic analyses of Carl Woese
 - * Examined ribosomal RNA (rRNA)
 - Present in prokaryotes and eukaryotes
 - Relatively stable, but changes occur over time; thereby acting as a chronometer
 - * Distinguished three separate groups (Domains) of living organisms
- ◆ Domains - rRNA sequence differences correlate with differences in cellular structure and physiology
 - * Bacteria - “true bacteria”
 - * Archaea - “ancient prokaryotes”
 - * Eucarya - eukaryotes
- ◆ Taxonomic grouping of “Kingdom” lies beneath that of “Domain”
- ◆ Though the fossil evidence suggests fungi were present on earth about 450 million years ago, aquatic fungi (Phylum Chytridiomycota) most likely were present about a million years before this time
- ◆ About 354 - 417 million years ago, fungi evolved with primitive land plants
- ◆ These plant-associated fungi probably helped their photosynthetic partners gather nutrients from the harsh soils of the time

- ◆ These fungi were the early ancestors of the present day phylum Glomeromycota
- ◆ Despite plant-fungus co-evolution, fungi are more closely related to animals

Defining the Fungal Kingdom

- ◆ Mycology is the study of fungi
 - * *Myco-* = fungi
 - * *-ology* = the study of
- ◆ Mycology originally arose as a branch of botany because fungi were once believed to be “achlorophyllic” plants

Why Study the Fungi?

- ◆ There are over 100,000 species of **known** fungi and probably 15 times that many that have yet to be discovered
- ◆ Fungi are an extremely important part of the ecosystem
 - * Recycling of minerals and carbon
 - * Cause plant and animal diseases
 - * Source of food, medicines, and chemicals
 - * Important models in scientific research

A Brief History of Fungi

- ◆ Greeks (about 300 B.C.) believed truffles were produced by thunder
- ◆ Oldest illustration of fungi was found among the ruins of Pompeii (A.D. 79) that depicted edible mushrooms
- ◆ Euripides (A.D. 450-456) recorded the first mushroom poisoning deaths
- ◆ During a period of the Middle Ages (A.D. 1470 to 1670), books on ‘herbals’ were published that included illustrations and descriptions of fungi
 - * Remarkably similar to those of Greeks
 - * Used same methods to divide mushrooms and truffles into poisonous and non-poisonous varieties
- ◆ The German herbalist Jerome Bock wrote in A.D. 1552:

“Fungi and truffles are neither herbs, nor roots, nor flowers, nor seeds, but merely the superfluous moisture of earth, of trees, or rotten wood, and of other rotting things. This is plain from the fact that all fungi and truffles, especially those that are used for eating, grow commonly in thundery and wet weather.”

[From Ainsworth (1976) *Introduction to the History of Mycology*, as cited in Moore-Landecker (1996) *Fundamentals of the Fungi*, 4th ed.]

- ◆ Other cultures also believed the fungi originated from thunder and lightning
 - * Hindu god Soma was a child of thunderstorms who offered hallucinogenic fluids from *Amanita muscaria*, one of the world's most poisonous mushrooms
 - * Similar legends existed in Guatemala and Mexico
- ◆ Modern times in the study of fungi began with the invention of the microscope (about 1590-1600) by Hans and Zacharias Janssen of Holland
- ◆ Robert Hooke used the microscope to make the first drawings of a microscopic fungus (*Mucor* or *Rhizopus*) in 1665 and published them in his book *Micrographia*
- ◆ In 1699, fungi are found to be a component of lichens
- ◆ Anton van Leeuwenhoek observes yeasts using a microscope (1673)
- ◆ Hereafter, the study of fungi exploded with many different contributions over the next 300 years, including the one gene-one enzyme hypothesis (Beadle and Tatum, 1941) and the 2001 Nobel Prize for cell division studies in yeast

