Chapter 9
Phylum: Basidiomycota

1. **Basidiomycota** is the second large phylum and with Ascomycota, comprises the **subkingdom Dikarya**, and also called the "Higher Fungi".

2. **Basidiomycota** include mushrooms, puffballs, stinkhorns, bracket fungi, other polypores, jelly fungi, boletes, chanterelles, earth stars, smuts, bunts, rusts, mirror yeasts, and the human pathogenic yeast, ***Cryptococcus***.

3. They are filamentous fungi composed of hyphae (except for those forming yeasts).

4. They are reproducing sexually via the formation of basidia that normally bear four external **meiospores** called **basidiospores**.

5. Some are reproduce asexually, and may or may not also reproduce sexually. They assigned to this phylum by gross similarity to others, by the formation of a distinctive anatomical feature (the clamp connection - see below), cell wall components, and definitively by phylogenetic molecular analysis of DNA sequence data**.**

6. Most of them are **saprophytes**, causing decay of litter, wood, or dung, and some are serious agents of **wood decay** such as ***Serpula lacrymans (Meruliums lacrymans)*** the dry-rot fungus.

7. Some of the toadstools which are associated with trees form mycorrhiza, a symbiotic association, but some are severe **parasites** e.g. ***Armillaria mellea,*** the honey agaric which destroys a wide range of woody and herbaceous plants.

8. Whilst the fleshy fungi enjoy a notorious reputation for being poisonous, the majority of toadstools are harmless.

9. They also include very important parasites, the rusts and smuts .

Diagnostic Characters

1- Basidium

It is the main distinguish character of this phylum. It is the site of meiosis and bearing basidiospores (products of meiosis) and usually located in specialized regions (gills or pores).

a. A typical basidium is aseptate (holobasidium**) and has four 1-celled haploid basidiospores (**ballisto-or statismospores**) on projection called** sterigmata **(sing. strigma).**

It may be transversely or longitudinally septate (**phragmobasidium**) and the number of basidiospores (statismospores) are occasionally fewer or more than four (Fig. 9. 1**)**.

Stages of basidium development:

1. Terminal cell of a hypha making up the gill tissue is densely packed with cytoplasm, and soon several small vacuoles appear (Fig. 9.2.).
2. Later a single large vacuole develops at its base and, by the enlargement of this vacuole; cytoplasm is pushed away towards its end.

3. **Sterigma** develops through four elastic areas of the wall of clear cap at the tip.
4. The basal vacuole enlarged and acts like a piston ramming the cytoplasm into the spores, forces the development of basidia and spores.
5. Nuclear fusion occurs in bi-nucleated young basidia (**probasidium)** (Fig. 9.3).
6. Meiosis occurs immediately, thus 4 haploid daughter nuclei result, one is distributed to each sterigmata and basidiospore (**metabasidium**).
6. In some basidia a mitotic division follows meiosis, so that some basidiospores are binucleate.
7. The plane of spindle–formation during meiosis may be
   a. **chiastobasidial**, or
   b. **stichobasidial** (longitudinal at different levels).

Types of Basidia: Basidium divided into three regions based upon nuclear events and anatomy

1. **Probasidium** (n+n to 2n): It is the site of karyogamy (Fig. 9.3. B)
2. **Metabasidium** (2n to n+n+n+n): It is the site of meiosis
3. **Sterigma** - section between **metabasidium** and basidiospores.

2- Basidioma

Basidioma(ta) is the term used to designate the basidiocarp or the sporocarp (=fruiting body) of basidiomycetes. Basidiomata are quite variable in an evolutionary sense several morphologies (e.g., the mushroom, puffball, truffle, etc.) are the product of convergent evolution

Structure (Fig. 9.4)

1. **Pileus: (**cap or upper surface of basidiocarp**)**

2. **Hymenophore (**spore producing region), lamellate , poroid and toothed

3. **Stipe** central, eccentric, lateral, absent, solid, hollow, stuffed.

4. **Peridium** outer tissue that enclose gleba of “gasteromycete”, homologous to pileus of mushroom, one to many layers

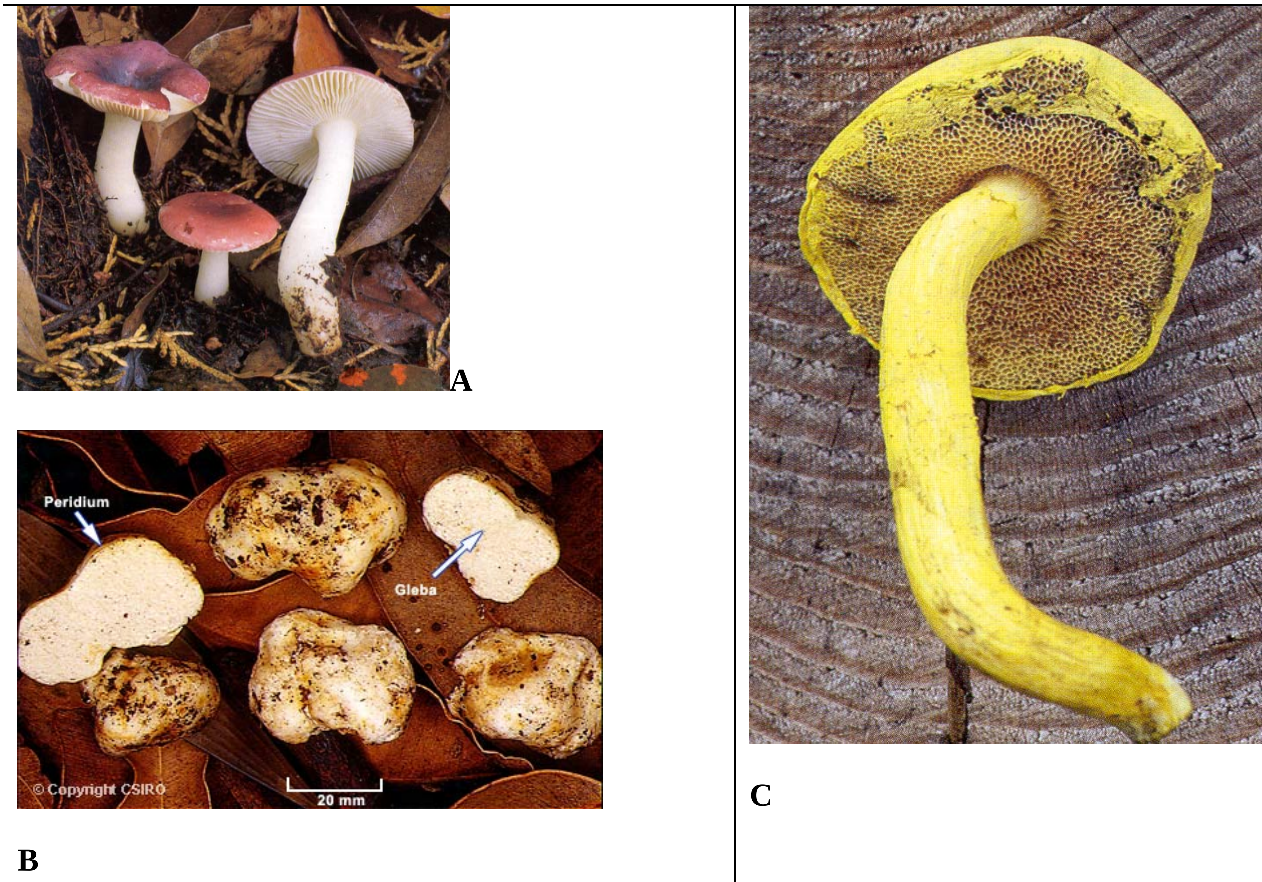

Fig. 9.4. Basidioma. A- lamellst, B- gleba, c-Poroid,

d. Basidioma composition (Fig. 9.5)

1.**Monomitic** = generative hyphae only
2.**Dimitic** = generative hyphae + skeletal or binding hyphae
3.**Trimitic** = generative + skeletal + binding

3- <u>Basidiospore</u>

1. A propagative cell

2. Typically **ballistospore** (i.e. **forcibly ejected)** but in **Gasteromycetes** are **statismospore (i.e. passively ejected)**.

3. It is containing **one** or **two** haploid nuclei produced, after meiosis, on a basidium.

4. Basidiospores are **2-8 per** basidium **(4 most common).**

5. Hilar **appendix and** Buller's **droplet in pellicle are present (Fig. 9.6.).**

6. The spore initial is formed by **inflation** of the apex of the **sterigma**.
7. The contents of the enlarging spore initial are in direct cytoplasm continuity with the lumen of the sterigma.
8. As the spore develops successive wall layers are deposited, derived from two membranes known as the internal basidial layer and the external basidial **pellicle**.
9. The first formed layer is the **eposporium** (thickest). It determines the shape of the spore. **Episporium** may, in certain forms, give rise to layer outside it, the **exosporium**. Opposite to the point of attachment, the wall layer may be thinner to form the **germ pore**.
10. The last formed layer is **endosporium**, the innermost layer. some spore may surrounded by one or two further layers, the **perosporium** and the **ectosporium**.
13. The wall of the spore is not always smooth, but is ornamented by spines or folds usually derived from the **exosporium**.
14. The spore may be pigmented or colourless. The pigment where present may be in the **cytoplasm** or in the **episporium** (or in both). Spore shape, size, ornamentation and pigmentation are important taxonomic characters at the generic or family level (Fig. 9. 7).
15. basidiospore give a spore print color characteristic for a species(Fig. 9. 7).
16. basidiospore give a characteristic staining reactions with iodine
    1. **amyloid/non-amyloid** - blue-black in iodine
    2. **dextrinoid** - red-brown in iodine
17. **Germination** by **germ** tube formation or **budding**.

4- The structure of the mycelium

1. Basidiomycota are typically **mycelial** but some are **yeasts** (or have yeast like state).

2. Basidiomycota yeasts may be distinguished from ascomycetous yeasts by the morphology of the bud scars, giving a red **colour with** diazonium blue B**, being** urease +**, having a** high GC **(guanine + cytosine) percentage.**

3. <u>Three types of mycelium occurs in life cycle:</u>

a. P**rimary mycelium** (monokaryotic).

b. **Secondary mycelium:** (dikaryon): Characterized by clamp connections in many taxa.

c. **Tertiary mycelium**: organized, specialized tissues that make up the basidiocarp

1. **Generative hyphae:** Thin-walled-± clamp connections-Septate, branched
2. **Skeletal hyphae:** Thick-walled, Aseptate, unbranched
3. **Binding hyphae:** Thick-walled, aseptate, highly branched

The three types of mycelium forming the basidiocarp occurs in three formations

1. **Monomitic =** generative hyphae only
2. **Dimitic =** generative hyphae + skeletal or binding hyphae
3. **Trimitic =** generative + skeletal + binding

5. Life Cycle.

1. Basidiospores germinates to produce a primary mycelium, multinucleate at first.

- Later septa (simple cross-walls) are laid down cutting the mycelium into uninucleate segments.

-The nuclei are derived from the original single nucleus that enters the basidiospore so that all are usually identical, or **homokaryotic** and each segment is **monokaryotic**.