Defining the Fungal Kingdom

- ◆ Fungi are simple, eukaryotic microbes
 - * Many are microscopic
 - * Studies typically employ standard microbiological techniques
- ◆ Mycologists (fungal biologists) have traditionally studied not only the true fungi (e.g., mildew), but also fungus-like organisms (e.g., slime molds)
- ◆ The kingdom Mycota is comprised of the true fungi
- ◆ True fungi have the following features:
 - * Eukaryotic
 - * Fungal hyphae repeatedly branch to form a network of filaments termed a mycelium (sing., mycelia)
 - * Some fungi grow as a single-celled entity, termed a yeast, that grows either by a budding process or via binary fission
 - * Some fungi can switch growth forms between a hyphal phase and a yeast phase, a property known as dimorphism
 - Typically induced by environmental conditions
 - A number of such fungi are disease-causing agents of humans and animals
 - * Heterotrophic (chemo-organotrophs) - require preformed organic compounds
 - * Absorb nutrients after degradation by exogenously released enzymes

- * Unique cell wall components
 - Chitin
 - Glucans
 - Rare instances of cellulose, but definitely fungal cell walls are not as rich in this polymer as are plants
- * Typically have haploid nuclei
 - Hyphae often have a number of haploid nuclei present in each cell
 - Some yeasts have a single diploid nucleus
- * Reproduce both sexually and asexually, typically through the production of spores
- * Other differences [Deacon, Table 1.1] between fungi and animals and plants include:
 - Histone types
 - Sensitivity of microtubules to inhibitors
 - Manner of lysine biosynthesis
 - Membrane sterols
 - Organellar structure/morphology

Major Activities of Fungi

- ◆ Plant parasites
 - * Irish potato blight of the 1840s
 - * Dutch elm disease
 - * Disappearance of frogs in Costa Rica
- ◆ Plant symbionts
 - * Lichens (can also form with cyanobacteria)
 - * Mycorrhiza
- ◆ Human pathogens
 - * About 200 known species of fungi are known to infect humans
 - * Diverse diseases including:
 - Dandruff
 - “ring worm”
 - *Pneumocystis* infection of HIV-infected persons
 - Candidiasis

- ◆ Biological control agents
 - * Mycoparasites (other fungi)
 - * Entomopathogens (insects)
 - * Nematophagous (nematodes)
- ◆ Decomposition
 - * Cellulose (plant material)
 - * Rumen fungi in cows
 - * Dry rot
- ◆ Toxin production (mycotoxins)
 - * Aflatoxins (peanuts and grains)
 - * Mushroom poisoning

Fungi in Biotechnology

- ◆ Foods and flavorings
 - * Edible mushrooms
 - 5 million tons produced worth \$14 billion (1994)
 - Diverse types now widely available in supermarkets
 - * Alcoholic beverages
 - * Breads, cheeses, soy sauce
 - * Quorn mycoprotein
- ◆ Fungal metabolites
 - * Two categories
 - Primary - intermediates or end products of common metabolic pathways essential for normal cellular function
 - Secondary - diverse range of compounds formed by specific pathways of a given organism and not essential for growth (but may provide some selection advantage)
- ◆ Fungal metabolites (cont.)
 - * Examples of primary metabolites
 - Citric acid (estimated 200,000 tons produced in the year 2000) [soft drinks]
 - Gluconic acid (estimated annual production of 100,000 tons) [food additive]
 - Itaconic acid (estimated annual production of 80,000 tons) [paint and adhesive manufacture]

◆ Fungal metabolites (cont.)

* Examples of secondary metabolites

- β -lactam antibiotics, e.g., penicillins and cephalosporins
- Non- β -lactam antibiotics, e.g., griseofulvin, gliotoxin, ciclosporins
- Pullulan - film-wrap for food in Japan
- Chitosan - sewage clarification, plant defense initiator

◆ Enzymes and enzymic conversions

* Extracellular enzymes

* Commercially valuable roles

- Food industry
- Bioconversions

◆ Heterologous gene products - expression of foreign proteins by fungi having medical/industrial applications