2. For fruiting to occur in most Basidiomycota:

a. Two compatible homokaryotic mycelia are fused together to achieve cytoplasmic continuity.

b. Nuclear migration occurs followed by **plasmogamy** at the point, **karyogamy** is delayed.

c. Thus **secondary mycelium** (**dikaryotic;** genetically distinct (**compatible**) nuclei) develops. It is strictly **heterokaryotic dikaryons**.

d. The two nuclei in each segment of a dikaryon usually divide simultaneously, and nuclear division is described as conjugate.

e. Generally all, dikaryotic mycelia bear at each septum a characteristic lateral bulge termed a **clamp connection**, or **clamp**. Not all dikaryotic mycelial species bear clamps, while clamp is confined to dikaryotic only.

3. C**lamp connection (Fig. 9.8):** It is a device that ensures that when a dikaryotic mycelium segments, each segment contains two genetically distinct nuclei. It is regarded as homologous to the **crozier** at the tip of **ascogenous** hyphae in **Ascomycotina**, and have argued that the Basidiomcota evolved from Ascomycota ancestors. It is a hyphal outgrowth, which at cell division makes a connection between the resulting two cells by fusion with the lower, **buckle**, **nodose** septum, **by-pass hypha**.

4. Formation of Clamp connection:

1- Hyphal outgrowth formed between the two nuclei of a dikaryotic hyphal segment.

2- Simultaneous nuclear division and formation of backwardly directed lateral branch into which one of the daughter nuclei passes.

3- Formation of **two cross-walls** cutting off an **apical cell** that contains two compatible nuclei, and a **lateral branch** with a single nucleus. The clamp remains permanently attached to the hypha.

4- The clamp **bends** and touches the cell near the lower nucleus. The intervening walls dissolve.

5- Fusion of lateral branch with sub-apical cell and migration of the nucleus into the cell occurs.

6- The result is a **dikaryotic** cell.

<u>The dolipore septum</u>

1. The septum of **dikaryotic** Basidiomycota is more complex than that of other fungi.

2. It is flares out in its center to form a **barrel-shaped** structure with open ends **(Fig.** 9. 9).

3. It has been found in numerous Basidiomycota (**Auriculariaceae**, **Tremellaceae**, **Aphyllophoralles**, **Agaricales**) but not apparently, in the **ustilaginales** or **uredinales**.

4. dolipore complex is cmposed of three basic structures:

a. the **barrel**-shaped **dolipore**; b. the **occlusions** within the pore; c. the **parenthesome** (pore cap) on each side that delimits the pore domain. The **centripetal**-most region of the cross wall comprises a **toroidal swelling**.

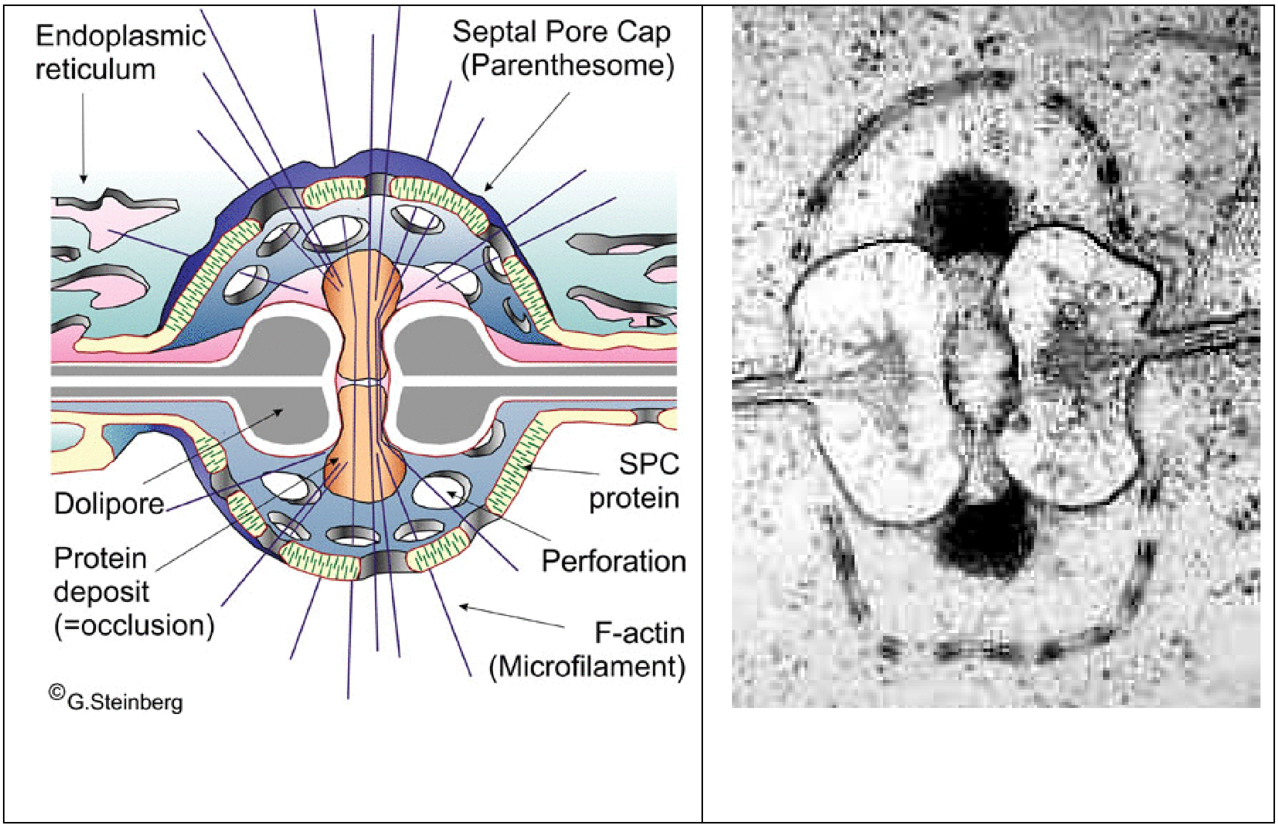

Figure 9.9. A. Dolipore septa with perforate parenthesome. Moore & Marchant (1972).

The cell walls of most Basidiomycetes examined are composed of microfibrils of **chitin** and also **glucans** with 1 → 3 linked and 1 → 6 linked B – D glucosyl units.

6. Mating Systems

Basidiomycota are either **homothallic** or **heterothallic**

A. Homothallism: Most basidiomycota are **homothallic** that is either **primary or secondary:**

a. **Primary homothallism** (in about 25% of all species of basidiomycetes): Dikaryon formation occurs in single, self-compatible thallus.

e.g. Coprinus sterquilinus, basidiospore germinates to form a **monokaryotic** mycelium that soon becomes **dikaryotic** bearing clamp connections. This mycelium is capable of forming fruit-body.

b. **Secondary homothallism:** Fungi that produce binucleate basidiospores contain two haploid nuclei with compatible mating type alleles (Fig. 9.11). basidiospore germinates directly into a **dikaryon (**no true monokaryotic stage). It is superficially resembles a homothallic species e.g. ***C. ephemerus f .bisporus*** the basidia bear two heterokaryotic spores. After meiosis, two nuclei enter each spore and a miototic division may follow. On germination, a single spore form a dikakyotic mycelium capable of fruiting.

B. Heterothallism (About 75% of all species of basidiomycetes): Self-sterile (self-incompatible) individuals requires the union of two, unique compatible thalli.

Mating type genes (MAT genes)

a MAT locus ON the chromosome consists of few to several tightly linked genes and occurs in the following type:

1-Unifactorial (=bipolar): one locus or factor (A) requires 2 different alleles for mating type compatibility (in **25%** of heterothallic species).

2- Bifactorial (= tetrapolar): two unlinked loci or factors on different chromosomes (A and B). It is requires **4 dissimilar** alleles for mating type compatibility (in **75%** of heterothallic species).

Oidia

Some **Hymenomycetes** reproduce by means of **oidia**, that may have a **sexual** role. They are common on homothallic and two-spored forms (Fig. 9.11). **Oidia** are either **wet** or **dry:**

a.* Wet *in C. cinereus:

- oidia are produced only on monokaryons on specialized erect oidiophore.

- They are formed at the tip of the oidiophore and coalesce in a **sticky globule** (insects disperse them). **Cylinrical**, **uninucleate** and **smooth**-walled or extended into numerous **filamentous appendages** (***Pasthyrella coprophila***) and enclosed in **mucopolysaccharrdes capsule.**

b. Dry in *C. miacaceus*: oidia are usually developing in **chains** of cylindrical arthroconidia.

c. Sexual role: If an **oidium** placed close to compatible hypha, **plasmogamy** occurs, nuclear migration and eventually a **dikaryon** established. This may occur between **oidium** and uninucelated approaching hypha. The result is death of the hybrid cell, and possibly some of the adjoining cells.

Thus life cycle is grouped as follow (Fig. 9.12)

1. **Germination** of the basidiospore to give a **septate primary** (haploid) mycelium, which may produce "**oidia**", but anamorphic states (except for yeasts, rusts, and smuts) have been neglected.
2. Later **diploidization**, the homo-or heterothallic primary mycelium becomes **secondary (dikaryotic**) mycelium that frequently has **clamp connexions**.
3. **Karyogamy** in the young basidium and **meiosis** before basidiospore development.
4. The mycelium may be perennial in soil or wood and may form "**fairy" rings**, **sclerotia**, **rhizomorphs** or **mycorrhizas**. The basidioma are typically macroscopic and take a variety of forms.

Sexual reproduction:

Distinguished sexual organs do not form, as we mentioned before, in the basidiomycota, and sexual reproduction takes place when the conditions of temperature and humidity are appropriate. The fungal hyphae are thriving and are done in the following steps Figure 9.12.

The formation of the basidial fruit begins as a small bulge in the form of a small knot of binuclear hyphae cells that soon increase in size and turn into a small spherical or oval body, called the button stage, and when this development continues its growth, the upper part turns into the fruit Ripe basidia, and there may be on the neck the **collar**, which is the remnants of the membranes that covered and protected the gills before maturity, and the gills are organized on the lower surface of the cap, and they carry the basidia and basidial spores, and the fruiting body consists of tissues and filaments, and the basidiums appear as terminal cells From the internal sutures in the structure of the gill tissues on the lower surface of the cap, they are arranged to form the fertile layer.

Initially, the basdium is filled with cytoplasm and has small vacuoles, then a large vacuole is formed at the base of the basdium, and by increasing its breadth, it works like a syringe piston and pushes the cytoplasm to the top, then 4 **streigma** appear. Four haploid nuclei, and at the tips of the four sterigma, bulges arise. Each nucleus moves into a bulge and with it the cytoplasm to form the basal spores and then repeat their life cycle again.

Classification

The Basidiomycota had traditionally been divided into 2 obsolete classes, the **Homobasidiomycetes** (including true mushrooms); and the **Heterobasidiomycetes** (the Jelly, Rust and Smut fungi). Previously the entire Basidiomycota were called Basidiomycetes, an invalid class level name coined in 1959 as a counterpart to the Ascomycetes, when neither of these taxa were recognized as phyla.

According to Hibbett, *et al.* 2007 basidiomycota divided into:

1. Three subphyla: **Pucciniomycotina, Ustilaginomycotina & Agaricomycotina**
2. Two other class level taxa: **Wallemiomycetes & Entorrhizomycetes**.

1. Agaricomycotina includes, Hymenomycetes (formed hymenial layers on their fruitbodies), Gasteromycetes (mostly lacking hymenia and mostly forming spores in enclosed fruitbodies), as well as most of the jelly fungi.

2. Ustilaginomycotina are most (but not all) of the former smut fungi in addition to Exobasidiales.

3. Pucciniomycotina includes the rust fungi, the insect parasitic/symbiotic genus ***Septobasidium***, a former group of smut fungi (in the Microbotryomycetes, which includes mirror yeasts), and a mixture of odd, infrequently seen or seldom recognized fungi, often parasitic on plants.

4. Classes **Wallemiomycetes** and **Entorrhizomycetes** cannot at present be placed in a subphylum.

Kingdom: Fungi
Subkingdom: Dikarya
Phylum: Basidiomycota
Subphyla/Classes
Pucciniomycotina, Ustilaginomycotina & Agaricomycotina
Incertae sedis **(no phylum): Wallemiomycetes** & **Entorrhizomycetes**.

Sub-phylum: Agaricomycotina

1. The Agaricomycotina (hymenomycetes) is one of three major clades of Basidiomycota.
2. It is comprises some 20,000 spp, about 98% of them are in the class **Agaricomycetes** (Fig. 9.14) : most of the fungi known as mushrooms, including the bracket fungi and puffballs.
3. Agaricomycotina Spp. that are not Agaricomycetes include the jelly fungi, certain "yeasts", ear fungi, and others, are gathered in the classes **Tremellomycetes** and **Dacrymycetes**.
4. "jelly fungi" (Fig. 9.15), have gelatinous, often translucent fruiting bodies (e.g., "witches butter" ***Tremella mesenterica***) (Hibbett 2007).

Discussion of Phylogenetic Relationships

1. It is based on multiple independent analyses, summarized by Hibbett et al. (2007).
2. Three major clades are formally named: **Tremellomycetes**, **Dacrymycetes**, and **Agaricomycetes** (include heterobasidiomycetous, Auriculariales and Sebacinales).
3. Analyses using a multi-locus study by Matheny et al. (2007), suggest that the **Dacrymycetes** and **Agaricomycetes (**formerly known Hymenomycetidae by Swann and Taylor, 1995) form a **monophyletic** group (here, the clade is unnamed).
4. Earlier studies using rRNA genes did not support that grouping (Begerow et al. 1997; Weiß and Oberwinkler 2001).

Class: Agaricomycetes

1. It contains approximately 16,000 described species, which is 98% of the described species in the Agaricomycotina (Kirk et al. 2001).
2. It produce mushrooms, and are therefore the most familiar and conspicuous of all Fungi.
3. Their fruiting bodies range from millimeter-scale **cyphelloid** forms, which look like tiny cups, to the giant polypores ***Rigidoporus ulmarius*** and ***Bridgeoporus nobilissimus*** (up to 130 kg; Burdsall et al. 1996).
4. It include the largest **fruit body** and the oldest individuals in any group of organisms; the honey mushroom, ***Armillaria gallica*** that produce average-sized mushrooms, but their mycelial networks have been estimated to cover areas up to 15 hectares, with a mass of 10,000 kg (comparable to a blue whale), and an age of 1500 years (Smith et al. 1992).
5. They live as decayers, pathogens, parasites, and mutualistic symbionts of both plants and animals.
6. widespread in virtually all terrestrial ecosystems, and a few have secondarily returned to aquatic habitats. This relay on their broadest ecological impacts that come from their activities as wood-decayers and ectomycorrhizal symbionts of forest trees (such as pines, oaks, dipterocarps, and eucalypts; Rayner and Boddy 1988; Smith and Read 1997) and as parasites of plants and animals.

8. The majority of edible mushrooms are Agaricomycetes (truffles and morels are in the Ascomycota, however).

   a. Cultivated edible Agaricomycetes are decayers that have been domesticated, such as button mushrooms (***Agaricus bisporus***), shiitake (***Lentinula edodes***), oyster mushrooms (***Pleurotus ostreatus***), and others.

   b. Most of the wild-collected edible species are mycorrhizal (making them difficult or impossible to cultivate), such as porcini (***Boletus edulis***), chanterelles (***Cantharellus cibarius***), and matsutake (***Tricholoma matsutake***).

9. Mushrooms have been used for medicinal and spiritual purposes in diverse human societies.

e.g. Ice Man who was discovered in a Tyrolean glacier, 5300-year ago was found carrying pieces of the birch polypore, ***Piptoporus betulinus***, which he may have been using to treat intestinal parasites (Capasso, 1998).

Another fascinating item of **ethnomycology** comes from the Northwest of the United States, where indigenous citizens, have carved figurines out of the fruiting bodies of the polypore ***Fomitopsis officinalis*** to serve as guardians at the graves of shamans (Blanchette et al. 1992).

This class divided into two subclasses viz; **Tremellomycetidae and Agaricomycetidae** according to Kirk et al. (2001).

Agaricomycetidae [divided into eight orders]

Subclass1: Agaricomycetidae

The main orders are Agaricales, Atheliales and Boletales.

1. They are almost always filamentous, without yeast phases, the hyphae are septated, with barrel-shaped dolipore septum that is flanked by membrane-bound parenthesomes
2. Yeasts are produced only by some species that are cultivated in underground fungus gardens by attine "leaf-cutter" ants in the neotropics (Mueller et al. 1998).
3. The dominant stage in the life cycle is typically a dikaryotic mycelium, but stable diploids have been reported in ***Armillaria*** (Anderson 1983).
3. Dikaryotic and monokaryotic mycelia have been shown to produce asexual spores in some species (Miller 1971; Nakasone 1990), but asexual forms are not widespread as in Ascomycota.
4. Mushrooms are fruiting bodies produced under favorable conditions by dikaryotic mycelia. Sometimes, produced at the periphery of a circular mycelium, resulting in a fairy rings. Fairy rings indicate the spatial extent of the mycelium, which is otherwise difficult to establish.
5. karyogamy and meiosis occur in basidia, which are formed the hymenium.
6. In addition to basidia, the hymenium often includes non-reproductive cells called cystidia. Cystidia used in Agaricomycete taxonomy (Clémençon 1997; Donk 1964; Singer 1986).
7. Basidia are mostly unseptated (**homobasidia**), but other members are septated, including the Auriculariales, Sebacinales, and certain members of the Cantharellales (***Tulasnella***).
8. Most of the fungi now classified in the Agaricomycetes used to be placed in the "Homobasidiomycetes" (Hibbett and Thorn 2001), but that name has been abandoned in recognition of the fact that not all members of the group have homobasidia.
9. Two to eight basidiospores (meiospores) are formed on each basidium—the most common number of spores is four.

Thus, there are diverse patterns of nuclear behavior leading to the production of spores. Variations in these patterns might provide clues to phylogenetic relationships in Agaricomycetes, but they have been studied in too few species to make broad generalizations (Hibbett et al 1994a, Mueller and Ammirati 1993).

Subphylum: Pucciniomycotina

Pucciniomycotina (Bauer et al., 2006) includes the rust fungi, the insect parasitic/symbiotic genus ***Septobasidium***, a former group of smut fungi (in the Microbotryomycetes, which includes mirror yeasts), and a mixture infrequently seen or seldom recognized fungi, often parasitic on plants.

Classes: Pucciniomycetes Cystobasidiomycetes Agaricostilbomycetes Microbotryomycetes, Atractiellomycetes, Classiculomycetes, Mixiomycetes and Cryptomycocolacomycetes

Class: Pucciniomycetes

1. Rust fungi: 14 – families, 164 genera (+139 syn.) and 7000 cosmopolitants species.
2. **Parasites** on seed plants and ferns, causing major disease. **Obligate** parasites but **axenic culture** reported for some species e.g. ***Puccinia graminis f. sp tritici.***
3. Mycelium (**lack clamp connection**) generally intercellular (frequently with haustoria), limited to parts of leaves or other aerial organs of the host (**local infection**), sometimes perennial, if **systematic** over **wintering** in roots or other parts.
4. Rusts have up to five spore states (frequently numbered **O – IV**: these roman numerals can be ambiguous unless restricted to a morphological system).
5. Traditionally the spore terminology was based on morphology, but later, (**Cummins, 1959; Hiratsuka, 1975**) related the spore states to the nuclear cycle, is followed here

6. The life cycle may be one of the following:

1- Heteroecism: require two taxonomically different host plants in order to complete life cycle

a. Alternate host: stages 0, I

b. Primary host: stages II, III

2- Autoecism: Entire life cycle completed on a single host species

Order: Uredinales

1. Most species are heterothallic
2. Obligate **biotrophs**, producing Intercellular hyphae with haustoria. Mostly form local infection
3. Complex life cycles with up to five distinct spore types; Many species are **heteroecious**, Some species are **autoecious.**

Spore states

State 0 = spermogonium bearing spermatia (n) and receptive hyphae (n)
State I = aecium bearing aeciospores (n + n)
State II = uredinium bearing urediniospores (n + n)
State III = telium bearing teliospores (n + n → 2n)
State IV = basidium bearing basidiospores (n)

Life Cycle occurs in the following types:

1. **Macrocyclic-** All five spore states are present
2. **Demicyclic-** Uredinial state is absent (± spermatial state)
3. **Microcyclic-** Aecial and uredinial state is absent (± spermatial state)
4. **Heteroecism-** two taxonomically different host plants in order to complete their life cycles.
5. **Autoecism-** completes its entire life cycle on a single host species.

O. Spermagonia (Sing.-ium; Pycniospores) Fig. 9. 16.

1. Result from infection by a haploid basidiospore. Haploid state. Thus small, pycnidial (spermagonia) structures formed, often in clusters. Develop in 4-6 days in herbaceous tissue, up to 3-4 years in conifer wood. This about 11 different types.
2. Receptive hyphae (=flexuous hyphae) arise from upper walls and protrude through ostiole
3. Spermatia—small, one-celled, hyaline; incapable of germination. Spermatia in sweet, sticky exudate which attracts insects; insects transmit spermatia
4. Dikaryotization occurs when spermatium fuses with receptive hyphae; nucleus moves down intercellular hyphae in host to aecial initials
5. In species lacking spermagonium, dikaryotization through hyphal fusion.

I- Aeciospores (aecidiospores, plasmogamospores) Fig. 9. 17:

1. Produced in **aecia** (sing.-ium; aecidiosori).

2. They are unicellular, non-repeating vegetative spores, usually resulting from dikaryotization (and thus usually associated with pycnia), which germinate to give dikaryotic mycelium.

3. Aeciospores are typically catenulate, thin-walled, and verrucose but sometimes they resemble typical uredinospores when they are designated, urediniod aeciospores by **Cummins** (= aecial urediniospores (II^{I})- laundon; primary uredospores, winter).

II- Urediniospores (uredospores, urediospores) Fig. 9. 18:

1. Summer spores, **red rust** spores, repeating vegetative spores (which give **urediniospores** again or **teliospores**), usually on dikaryotic mycelium, in **uredinia** (**uredosori**, **uredia**).

2. uredinospores are **unicellular**, **pedicellate**, **deciduous**, with the pigmented **echinulate** wall showing two or more germ pores. Rarely they resemble aeciospores.

3. **Amphispores** (II^{I1};x) or resting urediniospores are produced by some rusts. These spores generally have thicker and darker walls than normal urediniospores.

III- Teliospores (teleutospores, teleutosporodesma, winter spores, black rustspores) Fig. 9. 19

1. produced in **telia** (sing.-ium; **teleutosori**).

2. They are basidia producing spores.

3. teliospores are resting spores, **2 – or more** celled, **sessile or pedicellate** but **not** deciduous, and the **thick wall** is variously ornamented. Rarely they resemble typical aeciospores when they are designated aecidioid teliospores by **Communis** (= telia aeciospores (I^{III}) , Laundon).

4. Teliospores that germinate immediately especially in species of genera that usually shows dormancy may be termed **leptospores**.

IV – Basidiospores (sporidia) Fig. 9.20.

1. They are haploid, unicellular, thin-walled, short – lived spores produced on 2–4- celled basidia after meiosis and liberated from sterigmata by abjection.
2. **The life – cycle of a rust fungus is generally** constant**, though there may be no development of O, II, or sometimes I, because of weather or other conditions. A species with I, II, III, but no O, is sometimes termed as** cataspecies

Nuclear Cycle:

1. A rust fungus may be heterothallic or homothalli.

I. <u>Heterothallic</u> macrocyclic species

a. **basidium** has two (+) and (-) basidiospores.

b. A + (or -) spore, after infection of the right host, gives a **haploid** mycelium, **pycnia** with + (-) **spermatia** and **protoaecia**.

c. If taken (frequently by an insect) to a flexuous hypha of a – (+) pycnium, a + (-) spermatium may put out a "**peg**" to make a connexion, its nucleus goes into (**spermatizes**) the hypha, and by division gives nuclear for the diplodization of cells down to the **protoaecia**.

d. The cell of a **protoaecium** undergo conjugate division and their mycelia, are dikaryotic.

e. There is nuclear fusion in the teliospore, meiosis in the basidium.

II. **<u>Homothallic</u>** species, where pynia are not necessary and are frequently not present, the **dikaryophase** has its start from two cell nuclei at some point or point in the life cycle. Nuclear fusion and reduction as in heterothallic species.

Sub-phylum: <u>Ustilaginomycotina</u>

The Ustilaginomycotina (Bauer et al., 2006) are most (but not all) of the former smut fungi and along with the Exobasidiales. A subphylum within the phylum Basidiomycota consisting of the classes Ustilaginomycetes, Exobasidiomycetes and the order, Malasseziales.

Class: Ustilaginomycetes

It.is the class of true smut fungi (Fig. 9.22). They are plant parasites with about 1400 recognised species in 70 genera. It is consists of Orders **Urocystales** and **Ustilaginales**.

4. The order **Ustilaginales lack hymenium**, and spores are **solitary**, **clustered or** produced **in sori**,

5. Mostly plant pathogenic fungi (biotrophs) united by:

a- 5S rDNA secondary structure
b- Sequence analysis of large subunit rDNA
c- Host/parasite zone of interaction
d- Septal pores lacking parenthesomes, but some with dolipore
e- Parasitic dikaryotic phase and saprotrophic haploid phase

6. Many taxa dimorphic, with yeast-like haploid phase and mycelial dikaryotic phase

Order: Ustilaginales

"smut fungi"

The symptoms appear only on the floral parts. The floral spikes turn black and remain filled with the smut spores.

<u>Ustilago produces two main types of symptoms:</u>

1. The blackish powder of spores is easily blown away by the wind, leaving a bare stalk of inflorescence. Species showing such symptoms are called **loose smuts** e.g., Loose smut of wheat caused by *U. nuda var. tritici*.

2. The blackish powder of spores remains covered by the wall of the grain (**peridium**), and the spores are liberated only by the breaking of wall during thrashing. Species showing such symptoms are called covered smuts e.g., Covered smut of Barley caused by ***U. hordei***

General Characters:

1. **Facultative saprobes** have a mycelial **parasitic** phase and are **yeast**-like when cultured in vitro.

2. They are **parasitic on Angiosperms**, where they cause diseases of economic significance, smut.
3. They occur typically as **host-specific endophytes** that, but for 2 spp of ***Melanotaenium*** on ***Selaginella***, are parasitic on flowering plants, especially ***Gramineae*** and ***Cyperaceae***.
4. **Sori** are commonly limited to the ovary, anthers, inflorescence, or leaves (***Entyloma***) and stem of the host, though the root is attacked by ***Entorrhiza***.
5. The mycelium of delicate hyaline hyphae made up of uni-, bi-, or multinucleate cells which may be through out the plant or only at the points of infection.
6. The mycelium is commonly annual but sometimes as in ***Ustilago segetum var. avenae*** on ***Arrhenatherum***, perennial.
7. The hyphae are generally intercellular (except in ***U. maydis***) and frequently with haustoria and sometimes clamp connexions.
8. D**olipore** septum present, and always **lacking parenthesomes**.

9. **Conidia** may be formed on the surface of the host (esp. ***Entyloma***) although in most genera only the smut spores (**chlamydospores**, brand spores, resting spores, pseudospores, teliospores, ustospores, ustilospores) and basidiospores.
10. At maturity resting **spores** appear as **dark powder**, enclosed within host tissue or are unpigmented. The spores may be in **ones** (***<u>Ustilago</u>***)**.**
11. Mature spore has one **diploid** nucleus, and limited by a thin **endospore** and a thicker smooth ornamented **exospore**.
12- On **germination**, **meiosis** occur, **promycelium** (basidium, metabasidium, germ tube) bearing 4 or more basidiospores (sporidia, sporidiola, "conidia", promycelial spores), is produced by which **haploid yeast phase restarted (**Fig. 9.23).
13. Basidiospores in sori**.**
14. There is **segregation** for sex in the promycelium and conjugation between two basidiospores, a basidiospore and a promycelial cell, two cells or infrequently, two promycelia.
15. There are three main **types of infection:**

(1) seedling infection from resting spores on the seed;

(2) seedling infection by mycelium in the seed as a result of spore germination on the stigma;

(3) infection by wind borne **sporidia** among decaying plant materials (as for ***Ustilago maydis***, ***Entyloma***).

16.The genera in this order are ***Ustilago*** and ***Cintractia***

18. Economically important pathogens include:

a- *Ustilago maydis* (corn smut)
b- *U. avenae* (loose smut of oats)
c- *Urocystis cepulae* (onion smut)
d- *U. agropyri* (flag smut)

e.g. *Ustilago*

1. Sori in reproductive organs or vegetative tissues of host
2. Teliospores formed singly, usually pigmented with sculptured walls
3. Sterile cells absent
4. Ustilago-type germination.

Class : Exobasidiomycetes

Generally characters

1. unspecialized holobasidium.

2. Absence of well-defined basidocarp, where basidia forming a layer on leaf surfaces.

3. Plant parasites, especially on ***Ericaceae*** and ***Commelinaceae*** forming gall disease.

4. It includes ***Exobasidium camelliae*** Shirai, the camellia leaf gall and ***Exobasidium vaccinii*** Erikss, the leaf and flower gall.

5. Orders: Doassansiales, Entylomatales, Exobasidiales, Georgefischeriales, Microstromatales, Tilletiales.

Order: Exobasidiales

Generally characters

1.Plant parasitic fungi

2. Form holobasidia on leaves, no teliospores formed

3. Basidiospores become septate during germination

4. Dimorphic

Families **include** Exobasidiaceae and Graphioloceae

Family: Graphioloceae Fig. 9.24

***Graphiola* leaf spot or palm-false-smut (*Graphiola phoenicis*)**

Kingdom: Fungi

Phylum: Basidiomycota

Subphylum: Ustilaginomycotinia

Class: Exobasidiomycetes

Subclass: Exobasidiomycetidae

Order: Exobasidiales

Family: Graphiolaceae

Genus: *Graphiola*

Subject: ***Graphiola phoenicis*** (Moug.) Poit.

Graphiola leaf spot, also referred to as "***false smut***," is a foliar pathogen of certain palm species.. **Nutrient deficiencies**, such as **potassium or magnesium** deficiency, are much more serious palm health problems than this disease, especially for ***Phoenix*** species.

This disease is caused by the fungal pathogen ***Graphiola phoenicis***. It is a unique fungus, both in appearance and life cycle, but it is widely distributed throughout the date palm-growing world. While numerous palm species have been identified as hosts of this fungus, the disease is most prevalent in *Phoenix canariensis* (Canary date palm) and *Phoenix dactylifera* (date palm). It is rarely observed on *Phoenix sylvestris* (wild date palm).

Symptoms and Signs

The symptom of a disease is the plant's expression of infection from a plant pathogen, such as spots, lesions, cankers or root rots. The **sign** of a disease is the observation of the causal pathogen on the affected plant tissue. With **Graphiola** leaf spot, the signs of the disease are more prevalent and more easily observed than the symptoms of the disease. Both signs and symptoms will be observed on the oldest leaves, which are the lowest leaves in the canopy. The initial symptoms of the disease are very tiny (1/32 inch or less) yellow or brown or black spots on both sides of the leaf blade. They are easily missed without close observation. The fungus will emerge from these spots, rupturing the leaf epidermis (leaf surface) (Figure 24). It is the resulting fungal reproductive structures (sori) that are most commonly observed and which obscure any true symptoms.

The sorus (sori is the plural form) is a black fruiting body that is less than 1/16 inch in diameter (Figure 25). As the sorus matures and yellow spores are produced, short, light-colored filaments (thread-like structures) will emerge from the black body (Figure 24, 25). These filaments aide in spore dispersal. Once the spores are dispersed, the sori deflate and appear like a black, cup-shaped body or black crater. You can easily see the sori, but you can also feel the sori with your finger as they are raised above the leaf epidermis. The number of sori indicates the level of infection (Figure 25).

Disease and Fungal Life Cycle

After the fungus penetrates (infects) the leaf tissue, it has very limited growth within the leaf tissue, with most growth occurring just below the sorus (black fruiting body). The time span from infection to spore production is 10 to 11 months. This is unusual when compared to most leaf pathogens that have a life cycle often measured in weeks. This means that the active disease being observed today is the result of infection that occurred almost a year ago.

Foliar pinnae showed small yellow to dark lesions on both sides of the leaf blade, with brown to black globular, cylindrical or irregular sori (Figure 25A-C). Sori are fruiting bodies of 0.5 to 1.2 mm in diameter with a subepidermal origin, with dark and hard outer walls (Figure 25A-C). As sori mature, white to creamy thread-like filaments (Figure 25B-C) emerge through the ostiole of each sorus. Spherical to elliptical spermacia 2.5-3.0 µm diameter, with thick hyaline walls, were produced (Figure 25D). In SEM images (Figure 25D-F), it was possible to observed abundant spermacia attached to the filament, suggesting that filaments help with dispersal (Cienc. Inv. Agr. vol.44 no.3 Santiago dic. 2017)